Horizontal well placement for unconventional reservoirs- A field development prospective

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Summary

Well placement for unconventional oil reservoirs has significant economic impact for a field development prospective. Optimizing recoverable reserves from these reservoirs requires proper placement of horizontal well bores, drilling the laterals in right direction and keeping the lateral portion of the well bores in the target layer. It further requires production stimulation by hydraulic fracturing of the rocks in order to induce fractures extending laterally from the horizontal well bore. In this article, a method is presented to identify the optimum horizontal well drilling location by integrating geological, geophysical, geomechanical and petrophysical parameters using seismic and well data from a basin in China. Available 3D seismic, wells and image logs were interpreted and integrated into a conceptual geological model. A model-based seismic inversion algorithm was implemented to predict acoustic impedance (AI). A geomechanical model was developed for the field, which provided the reservoir pressure, *in-situ* stresses and rock properties to predict the optimal well trajectory. The seismic amplitude time slices generated at the top of the target show a wide zone of amplitude anomalies corresponding to the meandering channels interpreted from the image log analysis. The horizontal well was successfully drilled in the reservoir sands.

Introduction

Unconventional resource plays introduce challenges what were not present for the development of conventional reservoir system. These plays are driving evolutionary technological advances necessary to develop the resource base economically, particularly with respect to drilling and completing wells. The ability to efficiently exploit ultralow-permeability plays has invigorated the oil and gas industry around the globe. The transition from vertical to horizontal wells was spurred by development of revolutionary techniques for drilling and completion.

For tight oil/gas and shallow depth coalbed methane plays, a large number of wells are needed, and thus the environmental footprint is larger. To improve production from individual wells, a good understanding of the reservoir is needed so the wells can be optimally fractured and completed. Tight oil generally refers to the oil resources that have experienced short distance migration, gathered in either tight sandstone, tight limestone or tight carbonate reservoir layers, may be interbedded with or in close proximity to the source bed, the overburden pressure matrix permeability is less than or equal to 0.1 mD, and reservoir porosity is less than 10%. The oil contained within these reservoir rocks typically does not flow to the wellbore at economic rates without assistance from technologically advanced drilling and completion techniques.

Hydraulic fracturing of oil and gas reservoirs has been an accepted technique for enhancing production since its commercial introduction in 1949, and plays a major role in developing many oil and gas fields globally. The combination of fracturing technology and horizontal drilling has made exploiting source rock reservoirs a thriving endeavor in North America. While world economy growth explodes the demand of petroleum, horizontal well technique is being applied more and more worldwide in the oil and gas industry. If the existing horizontal well data can be combined with seismic inversion on reservoir characterization, it would be an innovative approach.

The primary objective of this study was to optimize a horizontal well placement and forecast production after fracture stimulation of a tight sandstone reservoir. This was achieved by integrating different disciplines in an innovative way of repaid reservoir development.

Materials and Methods

A multi-disciplinary approach of integrating geology, geophysics, petrophysics, was applied to design the optimal placement of a horizontal well in an unconventional reservoir from basin in china.

Geological Settings

The area of interest is located in the central Junggar basin, northwest China. The Badaowan Formation, comprising coals, mudstones and sandstones, the target of this horizontal well, was deposited on a lacustrine plain during the early to middle Jurassic (Fig. 1). The sandstones represent a series of amalgamated meandering channels and crevasse splays, separated by layers of finer sediments that act as local seals, whereas the coals are considered to be potential source rocks (Yang et al, 2012; Yang Y., 2014;

Xiao et al, 2010; Cheng-long Fan, 1991). A regional fluvial and lacustrine sandy shale seal was developed in the late Jurassic. Source rocks are from the Permian and middle and lower Jurassic formations (Zhai et al, 2002; Wu et al, 2004). The best developed source rocks are in the lower Permian Fengcheng Formation and the upper Permian Wuerthe Formation. These are dominated by lacustrine dark mudstones with mainly type II kerogen containing as much as 2% total organic carbon (TOC). The Jurassic source rocks consist mainly of dark shale and thin coal beds in the lower and middle Jurassic and contain mostly type III kerogen with TOC values up to 2%.

