EXTENDING FIELD LIFE AND MAXIMIZING ECONOMIC RECOVERY

Creating new opportunities in mature global basins

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Introduction

Basin-scale economic impact

Many oil and gas producing countries have large facilities at or near the end of their operational life. Decommissioning costs are significant and prolonging field life, improving production and reducing costs are vital in creating the greatest returns from these mature, high-cost offshore basins.

In the North Sea alone, it is anticipated that the cost of decommissioning will be more than £60 billion[1]. Similarly, in the Asia Pacific region, with around 2,600 platforms and 35,000 wells, the estimated cost is set to exceed US$100 billion[2].

If ageing fields become uneconomic and are decommissioned, linked infrastructure may also be removed. This can hit the economics of small fields that had been relying on a 'tie-back' to these facilities. Prolonging field life not only impacts the field itself but allows the economic development of those smaller, satellite fields, boosting basin-wide economics as a result.

Government incentives

Unsurprisingly, governments around the world are encouraging operators to improve efficiencies, decrease operational costs, increase production and extend field life. For example, Malaysia is promoting revised terms in the Production Sharing Contracts (PSCs) for Enhanced Oil Recovery (EOR) projects and the UK Oil and Gas Authority (OGA) has introduced the Maximising Economic Recovery (MER) strategy.

Substantial opportunities remain

Mature basins around the world still offer opportunity for attractive financial returns as governments look to encourage investment and defer decommissioning costs.

Unlocking the potential of existing, undeveloped and undiscovered hydrocarbons in mature basins relies on four key areas that will be explored in this paper.

Taking Action to Find and Produce Near and In-Field Reserves

Producing additional near and in-field hydrocarbons using existing infrastructure brings volumes onstream faster and more cheaply than new field development. This approach adds reserves and boosts or extends the production lifetime and may allow the tail of a field's base production to be realised that would otherwise be uneconomic.

Additional production can be achieved in a number of ways:

- The recompletion of existing wells.
- Re-configuration of producer-injector wells.
- Development maturation of outpost satellite targets.
- Exploration of shallower or deeper formations above or below the existing development.
- Exploitation of small pools and stranded accumulations using sub-sea tiebacks.

Producers have taken other creative approaches to exploit near-field opportunities. Many mature oil fields are in gas deficit today, where diesel is used for power and 3P gas is required for lift. Apache[3] has chosen to develop shallow gas accumulations in the vicinity of the Forties field as feedstock for fuel gas and lift gas. They use this to power the six production platforms, eliminating a significant aspect of the operational costs of production and improving gas lift performance.

Extracting greater detail from seismic data

Many of the options to extend field life require the identification of bypassed oil, unswept volumes or undiscovered accumulations. New wells, recompletion of potential productive zones or altering injector producer configuration can then be applied.

Seismic data can add significant value in these circumstances if the required resolution can be achieved and reliable estimates of fluid content obtained. The earlier these data are found, the greater an operator's chances of preventing unnecessary spend on drilling dry wells or carrying out unnecessary analysis.

Understanding what can be extracted from seismic data and when, how rocks behave before, during and after production activities, and how these results will impact operational capabilities and decisions later on in field life, is vital. Where seismic data are deemed useful for reservoir surveillance, the ability to extract fine detail and uncertainties is of huge benefit for hydrocarbon volume assessment.

Software to Support Identification of Additional Volumes

Ikon Science offers a range of subsurface modelling and analysis software that specifically addresses the challenges of identifying in-field and near-field hydrocarbons.

