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Horizontal Well Geo-Navigation: Planning, Monitoring and Geosteering

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Abstract

Geosteering process should not be seen as a process solely designated for the most expensive or highest profile horizontal wells. It can be regarded as another tool for improving the odds of success by remaining for longer periods of drilling in the productive zone. Also it can be used to optimize the positioning of a horizontal well bore in the sweet spots within the reservoir.

Exploration and Production (E&P) companies are continuously being driven to reduce the cost per BOE. Convergence of E&P needs and technologies related to advanced and accurate directional drilling, communication of vital data in real-time through the internet, as well as reduced cycle time associated with advanced forward-looking 3D geo-modelling and visualization technologies (Figure 1) are currently aligned. These have been advancing the horizontal well geo-steering process using Measurement While Drilling (MWD) into mainstream drilling practices.

Convergence of Technologies for Geo-steering

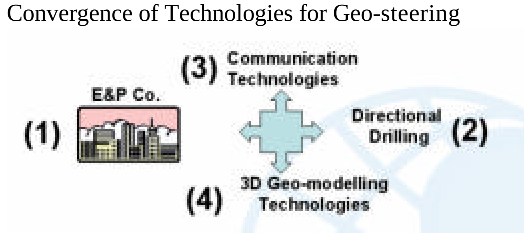

Figure 1

The universal economic benefits gained can be found in all resource play types (conventional oil and gas, heavy oil, tight gas and coal bed methane).

It is important to note that the process described here is essentially collaborative. For best results, there must be cooperation between the E&P operational staff, wellsite geologist, directional driller and geo-modeling staff as well as the consultants involved in the project (i.e. the team as a whole).

Introduction

Reducing Costs and Increasing Performance for Optimal Well Results

Whether drilling a long reach horizontal in heavy oil or a tight gas play, the basic requirements for a successful well are:

1) Planning the optimal path based on the current knowledge of integrated geological / geophysical models.
2) Monitoring the progress of the well through real-time updates.
3) Continuously remapping to identify the true stratigraphic position (TSP) of the bit relative to the reservoir. This information is used to provide advice to the drilling team for staying in the zone of interest while drilling.
4) Timely reporting on the updated road map for the horizontal well to provide the information necessary for drilling ahead of the bit.

Depending on the depth and/or rock type the speed of drilling can range from very fast (200 m/hr in shallow heavy oil horizontals) to very slow (3-10 m/hr in tight formations). For fast or slower drilling, the geo-steering process is used as a planning and monitoring tool. This reduces guesswork in the drilling process which translates into less drilling time for a given well ultimately decreasing the total cost and increasing profits. The 3D geo-models can be updated every few minutes for structural changes and periodically for characterization of the gamma ray (GR) and other reservoir attributes.

Another benefit for operators working in reservoirs that have multiple rigs drilling is that the information gathered and processed will influence and change the 3D mapping window (or highway) for current or subsequent wells. 'Just in time' modelling reduces re-drill costs associated with sidetracks.

Geo-steering a horizontal well while drilling is not only important, it is also profitable. The controlled placement of wells for mitigation of water or gas is another reason why geo-steering can be important for operation geologists, reservoir engineers as well as E&P companies. Although the complexity of the geological structures and changes in the reservoir quality can be overwhelming, automated gathering of MWD data, monitoring, frequent 3D mapping / characterization / visualization and reporting is now achievable and easier to use with current advanced systems.

There are also other operational cost savings associated with this 'just in time' mapping process. Faster and more productive drilling through the sweet spots in a reservoir can mean: operational time saving. This is particularly true in tight gas wells and in hard formations. Longer productive reservoir intervals are exposed in the wellbore resulting in higher productivity. Also drill bits last longer resulting in more cost savings.

Advanced Directional Drilling Technologies

Advances in directional drilling aiming at geological targets are well recognized today. These include increased accuracy in the placement of extended horizontal wellbores according to initial specks. 'Just in time' 3D mapping is a promising area that can add value to E&P's by reducing the inherent geological risk / uncertainty with any drilling.

Communication Technologies

A key component of the current synergy is advanced communication technology. Data must be available as soon as it is needed. Until recently, real-time requirements meant twice a day reporting. Current needs require immediate data access to vital well information in order for effective decision-making to influence the path of horizontal wellbores. There are currently systems that deliver the data from the well site (in the format of Wellsite Information Transfer Standard (WITS)) through Electronic Data

Retrieval systems or Electronic Drilling Recorders (EDR). Data from EDR systems is accessible through secured websites in an LAS report format.

