Integrating real-time drilling information into the geological model

Hugues Thevoux-Chabuel[1] explores various approaches to improving the geological model of a reservoir through more effective integration of real time drilling data.

The current economic uncertainty, low oil prices, and frozen capital markets, together with growing reservoir complexity, are having a significant effect on oil and gas exploration with a renewed focus on reducing risk and managing costs. This is particularly seen in well planning and drilling – one of the most expensive elements of the E&P process. In an era of complex wells and a need for greater efficiencies in drilling operations, effective well planning, and accurate wellbore placement is a vital tool in reducing uncertainties.

The last few years have seen an increase in well planning tools to reduce uncertainties and a growing relationship between the drilling and geosciences discipline, and between the geological construction of a well and the constraints imposed by the physics of drilling. This has resulted in well targets being digitized directly in 3D using all available data, such as seismic data, horizons, faults, and property models, and reservoir engineers having access to a geological framework surrounding the well bore. The wellpath is then automatically generated from the surface location to the target, respecting pre-defined constraints.

The growth of WITSML (wellsite information transfer standard markup language) has played a key role in this growing relationship. With WITSML, data feeds, real-time logging-while-drilling data can be monitored live from the wellsite. It also improves the ability to transfer drilling data in real-time between service and oil companies, and has encouraged software companies to develop real-time applications independently of the drilling company. According to Energistics, responsible for managing the evolution of the standard, 'the objective of WITSML is the right-time, seamless flow of well data between operators and service companies to speed and enhance decision making.'

While such developments have allowed for a greater level of real-time insight into the downhole environment, challenges, however, remain. One such challenge is the continued delays between the analysis and integration of real-time drilling data and the updating of geological models. Too often, in the past, static reservoir models and history matches have only tended to be updated intermittently, resulting in the process from drilling a new well or developing a new wellpath through to the updating of the static model and history matching of the new model taking many months.

There are increasing amounts of field data available, for example, IBM Business Consulting Services recently estimated that advances in monitoring technologies have resulted in a single oil or gas field generating on average up to one terabyte of data per day. With so much data, the need to reduce drilling risk, and a growing shortage of skilled people to undertake this work, it is essential to reduce the decision-making cycle time.

This article will examine how one can better integrate real-time drilling data into the interpretation cycle to help question, understand, and update the geological model closer to the time of the drilling.

It will focus on how to better co-visualize real-time drilling data with the geological model; the geosteering diagnosis tool which Roxar has developed and tested; and how MWD (measurements while drilling) and LWD (logging while drilling) data can be used to update the geological model within a fully 3D environment. This article will also show the steps that have been taken to date to integrate real-time drilling into the geological model as well as what needs to be done moving forward.

Real-time drilling data in the geological model

In order to integrate the real-time drilling information into the geological model, it is essential to be able to co-visualize these data with seismic, horizons, faults, grid properties, and other wells. Monitoring should consist of gathering different types of real-time information, such as survey data, LWD data, drilling information, and bottom hole assembly (BHA) information for the different drilling phases. All this data can be displayed into multiple views in combination with elements of the geological model.

BHA data is particularly important (see Figure 1). Each of the physical property measured by the MWD/LWD tools can be defined onto the BHA by its distance from the bit.

The BHA specifications can be automatically subscribed via the WITSML receiver and the information used to position each of the logging tools behind the bit. Each physical property recorded by the MWD/LWD tools can be characterized by a measurement point defined as an offset

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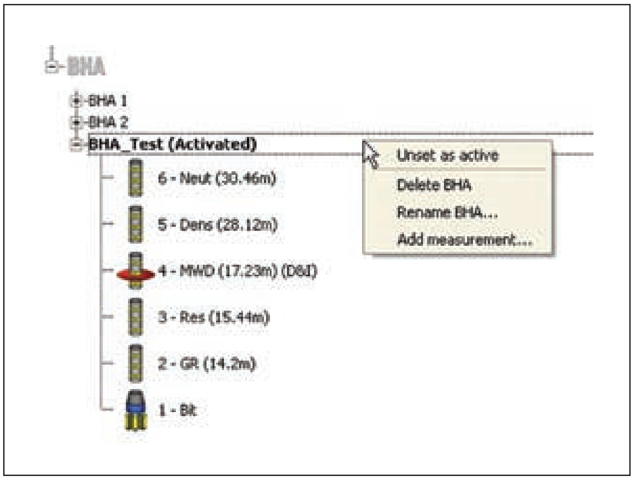

Figure 1

from bottom. The bit, MWD/LWD tools, and the measurement sensors are co-visualized with the 3D geological model. For the geologist, this provides an understanding of how far behind the bit the logs are recorded and within the geological model and with the knowledge of the BHA program, logging tools can be visualized and combined with other well data.