- Ikon's Rock Physics module allows geoscientists to establish a consistent, validated interpretation framework and Bayesian apriori for probabilistic seismic reservoir characterisation, enabling a robust understanding of what value can be added through seismic inversion.
- Advanced well tie and wavelet estimation tools guarantee dependable wavelets and uncertainties for use in seismic characterisation, maximising the resolution and reliability of the inversion results.
- Seismic data conditioning tools ensure seismic are fit for purpose for AVO inversion and boost the signal required for thin, marginal reservoir detection and improved confidence in the pore-fill prediction.
- Ikon's Joint Impedance and Facies Inversion (Ji-Fi) tool/module provides a credible, consistent means of estimating pre-drill reservoir and pay distributions, in-place volumetrics and associated uncertainties.
- Ikon's Rock Physics and Reservoir Characterisation modules deliver an effective geophysical workflow for the identification, risking and ranking of near-field leads and prospects, ultimately providing reliable reserves estimates that can contribute to bookable 2p reserves.

Figure 1, illustrates the application of Ikon's Ji-Fi at the Forties oil field[4].

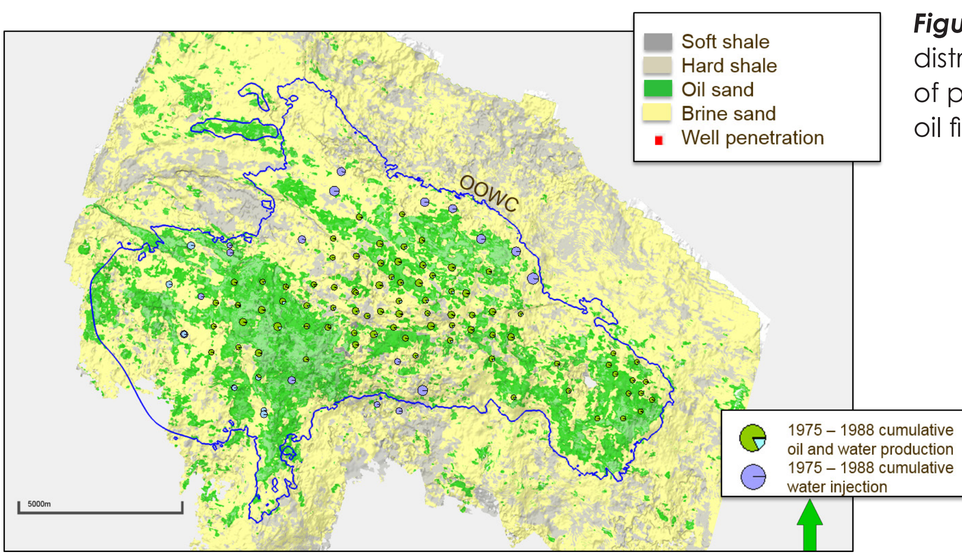

Figure 1 Ji-Fi predicted pay distribution after first 13 years of production at the Forties oil field, North Sea.

Modelling successfully identified bypassed pay and infill drilling and outpost drilling opportunities.

Early Planning to Improve Well Placement and Maximise Well Productivity

Well placement is a major determinant of plateau production and ultimate recovery rates[5] and getting this right is key during field appraisal and development.

Questions to be addressed include:

- What are the subsurface reservoir connectivity and flow characteristics?
- What is the potential volume of rock/drainage radius impacted during hydraulic stimulation?
- How do these relate to each individual well's projected EUR and optimum well spacing?

In both conventional and unconventional reservoirs, operators must go beyond the size and connectivity of potential drilling targets. In-situ and post-production stress states, formation strengths and other factors need to be understood. These will impact well design, drilling efficiency, pressure maintenance, well performance and ultimate field productivity for use in the wider depletion forecasting strategy.

To achieve this, a high level of integration is needed across disciplines in order to capture uncertainties.

The optimum field development plan will include:

- Drilling management - what are the pressures and stresses and how do these impact wellbore stability?
- Performance - where and how to complete the well?
- Productivity - how to prolong the life of the well and field?
- Regional productivity - how field-scale production-related stress changes impact reservoir performance and drilling windows etc.?

Software to Optimise Well Placement and Productivity

Ikon Science's subsurface modelling and analysis software allows well placement to be accurately planned and productivity modelled.