The WITS format has been upgraded to WITSML (ML stands for Markup Language) that has been used in Europe for over two years. This format is now available in North America. Operators such as Statoil, BP and Shell, who have been joined by several major service companies, have initiated the future of data acquisition. The WITSML process is consumer driven (E&P) and its interfaces are comprised of two types, publish/subscribe and store.

The significance of this type of access is that its subscribe format is comparable to an electronic news service where information is continuously updated, allowing the consumer to choose the frequency and type of information they would like updated.

Using horizontal well drilling as an example, several types of data streams that may need frequent updating for geo-steering, such as gamma ray (GR), well trajectory data and/or rate of penetration (ROP) can be delivered to the dynamic geo-steering / geo-model on a 'while drilling basis'. This allows for real-time monitoring and subsequent re-mappings.

Reduced cycle time using Advanced and Automated 3D Geo-modelling Technology

The E&P or consulting / service companies initially produce integrated geo-models using geological and geophysical data. The 'pre-drill' models integrate all available data from the rig and collaboration between the team.

While Drilling Visualization & Characterization

Visualizing trajectory and trace data from MWD

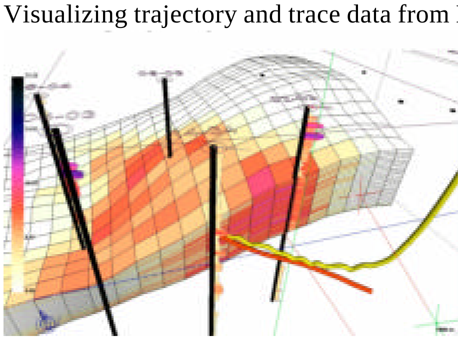

Figure 2

These geo-models can contain as few as three wells to over 1000 wells. The above example illustrates a horizontal injector in a small oil reservoir. The pre-drill model had eight wells and a 3D seismic generated surface (Figure 2). This model also integrated strip log porosity data for enhancing the model.

At the outset, the geo-model is used to plan the path of the heavy oil or tight gas horizontal wells through previously mapped out characterizations.

Example 1 below shows a proposed and actual well through hydrocarbon pore volume (HCPV) of a heavy oil well in southern Alberta (Figure 3).

Example 1: Heavy Oil Geo-modelling

Horizontal well trajectory with HCPV zone data

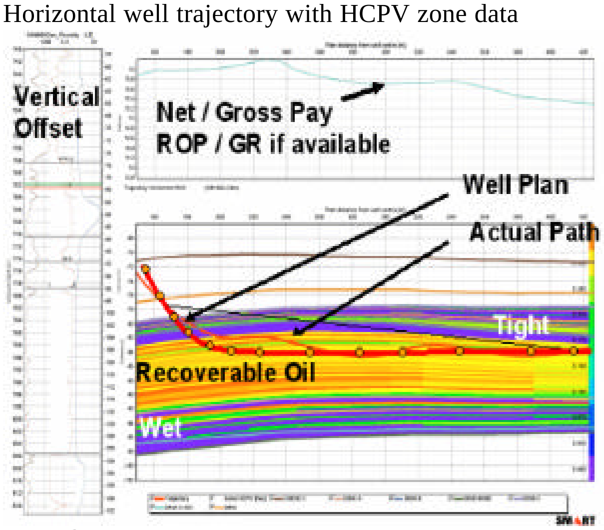

Figure 3

The frequently monitored and tested automated 3D mapping, characterization and visualization are accomplished in commercially available 3D geo-modelling software / technology where the pre-drill model is updated at required frequencies.

Several features of these models include:
1) The enabling of accurate well planning for horizontals through the 3D reservoir target window.

2) Monitoring capability with real-time data using standards such as WITSML.

3) The geological context for determining the true stratigraphic position of the bit.

4) Forward-looking window, providing the driller with a view to the target.

Periodically, strip-log data from the well site geologist is integrated into the geo-modeling / geo-steering profile while drilling. The geo-model results are provided as a report back to the clients. These reports consist not only of 3D views of the planned and actual drilling but also along the length and plan distance from well center. After drilling, newly acquired logs are incorporated back into the model. A final report on the well is provided for completion and other purposes.

