EXPLOITING UNCONVENTIONAL RESOURCES

Reduce risk and enhance production through integrated subsurface understanding

Ikon SCIENCE

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Introduction

Exploiting Unconventional Resources

Unconventional resources are characterized by low permeabilities and typically require fracture stimulation or other enhanced recovery techniques combined with long horizontals to be economic. They are engineered plays where effectively extracting the resources as opposed to locating the resources is the key technical challenge. Optimizing well placement and completion design to maximize production, while minimizing drilling and completion costs is essential to maximize economic return.

Changes in rock properties and in situ conditions can have a significant impact on well performance, stimulation behaviour and drilling cost. Understanding this variation and its impact enables optimal decisions on well placement, well design and completion strategy. Well control incidents, drilling hard layers and poor well placement have all lead to significant additional costs and lost production.

Over the past decade, onshore exploration and production has seen a rapid rise in growth, most notably in the US and Canada, thanks to numerous developments including technological advancements in horizontal drilling and hydraulic fracturing. In the US alone there are currently 9000 companies active in onshore exploration, production and drilling and with an estimated 1 million new wells expected to be drilled in the Permian Basin alone by 2025[1]. The production volumes of 2.5 mbopd achieved to date now exceeds the peak of conventional oil production of 40 years ago[2]. With this level of activity, there is a large international focus on exploiting and maximizing the productivity of these unconventional plays. To date this has been an operational drive to take costs out and ramp up well count, however amongst some operators there is a growing recognition that the intrinsic compositional and mechanical rock properties are a critical factor in asset quality and production performance.

The only data capable of illustrating critical lateral variations between wells across an asset is seismic. Integration of seismic data with stresses, pore pressure and rock properties can significantly reduce costs and enhance production through improvements in three key areas: well placement and geosteering; well planning; and stimulation design.

Play types

Unconventional resources can be classified into three broad groups based on their geological elements. Each of these play types present their own unique technical challenges that must be addressed and overcome for successful exploration and exploitation:

Hydrocarbons found in reservoir rocks:

- Tight oil/gas – oil/gas extracted from low permeability reservoirs, these can be stacked pay reservoirs with multiple targets or a single reservoir completed horizontally (e.g. Bakken Shale, Barnett Shale and Eagle Ford Shale, USA).
- Heavy oil – oil with very low API (<20°) that requires an alternative recovery method, typically steam injection to enhance flow (e.g. Oil Sands Northern Alberta, Canada).
- Carbonates and Chalks – Low permeability, hard rocks where porosity may be highly heterogeneous (Middle East, Brazil, Onshore US).

Hydrocarbons found in source rocks:

- Shale gas – gas extracted from naturally fractured or hydraulically fractured shale formations (e.g. Monterey Shale, USA).
- Coal bed methane – natural gas extracted from coal seams. Wells maybe completed in the coal seams and not necessarily fracture stimulated (e.g. Bowen Basin, Queensland, Australia).

Well cost and performance

Drilling and Completion costs are very similar across most North American onshore plays where the average drilled and completed well cost is between $5 MM to $10 MM and cycle times are high[3]. This has resulted in a lack of quantitative analysis leading to sub-optimal well placement, well planning and stimulation design, adding to cost and reducing production.

An added complexity of unconventional reservoirs is that wells that are fracture stimulated typically have production rates that rapidly deteriorate. For example, the average decline of tight oil wells in North Dakota's Bakken shale field is 44% per year, with some wells losing 70% or more of their production in the first year1.This necessitates continual development with new wells required to maintain production. Optimizing the placement and design of these wells is critical as development moves away from the initial "sweet spot". Economic success of a development can be determined by the ability to economically develop the sub-optimal acreage within the asset.

Summary

The primary focus of this white paper is to explore what is required to fully exploit unconventional resources. A full development cycle of natural resources includes exploration, evaluation, drilling, completion and production. We discuss our integrated workflows that aim to deliver an understanding of the subsurface which evolves around the availability of data, the rock characteristics and the technologies that allow better and more informed decisions to be made.

Integrated Disciplines in Unconventional Plays

Exploration and exploitation may occur simultaneously in a single drilling effort, leading to more complex targeting plans (e.g. operating multi-landings and extension into secondary targets). Ultimately, a full understanding of the subsurface is required using all available data in order to drive decisions on where to place the well, how to stimulate it and what the likely production is to maximize return on investments and achieve production targets.