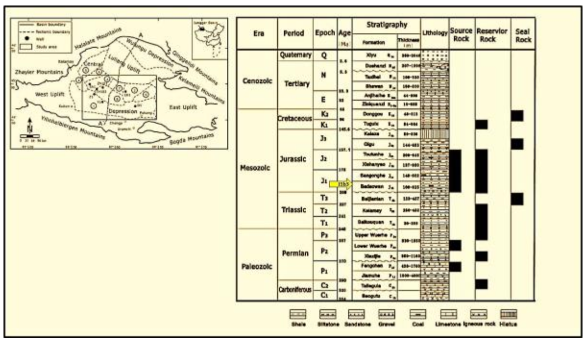

Figure 1: Stratigraphic column and location map. Yellow arrow points out to the target interval, the J1b3 Badaowan Formation

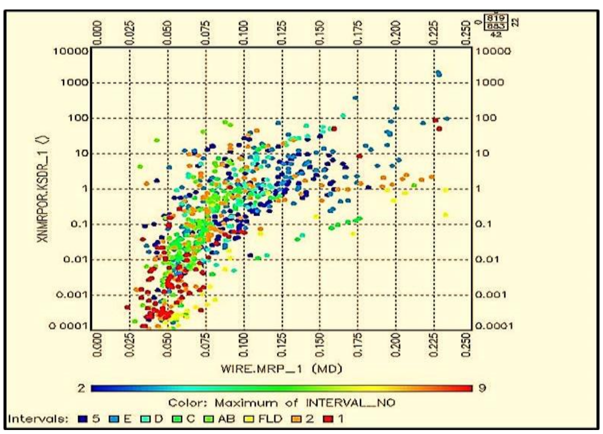

Figure 2: Porosity vs Permeability from NMR data

Petrophysical Understanding

Petrophysical tasks focused on selecting the best reservoir interval from a pilot vertical well and deriving suitable input parameters for basic reservoir modelling and production forecast. A zone with the highest oil saturation, best porosity and highest permeability was chosen as the primary target interval for the horizontal section to be drilled through. NMR porosity from the vertical well correlated well to the core porosity. Zones with higher porosity were associated with dissolution but this relationship did not correspond with higher permeability. The NMR porosity and permeability cross-plot showed a steep porosity-permeability relationship at low porosities (Fig. 2). Permeability from the NMR log and air permeability from core plug data showed an acceptable agreement. Permeability was generally below 0.5 mD; very low due to compaction and cementation. In summary, the reservoir has very low permability and porosity has a patchy, random distribution controlled by dissolution diagenesis.

Understanding Sedimentology

A detailed structural and sedimentological study of the image log was performed with two main objectives:

- Quantify borehole breakout and measure the direction of maximum stress, and
- To measure and interpret the paleocurrents over the primary sand objective.

The vertical succession of lithofacies was analyzed and grouped into four lithofacies associations, representing sub-environments of an alluvial-fluvial plain and lacustrine-delta setting, namely: lacustrine/delta plain, lower channel fill, upper channel fill and flood-plain. The reservoir section comprises lower and upper channel fills.

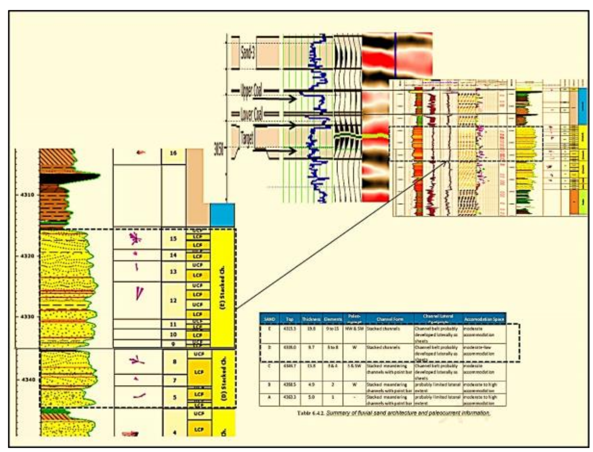

Figure 3: Image log analysis showing sand architecture and paleocurrent orientation. Dash black rectangle represents the target interval. Upper right: image log tied to seismic data.