- Ikon's Ji-Fi tool/module delivers industry-leading levels of resolution and detection from 3D seismic data. Reservoir characterisation gives estimates of reservoir and pay distribution, connectivity and connected bodies and properties important for flow, such as clay content and porosity.
- Ikon's RokDoc Geopressure allows the analysis of offset well data and combination with local models to estimate in-situ pore pressure, vertical stress, fracture gradients and Sh(min) susceptibility to hydraulic fracturing.
- Ikon's RokDoc Image log analysis delivers surface sets for interpretation of breakouts, drilling-induced tensile failure, fractures (their orientations, densities and permeability), bedding planes and other drilling-related attributes that are key to estimation of in-situ stress states and that impact on seismic anisotropy. Outputs from the image log interpretations feed directly into the RokDoc anisotropic modelling workflows.
- Ikon's RokDoc Anisotropy and VSP analysis tools deliver data-driven estimates of interval/formation specific anisotropic parameters that are key in deriving robust in-situ stress estimates/fracture orientations and that can be used during anisotropic facies based seismic inversion to improve isotropic property estimation, improving the accuracy of all model derivatives.
- Using the target location and distribution from RokDoc Ji-Fi, vertical stress and fracture gradient estimates from RokDoc Geopressure analysis, and estimates of formation specific anisotropy, multiple scenarios can be rapidly modelled using the RokDoc Geomechanics tools. Multiple well plans can be assessed such that the final well can be designed to intersect the accumulation with the right trajectory, minimising well bore stability issues and engineering/borehole related non-productive time.
- The static geological properties (Vclay, porosity, saturation) estimated from the probabilistic reservoir characterisation workflow and integrated with wells are combined with the field-scale pore pressure model and stress fields derived from the RokDoc Pressure Suite to deliver an interactive, highly updateable 3D analytic Geomechanical shared earth model. Other acoustically definable static properties may include total organic carbon content, often a critical factor in the highest productivity highest liquid content shale reservoirs.
- Multiple well bore trajectories can be planned, tested and extracted from the model and used in scenario modelling to determine ranges of ultimate recovery based on modelled perforations, frack stages etc.

Figure 2, shows a 3D perspective of oil probabilities, computed from multi-scenario, multi-realisation facies-based inversion over a North Sea oil field, using Ji-Fi.

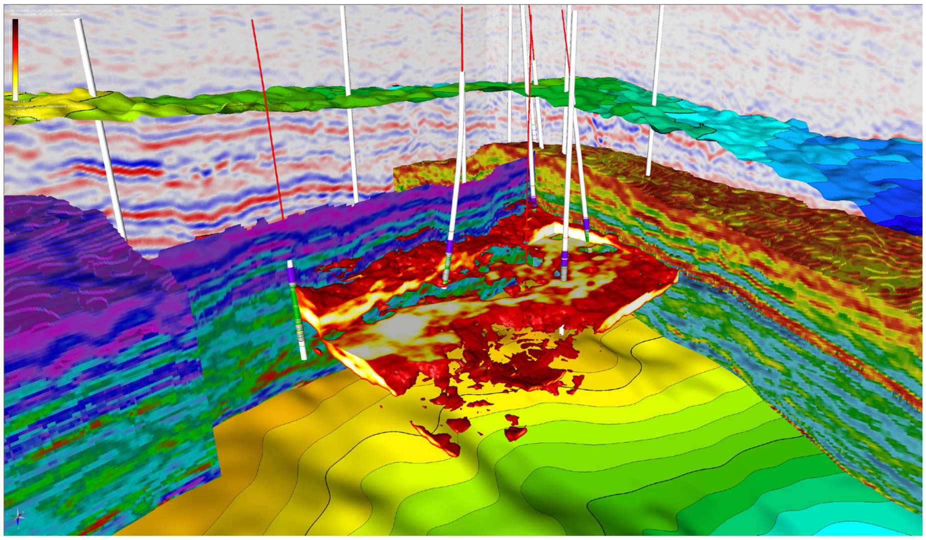

Figure 2 3D perspective showing hydrocarbon probability rendered from a large number of joint impedance and facies realisations from 3D seismic data

Reservoir geometry and hydrocarbon pore volumes and connectivity were assessed quickly and easily (or something else good) and incorporated into the field development and drainage strategy.