Unconventional plays are engineering driven with optimizing the recovery as opposed to locating the resource being the critical driver. However, subtle variation in the rock properties can lead to significant variation in the well performance. Consequently, it is critical to understand both the variations in rock properties and how this variation leads to changes in behaviour and subsequent performance. Seismic provides the data between wells that can be used to understand lateral variations in key properties and provides the resolution that can drive performance. Seismic data gives the greatest value where there are large lateral variations in the subsurface.

High quality rock physics models are required to extract the properties of interest from the seismic data. These properties can be integrated with geomechanical models to understand and predict the variation in behaviour. Hence an integrated workflow is required, which incorporates the feasibility of reliably predicting the variation in rock properties at the required resolution.

Unconventional plays are often characterized by a large number of wells covering large geographical extents but with variable amounts and types of data that can corresponding to a large range of uncertainty in subsurface models. Specifically, datasets are extremely diverse in both type and storage format; being able to load disparate and discrete multidisciplinary datasets scattered across different storage media into a single space for coherent interpretation is often required.

Conversely, large datasets with hundreds of wells can be problematic in unconventionals when using traditional exploration and production workflows where iterative blind well testing and model calibration is often difficult and, crucially, a very time consuming effort. Value realization through analysis of multiple data types across multiple disciplines through rapid data acquisition and processing of, for example, preliminary petrophysical analysis, core descriptions, fracture analysis and with continuous integration of data such as, source rock analysis, updated petrophysical analysis, rock mechanics, leads to more robust geological models that have direct and timely impact on drilling and completion decisions.

Therefore having streamlined workflows that are actionable between these disciplines and establishing the link between subsurface and engineering, is crucial to exploit these resources. Having the ability to work in a fully integrated cross-discipline workflow reduces the chances of data corruption, reduces cycle time, ensures all data is captured and that models are fully calibrated in order to make informed decision in an appropriate timeframe.

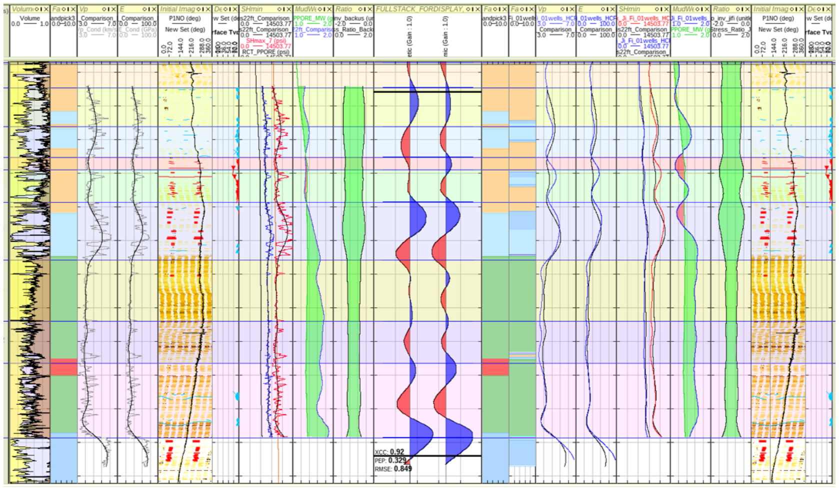

Figure 1 Well based feasibility analysis[4]. The calibrated well based geomechanical model accurately explains the well behaviour. This model is upscaled to seismic resolution to see if the required variation can still be detected and subsequently compared to the seismic based prediction to understand the feasibility and reliability of the estimates.

Prediction of Geotechnical Behaviour with Improved Accuracy

Once high-resolution models based on rock properties and multiple data types are established, the interdependent links between the stresses, pore pressure and rock properties may be exploited in the operational phase. The sweet spot may be an optimization of any number of key economic parameters (quality rock, surface land access, drilling and stimulation costs, production, localized break even period etc.) and understanding the relationship between the earth properties and these economic parameters is the key to drilling a successful well.

Well Placement and Geosteering

Well placement is dependent on maximizing production and minimizing drilling and completion cost. As we exploit more complex plays and continue the push for increased oil recovery, the industry is moving towards increasing contact with the reservoir through longer horizontal wells and with enhanced completion strategies necessitating an accurate understanding of variations in rock properties and behaviour to optimize well placement. Accurate well placement helps improve construction efficiency, reduce drilling risk, extend reservoir contact, maximize reservoir exposure, improve well performance and enhance ultimate hydrocarbon recovery.