These sands are divided into four depositional units representing channel belts. Both the internal architecture and paleocurrent direction are different for each unit. The target sand has a predominantely West to North-West (W to NW) paleocurrent direction, representing a channel belt within a sequence of stacked channels. Once the lithofacies scheme was defined, it was calibrated to core, open-hole logs, and seismic. (Fig. 3)

Geophysical and Geomechanical Analysis

The post-stack statistical wavelet was extracted from well-seismic ties. A check shot was used for time-depth relationships and further integrated with the P-sonic logs to ensure the highest correlation between synthetic and seismic data using the final wavelet. The wavelet and well ties were of good quality. Correlation was acceptable for the Badaowan Formation. The top of the interval was interpreted every other crossline and inline in a circle of 2 km radius from the vertical well. The horizon was later flattened in order to remove any structural effect and three horizon slices were generated. Seismic amplitude tiemslice (Fig. 4A) was almost coincident with the top of the target, showing a wide zone of amplitude anomalies that were interpreted as stacked channels and crevasse splays, supported from the analysis of the resistivity image log at the well location. A model-based seismic inversion algorithm was implemented to predict acoustic impedance (AI) (Fig 4B). To predict porosity (Fig. 4C) from AI, a linear relationship between impedance and neutron porosity was established and applied to impedance volume.

A geomechanical study was performed to optimize an operational mud weight window for drilling the planned well. A geomechanical model is comprised of a few components: rock mechanical properties (uniaxial compressive strength UCS, internal friction coefficient, Young's modulus and Poisson's ratio), field vertical stress S_v, formation pressure P_p, minimum horizontal stress S_{hmin}, maximum horizontal stress S_{Hmax} and the orientation of the horizontal stresses. The historical well drilling data, wireline logs, field tests, and newly obtained minifrac data, provided inputs for deriving a well-centric geomechanical model for the field.

The S_{hmin} profile was calibrated with a fracture closure pressure (FCP) measurement in another historical well at the minifrac test depth. An effective stress ratio principle was used to extend the profile from ground level to the target depth. This S_{hmin} profile was used for wellbore stability analysis. For hydraulic fracturing optimization, the S_{hmin} profile was further refined according to constant strain principle to model the stress contrast among various lithologies using acoustic log data available. The image data analysis introduced earlier had derived the orientation of the maximum horizontal stress S_{Hmax}, which is 025ºN/205ºN. The magnitudes of the S_{Hmax} were then determined by modelling the wellbore failure indicated by image data (Fig. 5). The derived parameters were together verified by comparing the predicted wellbore condition (breakout or not) with the observed drilling drilling experiences of reference wells. The calibrated geomechanical model was used to predict the optimal mud weight window for the planned horizontal wellbore to avoid breakouts and mud losses, minimizing the costs.