Case Studies

The following heavy oil example in northeast Alberta shows the degree of mapping details for the path of a horizontal well. The reservoir contains hundreds of extended horizontals. Most wells have tops implemented at every 50m of length.

Example 2 (Figure 4) shows that once geologists implement the tops by positioning an independent marker above and below the trajectory (using the gamma ray log response, offset well info and trajectory position), the automated geo-model implements the top within a few minutes (continuous surfaces mapped in the example as top and base). Once this mapping process is completed, it creates the window for drilling the next infills prognosis.

To illustrate the point, example 3 (Figure 5) in the same reservoir shows existing wells with no tops implemented at this stage of mapping. These are already drilled and logged locations for which data has not been incorporated into the model and yet the previous prognosis is consistent with the actual results. Therefore, example 2 indicates a proactive process that maps out the road map for the next set of infills. The increase of the gamma ray log response corresponds well with the mapped surfaces and the trajectory path, even without a single implemented top.

This textbook example is a result of conducting a detailed pre-drill model, which can pay dividends for infill drilling programs. The economic benefits are obvious when the outcome can assist in longer time spent in the pay zone and avert costs associated with sidetracks, etc.

Example 2: Heavy Oil Geo-modelling
Refreshed HW profile with control points.

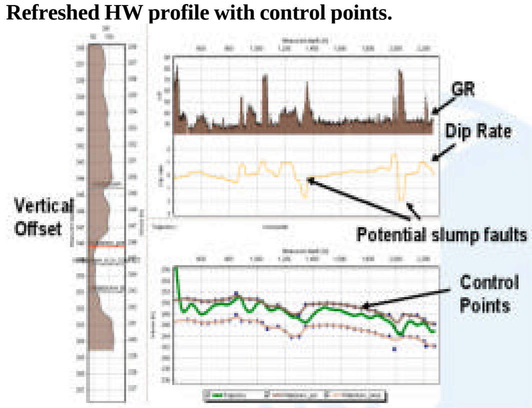

Figure 4

Example 3: Heavy Oil Geo-modelling
Refreshed HW profile with NO control points.

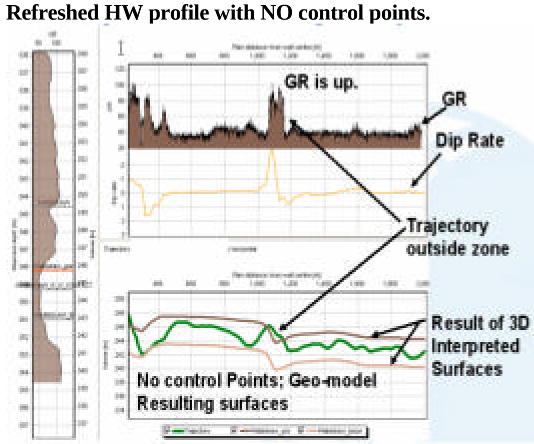

Figure 5

The next examples are cases of tight gas in the Jean Marie (Figure 6) formation in N.E. British Columbia and the Shunda (Figure 7) formation in Central Alberta. The geo-steering process is the same; a pre-drill model is used in the starting position of drilling, while trajectory and other log data such as GR and ROP, gas shows, etc. are updated while drilling.

The well planning and monitoring capabilities are used and the geo-steering process proves beneficial for providing additional guidance for the remaining well length thereby optimizing the path when it is most advantageous to do so. The well placement is monitored continuously through top views (Figure 8) and side views along the length (Figure 9). Also a plan distance from the well center is detailed (Figure 10).

While Drilling Reservoir & Trajectory Visualization

INCORPORATING REAL TIME EDR DATA.