In recent years the industry has witnessed new developments in data acquisition, interpretation, visualization, and integration technologies in unconventional plays. Mapping of unconventional facies from seismic is crucial. By building accurate high resolution images of the subsurface, one can make better, more informed decisions on well placement and geosteering. Put simply, a more data driven approach to seismic analysis for facies descriptions can deliver improved interpretation of subtle lateral variations in complex seismic response leading to better predictive models. Using these facies volumes can help geosteer around lenses of hard rock and to land and steer the well in the targeted lateral section with a high degree of confidence.

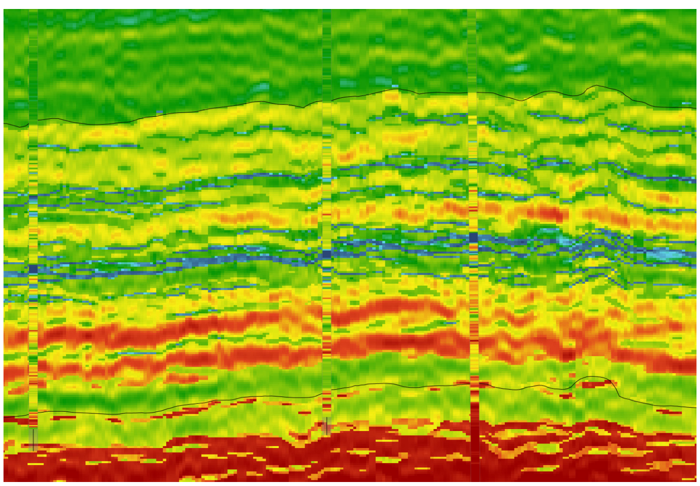

Figure 2 Enhanced detection of thin, meter scale coal seams augments property prediction in neighbouring Cretaceous tight clastic reservoirs (Alberta, Canada). The soft, sub-seismic coal properties are smeared in conventional inversions, but by jointly inverting for facies and impedances with Ikon technology, the porosity from impedance prediction in the neighbouring tight sands is made viable significantly altering well placement decisions. The improved property model also has implications for wellbore stability modelling and stimulation behaviour.

Well Planning and Design

Once a prospective region has been identified, wells need to be designed to optimize cost-effective and safe operations. There are many factors to be considered, including; pad placement, mud planning and well design, geosteering, bottom hole assembly design, bit selection and optimization, drilling fluids, hydraulics, hole cleaning, wellbore integrity, torque and drag. By ensuring that all subsurface data are fully integrated, the well design and drilling schedule can be optimized, leading to better resource development decisions.

Wellbores in unconventional gas and oil plays are characteristically drilled and completed with a long horizontal section for maximum exposure through the producing reservoir. Drilling the horizontal reservoir section typically does not present too many problems, since the rock strength is adequate to maintain a stable / gauge wellbore.

Typically, the main challenge in drilling the horizontal section is related to staying within zone since the formations are often thin with large lateral extent. It is in this area that 3D seismic data can provide crucial information in terms of depths to top of target interval and interval thicknesses, derived from e.g. high resolution facies based inversion. Challenges can be encountered in the horizontal section or when building the wellbore angle from vertical to horizontal through the overburden formations, resulting in wellbore stability through drilling these formations with sub-optimal mud programs.

Pad drilling of unconventional plays can also give rise to further complexities in drilling and completion operations where simultaneous operations can lead to 'collision' caused by the close proximity of well-planned trajectories.

The analysis, modelling and prediction of offset well behaviour and transformation from LWD / wireline to seismic resolution is often critical in developing a robust picture of the subsurface at a variety of scales. Through careful integration of these subsurface data it is possible to leverage the link between stress state and rock properties to better guide the selection of optimum landing locations not possible using well data alone. Furthermore, these data driven models of rock types, rock properties and sonic velocities can be used to build robust models to help with e.g. bit selection. Estimates of pore pressure, stress state, collapse pressure and initiation pressure can also be derived to help with well planning, casing design and completions.