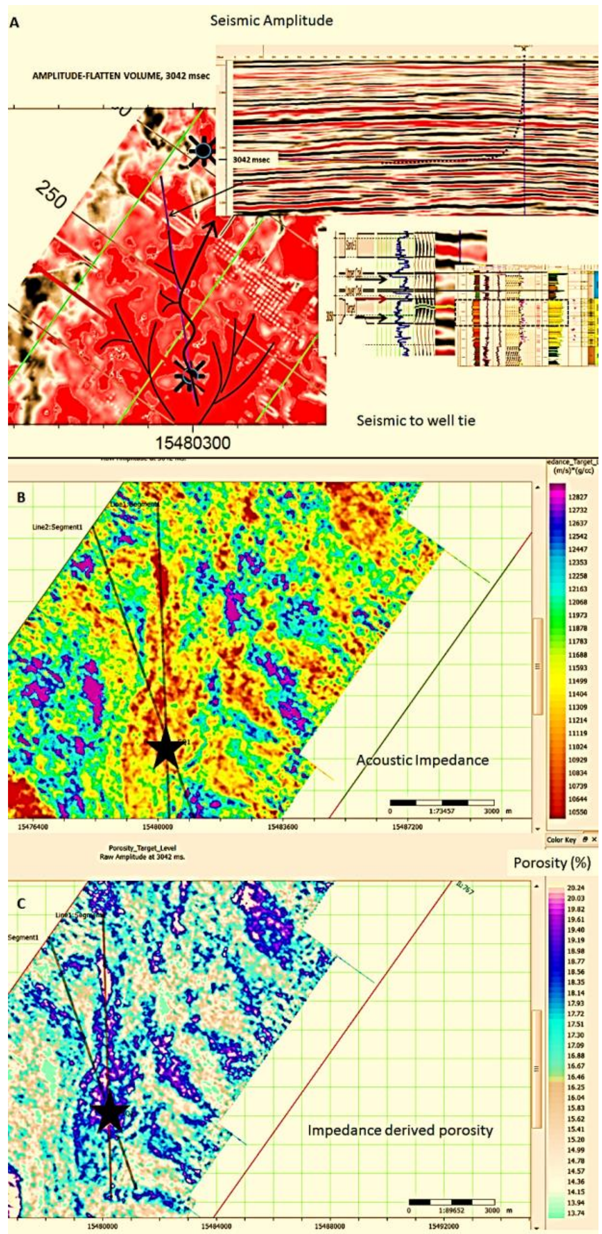

Figure 4: Seismic amplitude, inversion derived impedance and porosity are shown. [A] Horizon slice placed very close to the top of the target. In purple, the orientation of the

deviated well. The seismic line at top right runs through this direction. Below the line, a composite picture showing the GR, tops and the interpreted image log (dash black area is the target sand) [B] Acoustic imedance and [C] Impedance derived porosity are showing the similar trend. Well location is marked by a black star in B & C.

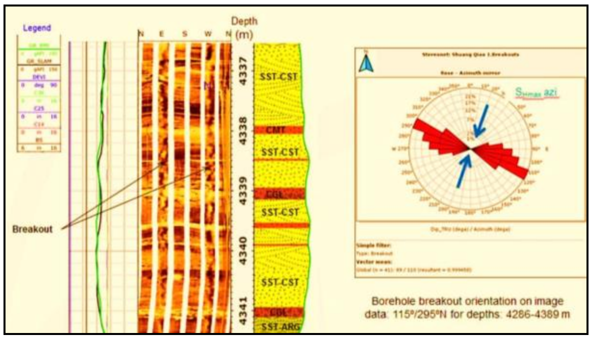

Figure 5: Interpreted image data showing breakouts (red bars) oriented 115ºN/295ºN in the interval between 4286 m and 4389 m of the key reference well. The S_{Hmax} orientation (blue arrows) is perpendicular to the breakout orientation.

Remarks

To determine the optimum azimuth for the horizontal section, the information from petrophysics, geology, sedimentology, and geophysics was integrated with the results of the stress regime and wellbore stability study. A well trajectory to 351 degrees (north) was expected to be optimal based on the modeled fracture propagation and sand distribution observed on the horizon slice at the top of the target. This orientation also crosses the best developed amplitude anomalies along the trajectory. The target was located between the peak and the base of such wavelet. The real trajectory of the well was placed over the line. More than 600 m of good quality sand were drilled following the proposed orientation with no wellbore stability problems. A few layers of shale appeared and were interpreted as pinchouts or shale-out at the edge of channels or crevasse splays.

Conclusions

The overall goal of this multi-discipline study was to make the best use of available data to reduce uncertainties in drilling a horizontal well for an unconventional hydrocarbon reservoir development prospective. The primary challenges were to identify an optimal well trajectory by the integration of geological, e-log imagery, petrophysical, geophysical, and engineering information with the results of the stress regime and wellbore stability study. The horizontal section was successfully drilled in 20 days following the proposed north 351°azimuth. The hole had no geomechanical problems at all navigating through more than 600m of reservoir sands with hydrocarbon shows.

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