EOR Techniques to Improve Hydrocarbon Recovery

Tertiary, or EOR, techniques have been widely adopted and used to push recovery rates 'to the technical limit'. However, in many reservoirs a significant gap to achieve that potential recovery exists.

It is estimated, for example, that in the North Sea, where EOR has only seen very limited adoption, up to 8 Billion barrels of additional oil recovery could be achieved, with around 1 Billion barrels coming from as few as 40 fields[6].

Screening opportunities for the application of thermal, steam assisted gravity drainage (SAGD), water alternating gas (WAG) or chemical/polymer flooding are difficult, often requiring a pilot project before full investment. Given the cost and expertise to fully implement these techniques, appropriate feasibility studies to demonstrate the potential benefits of EOR to a development are essential.

Modelling needs to consider fluid flow, wettability and irreducible saturation but should also include the ability to monitor in '4D', the subsurface distributions of perturbed rock-fluid volumes. The lowest-cost improved oil recovery (IOR) is often through improving the traditional waterflood, or the more novel WAG injection or gas blow down. Each of these approaches can be better managed through rigorous 4D reservoir characterisation and modelling[7].

Software to Enhance Fluid Modelling and Reach Technical Recovery Limit

Ikon Science software contains a selection of models to explore the physical characteristics of differing EOR techniques. Through rigorous modelling and analysis of the petrophysical, elastic and geomechanical impact of different EOR methods, it is possible to better plan for and monitor the outcomes, leading to better decision making throughout a fields lifetime and improved understanding of the commercial gains.

- Ikon's RokDoc Rock Physics module provides a rich selection of models for the calculation of common EOR related fluid types such as steam, CO2, heavy oil
- Ikon's RokDoc External Interface and Python plugin combine to allow users to develop customised field and development-specific EOR rock physics and fluid mixing models (available as simple user interfaces in the RokDoc software) that can be used to identify and monitor EOR performance using, e.g. seismic methods

Using Time-Lapse Seismic to Monitor and Maximise Lifetime Field Depletion

Time-lapse seismic monitoring is a proven technology that has significant potential to impact reservoir management and drive and to optimise life-of-field depletion planning, such as at the Forties Field on the UKCS, where oil re-saturation targets identified from 4D analysis have added 14.6mmbo to reserves/production between 2011-2015[8].

With care and an appropriate baseline survey, the impact spans the entire field life. In the early stages, it offers the potential to identify inconsistencies with early simulation models and indicate possible intervention strategies. And in late field life, it can be used to highlight bypassed pay and find late stage infill drilling opportunities.

The first part of any time lapse project is to perform feasibility studies with a key step being the development of 4D rock physics models that integrate logs, core and laboratory measurements. These models can then be combined with 3D static and dynamic property models to estimate the presence, magnitude and timing of seismically detectable changes in the subsurface properties.

A significant challenge is that the geological and simulation models are rarely built with the long-term goal of utilising them for 4D work. Time lapse studies are highly integrated, bringing together information from all disciplines and the barriers between otherwise siloed disciplines, must be removed.

Safety and recoverability impact

Integration of expertise from the outset, is essential to successful field management and planning, and the cost of not working in a cross-disciplinary manner can be significant.

There are examples of fields being prematurely abandoned where the original development strategies didn't identify or suitably monitor production-related volume or stress changes. This can lead to the reservoir becoming 'un-drillable'.

Worse still, significant operational safety risk can result when unmonitored volume and stress changes re-activate faults, resulting in a breach, or existing production wells being rendered useless through e.g. casing shear. In 2017, for example, the Groningen field was shut in as a result of significant production induced seismicity giving rise in one case to a 3.4 magnitude earthquake. Given that Groningen delivers gas to as much as 90% of Dutch homes, this presents a huge, and in this case national, challenge[9].