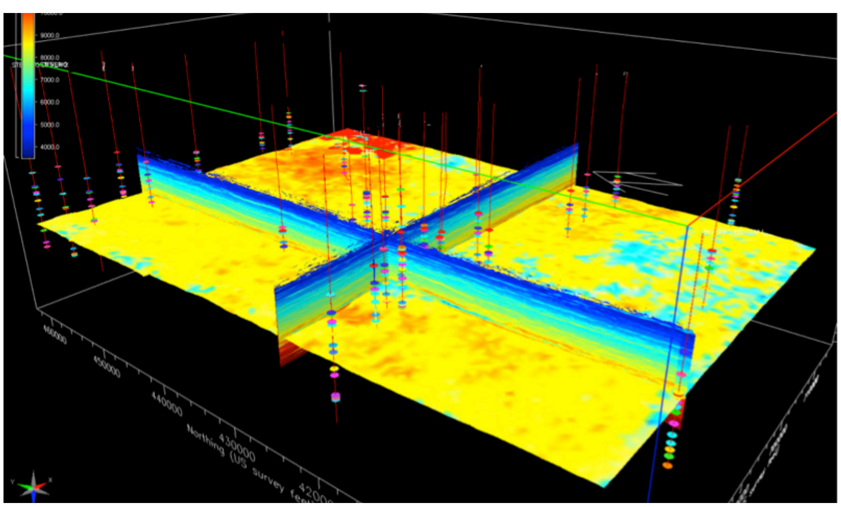

Figure 3 Predicting pore pressures on-shore in the Delaware Basin using wireline logs, core data, pressure information and drilling histories[5].

Fracture Stimulation

When hydraulically stimulating horizontal wells, in order to exploit the hydrocarbon potential of unconventional plays, multiple datasets and disciplines are involved; drilling, geoscience, geomechanics, reservoir, completions and operations. The largest overriding impact on the successfulness of a stimulation programme relates to the understanding of the stress state and rock properties, and their impact on the fracture behaviour.

Fracture interference, fracture geometry and fracture design must also be considered which are primarily a geomechanical issue in unconventional reservoirs. Factors such as the type, size, and concentration of existing fractures and / or stimulated fractures and their permeabilities are entirely controlled by the situ stresses and elastic properties of the rocks. Understanding these properties at offset well locations and extrapolating these to new locations by leveraging the elastic properties derived from seismic in the geomechanical workflow provides a simple, quick and cost effective solution to evaluate completions designs and well performance, particularly along the length of the lateral where a very limited log suite is typically acquired.

Identifying Known and Future Well Performance with Seismic Derived Attributes

It is widely known that one of the key challenges in unconventional resources is that there is often a lack of consistency in well performance between wells, and within the same wells, leading to highly variable productions rates, often with rapid decline. Furthermore, it is also accepted that the well performance is greatly affected by the type of completion configuration implemented in the reservoir and horizontal well section (e.g. length of horizontal section, frac stages, frac interference). In the recent past, much focus has been on addressing these issues through advancements in engineering and well design.

There is now a growing realisation that the subsurface and the in situ stress and elastic rock properties provide a first order control on well performance. A key industry challenge has been how to objectively and robustly derive 3D elastic property volumes that can be utilized in geomechanical model buildings. In the past, elastic property cubes would typically be derived through simultaneous seismic inversion, a process suffering from a number of pitfalls (lack of resolution, poor rock physics consistency and interpolation bias). New inversion technologies, such as Ikon Science's Ji-Fi technology, overcome many of these challenges.

By inverting the seismic data directly to facies and elastic properties (through utilisation of facies based VTI anisotropic reflectivity equations) and by constraining the elastic properties to honour per facies rock physics models, it is now possible to derive high resolution facies images and robust elastic properties that honour both the seismic and well data and that are not biased by what are now increasingly being seen as outdated interpolation algorithms. These facies and elastic property volumes provide optimum inputs into 3D geomechanical models, where they can be used to identify and high grade sweet spots and generate and analyze different drilling and completion scenarios.

By integrating multiple datasets, offset well data, engineering data and seismic data it is possible to construct accurate elastic property volumes to understand lateral variations. Utilizing these property volumes in the geomechanical workflow allows the stresses and associated fracture initiation pressures to be resolved at and away from well locations. Volume sculpting can be performed, based on the combination of elastic properties, stresses and pore pressures to determine volumes of potentially productive rock or maximum volumes of rock that can be stimulated and that can contribute to Estimated Ultimate Recovery (EUR). These volumes and their petrophysical properties (porosity, TOC, permeability, etc) can be used to assess past, present and future production characteristics and potential.

Software to Help Exploit Unconventional Resources

Ikon Science offers a range of quick and effective subsurface modelling and analysis software meaning exceptional turnaround times for well decisions in exploration and exploitation of unconventional plays. The platform brings together core subsurface disciplines in one package, unlocking greater value across assets and teams.