During the drilling session, the WITSML client communicates with the WITSML server and provides access to the real-time data. The user can co-visualize the data with the geological model. Modelled logs can be calculated along the real-time trajectory and then compared with the real-time models. Mismatches between the real-time and model log can trigger a need for a model update. Co-visualization must also include displaying the trajectory, uncertainty envelop, logs, and bit positions. Planned trajectory ahead of the current bit position is used to predict future trends and helps the decision process.

Figure 2 is an example of monitoring the drilling in real-time using WITSML. Bit position and logging measurement points behind it are visualized within the 3D geological model. The red disk on the well represents the position of the survey tool. The planned ahead trajectory with a return to target option is constantly updated based on the current bit position. Modelled logs can be automatically calculated and displayed along drilled and planned sections of the well.

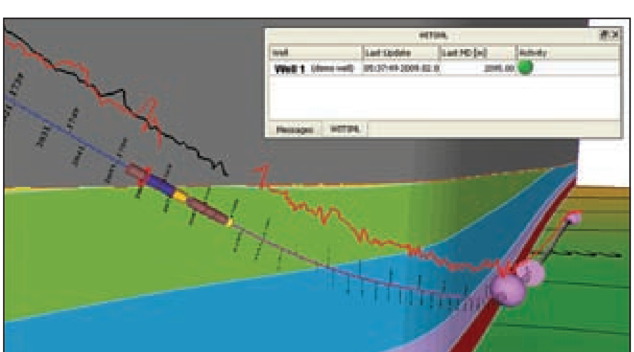

Figure 2

Workflow-based approach

There are a number of specific functionalities to constrain the update of the model locally around the well trajectory. These include well pick editing, synthetic vertical wells along the section, and isochore thicknesses and/or structural dip preservation. Log forward modelling can also be used to understand the stratigraphic position within the model, quantify the editing process, and validate the model.

A workflow-based approach here is vital. It allows for the local updating of the structure, the 3D grid, and log and property modeling and ensures the repeatability and automation of the whole process with a reproducing and standardizing of the different steps. Figure 3 illustrates a workflow-based approach from model updating while drilling. Drilled and planned ahead sections of the well are displayed with the real-time logs. Well picks are calculated and displayed along both sections of the well. The 3D geological model in this example is composed of the effective porosity grid and the horizons.

Real-time geosteering

Geosteering is becoming a key well planning tool. In the Haradh III project in Saudi Arabia, for example, Saudi Aramco describes geosteering as a key enabling technology in the accurate placement of multilateral wells to achieve the desired production rates of 10,000 B/D (Saleri and Muallem, 2006).

Operator benefits will be a better characterization of reservoir entry, an optimization of the wellbore positioning within the reservoir (thereby increasing well production), and the ability to update the structural model while drilling, automatically reposition the targets, and redesign the planned trajectory ahead of the bit.

The geosteering methodology is widely used to optimize horizontal wellbore placement into the reservoir and, fol-

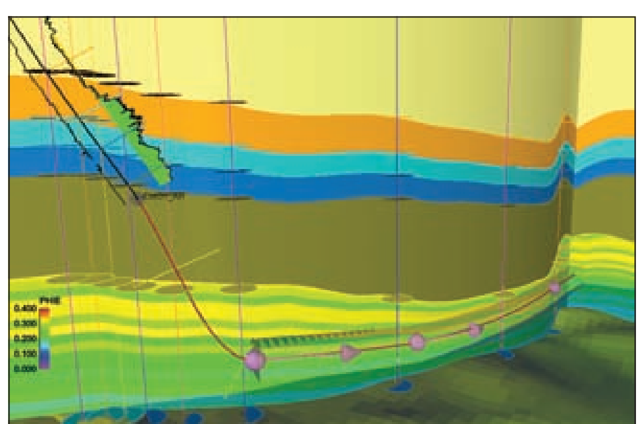

Figure 3

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lowing this, is a means of integrating real-time data into the geological model. It is designed to automatically quantify the position of the well under monitoring within the geological model through the automatic and real-time updating and extrapolation of well paths from current positions and targets. Within its reservoir modelling software, Roxar has developed a Geosteering Diagnosis tool which can monitor the real-time drilling data, and identify and predict combined geological and drilling events. Roxar's Geosteering diagnosis methodology has the following capabilities:

- An understanding of the position of each of the LWD tool's sensors behind the bit within the geological model.
- The ability to differentiate between multiple types of objects within the geological model.
- Different methods for calculating distances between the bit, or a measurement sensor behind the bit, and a defined object belonging to the 3D geological model. The proximity between the bit, or sensors behind the bit, and objects in the model are constantly monitored. Objects in the model can include horizons, contacts, faults, targets, well trajectories, grids and volume properties, and log properties.
- Rules to monitor distances from the bit, or any measurement sensor behind the bit, relative to defined objects within the 3D geological model.
- And the ability to apply the rules on the already drilled section and on projected sections.

Distance calculation can be performed in a number of specific directions. For example in Figure 4, the up/down distance is calculated from bit to Top C and from density measurement point to Top B. In Figure 5, the left/right distance from MWD measurement point to fault B05 and the measure depth distance from bit to fault B05 following the planned ahead trajectory are calculated.

Alarm methodology

Roxar has also defined an alarm methodology based on the distances between objects and on the differences between property values to help the geologist's decision making.

Yellow and red warnings can be defined based on the uncertainty position on the object of the model. As part of the rules, there are two thresholds to separate the three warnings of green, yellow, and red with the threshold definition based on object uncertainty. These are applied after an update of the real-time data or an update of the model.

Warnings are activated when the monitored object (the well) crosses the vicinity of the targeted object (Cross It), when the monitored object leaves the vicinity of the targeted object (Stay Within), and when the monitored object does not stay above (Stay Above) or does not stay below (Stay Below) the targeted object. As Figure 6 below illustrates, different rules apply to different objects depending on the type of object in the model.

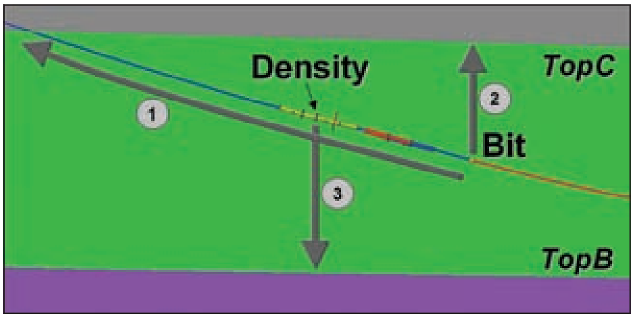


Figure 4

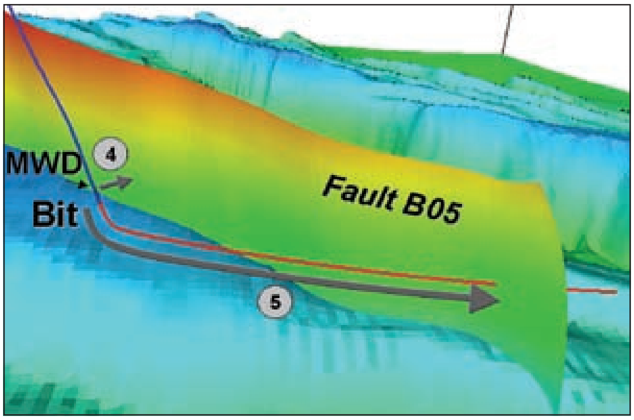


Figure 5

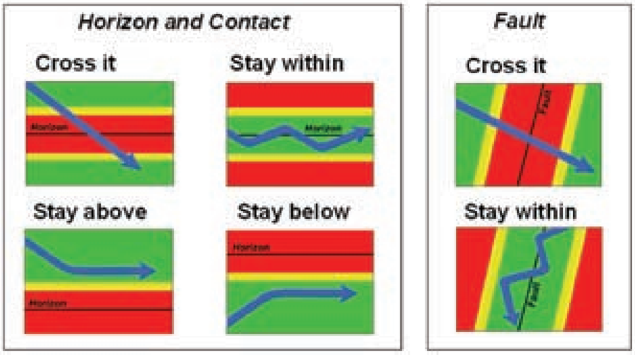


Figure 6

The result is that distances between the objects of the bottom hole assembly and geological objects can be calculated and the MWD/LWD information can be monitored against the geological model to predict future trends of the data based on the project-ahead trajectory.