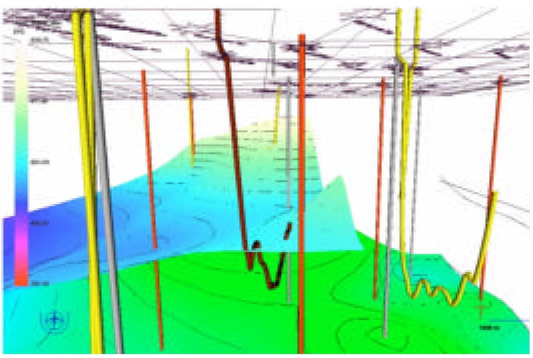

Figure 6

Time Based Model of Structure and Porosity

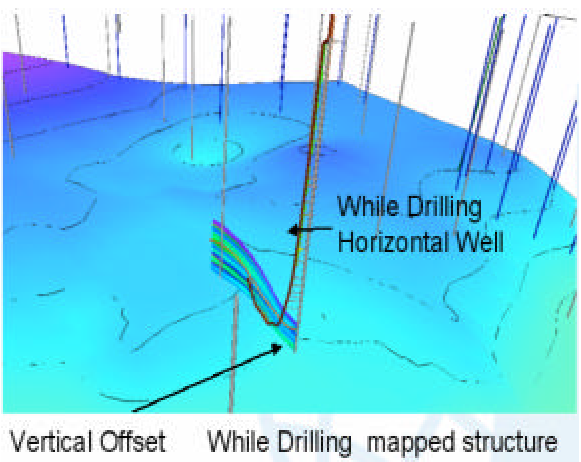

Figure 7

Time Based Model of Proposed vs Actual Trajectories

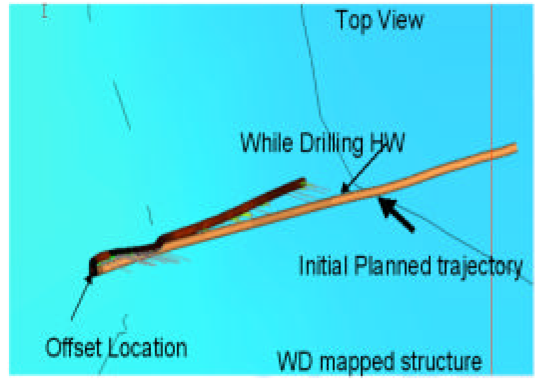

Figure 8

Time Based Model of Structure and Porosity along the Horizontal

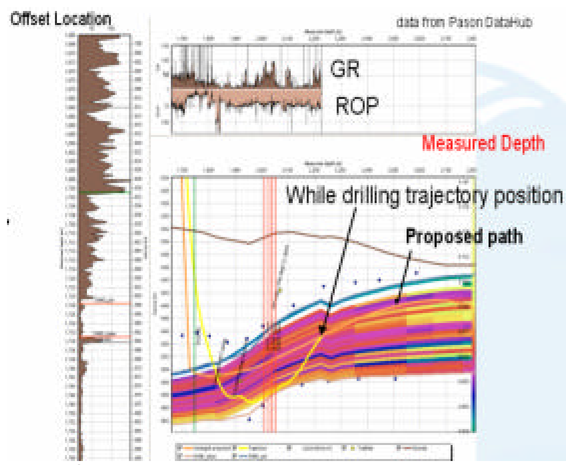

Figure 9

Time Based Model of Structure and Porosity along the Horizontal

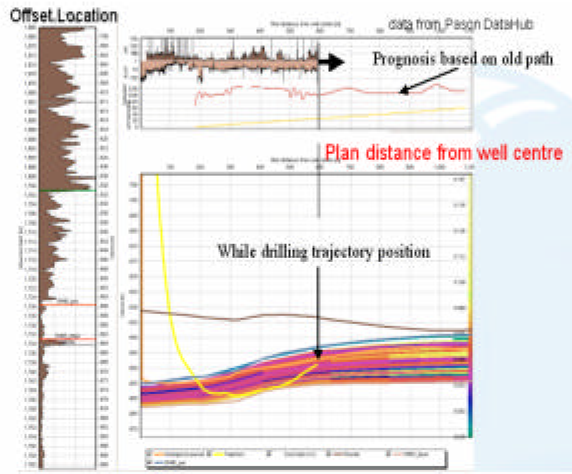

Figure 10

Collision Avoidance

Collision avoidance in tightly spaced and extended horizontal wells is a real issue. Its importance extends to any reservoir, whether oil or gas. Safety and operational cost considerations are major concerns to operators and field personnel. The risk of losing an existing oil producer or getting 'stuck in the hole' leads to costly down time as well as lost revenue from poor well placement on the new drill. Other concerns include the additional cost of sidetracks, drill bit damage and equipment loss. While drilling, the geo-model visualization provides the visual check for errors associated with the surveys of horizontal wells.

The example below is from the Dina sands reservoir in the Hayter Field, southeast Alberta. Development in the filed has progressed to the point that there are several dozen horizontal wells within each section (one square mile) (Figure 11).