- Joint Impedance and Facies Inversion (Ji-Fi) – Derive high resolution facies and isotropic elastic properties through anisotropic, facies based inversion of pre- or post-stack seismic data. The high resolution outputs image thin layers which can be crucial in bit selection (e.g. high impedance barriers), but are equally important in the planning of long horizontal sections where geosteering must keep the well in zone and in contact with the target formation sweet spot. The isotropic elastic properties can be transformed, via the appropriate rock physics model, into accurate estimates of petrophysical properties which in turn feed into the identification of sweet spot trends.
- Rock Physics Module – Understanding the effects of organic richness, mineralogy, micro-cracks, pore shape, and effective stress is a major challenge when developing unconventional resource plays. Ikon Science's rock physics module contains seventeen rock physics models (RPMs) specifically for use in unconventional plays in order to decipher which combination of these properties is controlling the seismic response from the reservoir.
- Anisotropy Add-On – Stress and rock anisotropy analysis is important for estimating both stress regime and fracture geometry for the efficient development of unconventional resources. The Anisotropy Add-On allows interpreters to build 1D and 2D synthetic seismicmodels to explore the impact of anisotropy on the seismic response and allows for the stress anisotropy to be fully modelled using anisotropic poro-elastic strain equations. Well log corrections can be applied to measured sonic data through inclined sections of wells, leading to improved estimates of e.g. TOC, when using methods such as that of Passey6.
- Pressure Prediction Module – Build accurate pore pressure models, quickly and easily combining all data types to create powerful pore pressure models to help with faster drilling, reduce non-productive time, better log acquisition, more robust geomechanical models, and improved sweet spot identification.
- Geomechanics Add-On – For unconventional reservoirs, the geomechanical properties of the subsurface greatly influence the processes of both drilling and hydraulic fracturing. Build high fidelity rock property models from inversions and the seismic to derive accurate geomechanical models for better understanding of wellbore stability, stimulation design, casing deformation and induced seismicity.

Conclusion

Any subsurface prediction is dependent on the rock properties we can measure at a well scale or the seismic scale. Ultimately the rock properties are controlled by the geology, e.g. the basin litho-stratigraphy, facies distributions and bed-scale elastic properties, and thus a better understanding of variations in the subsurface leads to more accurate predictions and improvements in the decision making process in unconventional resources.

Ikon Science is a global geoprediction company offering software and solutions for all geophysics, geopressure, and geomechanics needs, unlocking the value of hydrocarbon reserves while reducing costs and uncertainty. We integrate multiple data types and disciplines to provide 3D volumes of rock properties that are critical to efficient unconventional resource development. Using our cutting-edge, 3D facies inversion technology, RokDoc Ji-Fi, with geomechanical analysis, we can predict optimal drilling locations, trajectories and assess various risks impacting well performance and design. Our constant goal is to create the most valuable products for oil and gas operators in today's price environment.

Adding further value through joint ventures

Fairfield Geotechnologies and Ikon Science have formed a joint venture to offer complete geoprediction services to the oil and gas industry in North America. The joint venture leverages Ikon Science's geoprediction technology, which includes innovative workflows for unconventional and conventional reservoirs and award-winning RokDoc Ji-Fi inversion software, with Fairfield Geotechnologies' seismic acquisition, processing and multi-client data library. Together, the two companies will be able to offer their clients customized, high-quality geotechnical solutions designed for comprehensive reservoir characterization.

The new Fairfield Geotechnologies/Ikon Science partnership offers a complete geoscience solution from seismic acquisition to well planning:

- High resolution imaging of complex geology
- Well planning – get in the zone, stay in the zone
- Rock property prediction for reservoir management; planning and ranking your opportunities accurately to maximize the value of your asset.

References:

[1] European Parliamentary Research Service. 2014. EPRS: Unconventional gas and oil in North America: the impact of shale gas and tight oil on the US and Canadian economies and on global energy flows. Available at: URL www.europarl.europa.eu

[2] Larson, J.W. 2012. Unconventional plays fueling economic growth. The American Oil and Gas Reporter.

[3] The Oxford Institute for Energy Studies. 2017. University of Oxford: Completion design changes and the impact on US shale well productivity. Available at URL: https://www.oxfordenergy.org

[4] Payne, S. and Meyer J. 2017. Using seismic inversion to predict geomechanical well behaviour: a case study from the Permian Basin, Unconventional Resources Technology Conference, Abstract, 2665754.

[5] Rauch-Davies, M., Schmicker, B., Smith, S., Green, S. and Meyer, J. 2018. Predicting pore-pressure from onshore seismic data in the Delaware Basin, Unconventional Resources Technology Conference, Abstract 2888832.

[6] Passey, Q.R., Creaney, S., Kulla, J.B., Moretti, F.J. and Stroud, J.D. 1990. A practical model for organic richness from porosity and resistivity logs, AAPG Bulletin, v. 74, p. 1777-1794.

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