Perhaps the worst case is the creation of dangerous flow paths leading to well-control incidents that present danger to life. In 2012 for example, the Elgin-Frankin field, which was producing some 140,000 BOEPD suffered a major gas leak, in part caused by geomechanical effects in the overburden (Hod formation) as a result of significant production/depletion in the deeper target reservoirs. The field remained offline for an entire year before operations and production re-started at a more limited production rate of c. 70,000 boepd[10].

Software to Support 4D Investment

Ikon Science's software integrates data across disciplines to create robust models for use in 4D.

- Ikon's RokDoc Rock Physics module delivers interactive 1D and 2D modelling workflows for the integration of core, log, seismic and engineering data to determine the feasibility of 4D reservoir surveillance.
- Ikon's RokDoc Rock Physics, combined with the External Interface module, provides a rich selection of rock physics models which can be calibrated and tuned to specific reservoir and production conditions, allowing for the inclusion of bespoke, corporate modelling strategies.
- Ikon's RokDoc Geopressure Suite and Geomechanics add-on allow calibration of direct and indirect pressure and stress measurements that can be used in the construction of 1D relationships that can be extrapolated to 3D or used in conjunction with outputs from the seismic reservoir characterisation process to augment and enrich the subsurface modelling workflow.
- Ikon's RokDoc SDC (seismic data conditioning) and Inversion and the Advanced Seismic Data Conditioning add-ons provide de-noising and 4D AVO conditioning tools to optimise multi-vintage seismic data and enhance NRMS between baseline and monitor surveys.
- RokDoc 4D provides a framework for the development of a field-scale shared earth model, delivering a single platform for the integration of well and engineering data from the surface down to and beneath the reservoir objective. Multiple static and dynamic geomodels can be combined with geostatistics and rock physics relationships to develop a 4D shared earth model that can be used to study the effects of production on the elastic and geomechanical properties of the subsurface throughout the field's life.

Figure 3 shows a 3D field perspective, combining a 3D facies-based inversion of the base-line seismic with seismic acquired 12 years after production began, to create a 4D seismic analysis, identifying areas of oil sweep.

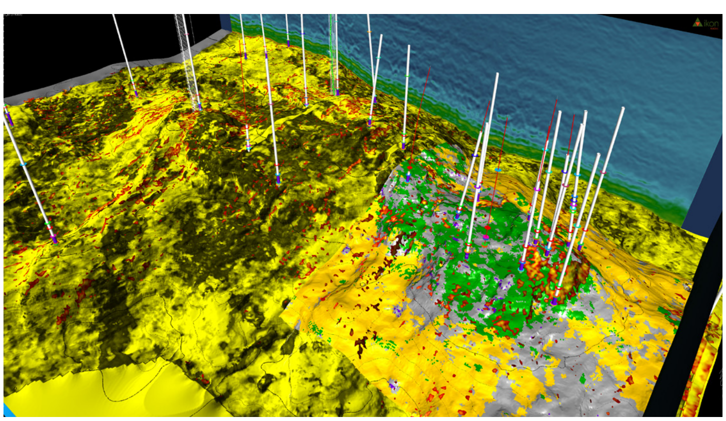

Figure 3 3D perspective of inverted VpVs and Facies inversion of baseline survey combined with 4D analysis (orange overlay) of monitor seismic to identify oil sweep (easternmost well cluster) after 12 years of production.

Conclusion

Extending field life and maximising economic recovery are at the heart of many new government initiatives and offer investment opportunities to new basin entrants.

Oil and gas operators are constantly striving to grow exploration success rates and maximise hydrocarbon recovery by reducing risk and improving sub-surface prediction. Over the last 15 years, Ikon Science has been dedicated to researching and developing new and existing technologies and workflows to help our clients achieve that goal.

Our tools and workflows are breaking down silos between the core disciplines - specialist geophysics, geology, reservoir and well engineering, geopressure and geomechanics - engaged in exploration and development well planning and reservoir management.

Ikon Science offers a variety of technologies to improve production efficiency, field management and prolong field life.

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