A typical long reach horizontal well (~1500m) with an average survey error uncertainty of one degree from the kick off point can have up to 25 m of potential drift (Figure 12).

Figure 13 shows a perspective view of porosity distribution and trajectories in this reservoir.

Visualizing the Trajectories on Horizontal Wells

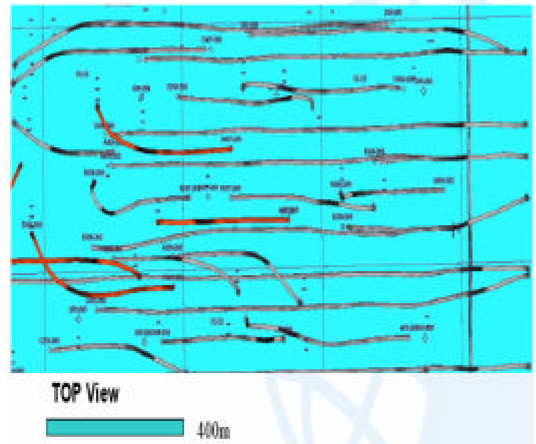

Figure 11

HW Trajectory Detailed View

Cones of Uncertainty around the survey from Kick Off Point (KOP) – Top view

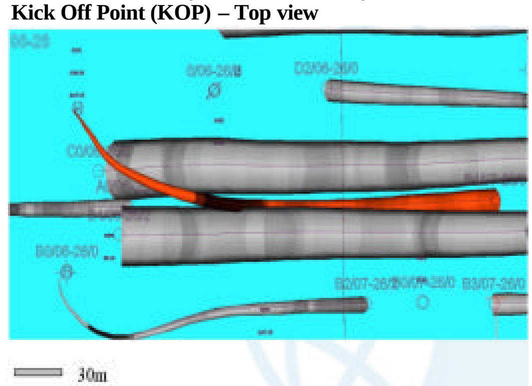

Figure 12

Visualization of Survey Errors for Mitigating Wellbore Collision

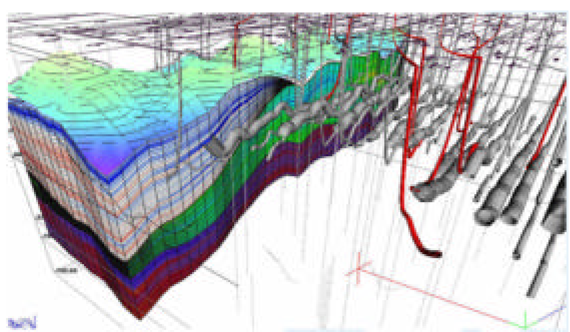

Figure 13

Conclusions

Available technologies and services have converged to provide on-demand mapping for more productive horizontal wells. E&P companies who use advanced directional drilling, communication and 3D geo-modelling technologies and services can take advantage of this.

Real-time planning and monitoring capabilities for faster drilling of horizontal wells and geo-steering capability for slower drilling (hard formations) are accessible for all horizontal wells. The geo-steering capabilities have advanced to the point that they should be incorporated into the work process of any horizontal or directional drilling in order to increase operational efficiencies and profitability.

Mitigation of gas and water in oil reservoirs and collision avoidance are two more reasons for incorporating geo-steering into the drilling process.

The collaborative process between E&P operational staff, consultants / geo-steering services, directional drillers and real-time data providers is required in every stage of drilling operations for successful geo-steering.

The cost-savings and the improved communication that new technology has brought provide key benefits to a team in the field and in the office.

When compared to current 1D and 2D modelling systems with applications for geo-steering, new 3D systems provide better modeling. This leads to an enhanced "forward looking window for drilling", cost effectiveness, better communication and an enhanced bottom line.

Acknowledgement

All images reported are from various United Oil & Gas Consulting projects using SMART 4D Modelling, integrated geo-modelling software.

About the Author

Rocky Mottahedeh is a P. Eng. and P.Geol.. He is currently the President of United Oil & Gas Consulting Ltd. Rocky graduated from the University of Toronto in 1981 with a B.Sc., Geological Engineering. He has 24 years of oil and gas experience with emphasis on new technology and integrated reservoir studies in gas, coal bed methane, oil sands and heavy oil at E&P companies in Canada and internationally. In the past 8 years Rocky has been involved in technology development focused on geo-modeling and geo-navigation through his company, United Oil and Gas Consulting Ltd.