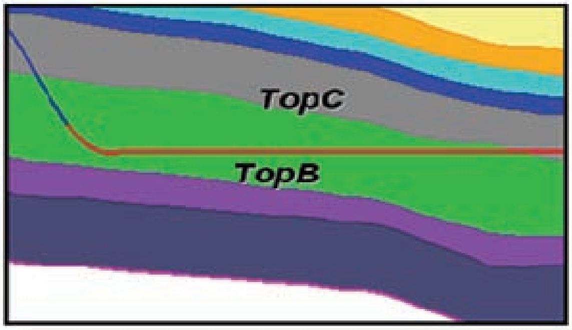
The geosteering diagnosis can consist of 'while drilling monitoring', where the operator evaluates the status of the rules at the current location of the bit or the sensor behind the bit; or 'while drilling prediction', where the operator applies the rules along the project ahead trajectory at regular intervals and displays the MD of the two next changes of status; or where the diagnosis applies automatically after an update.

In the first example illustrated below (Figure 7), the TVD (true vertical depth) is monitored from the bit to TopB with a Cross-it rule. A green warning is triggered.

The while drilling monitoring finds the bit to be at 37.20 m TVD above TopB. The prediction while drilling is that the well is not expected to cross TopB.

The second example monitors the measure depth (MD scanning) from the bit to TopC. While drilling monitoring finds the bit 99.41 m MD after TopC. The rule is Cross it and the red warning is triggered. The while drilling prediction is that the yellow warning will be triggered in 2 m MD and the green warning will be triggered in 102 m MD (Figure 8).

In the final example illustrated below (Figure 9), the left/right distance from the survey measurement to the fault B05 is being monitored with a Cross-it rule. B05 is 257.85 m on the left side of the survey tool, initiating a green warning. The 'while drilling' prediction triggered a yellow warning at 1933 m MD, and a red warning in 1951 m MD.

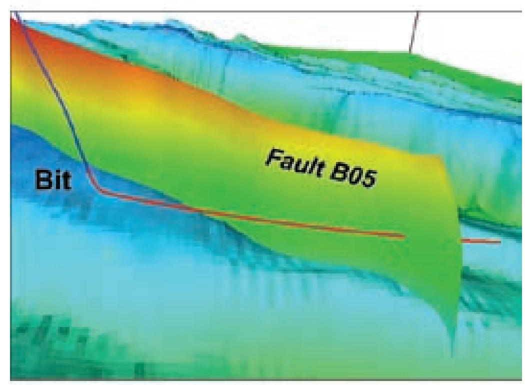


	TopB TVD from Bit
Category	Horizons
Monitoring	
Monitored Object	Bit
Monitored Object MD [m]	2201.78
Monitored Object TVD [m]	1532.28
Monitored Object Property	-
Targeted Object Type	Horizon & Contact
Targeted Object Name	TopB
Targeted Object Scanning	Up / Down
Targeted Object Property	-
Targeted Object Distance [m]	37.20 Down
Analysis	
Rule method	Cross it
Prediction	
MD from Monitored Object [m]	-
MD from Monitored Object [m]	-

Figure 7

	TopC MD from Bit
Category	Horizons
Monitoring	
Monitored Object	Bit
Monitored Object MD [m]	2201.78
Monitored Object TVD [m]	1532.28
Monitored Object Property	-
Targeted Object Type	Horizon & Contact
Targeted Object Name	TopC
Targeted Object Scanning	Measured Depth
Targeted Object Property	-
Targeted Object Distance [m]	99.41 After
Analysis	
Rule method	Cross it
Prediction	
MD from Monitored Object [m]	2.00
MD from Monitored Object [m]	102.00

Figure 8



	B05 LeftRight from
Category	Faults
Monitoring	
Monitored Object	Survey
Monitored Object MD [m]	2170.78
Monitored Object TVD [m]	1519.7
Monitored Object Property	-
Targeted Object Type	Fault
Targeted Object Name	B05_001
Targeted Object Scanning	Left / Right
Targeted Object Property	-
Targeted Object Distance [m]	257.85 Left
Analysis	
Rule method	Cross it
Prediction	
MD from Monitored Object [m]	1933.0
MD from Monitored Object [m]	1951.0

Figure 9

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Geosteering Diagnosis on Troll Field

The Geosteering Diagnosis has been applied (for demonstration purposes only) to the North Sea's Troll field to monitor drilling against the predefined geological model.

The Troll field lies in the northern part of the North Sea about 65 km west of the Kollsnes natural gas processing plant. The water depth in the area is more than 300 m. The field has huge gas resources and one of the largest oil volumes remaining on the Norwegian continental shelf.

The objective was to demonstrate how the Geosteering Diagnosis can help in validating the interpretation while monitoring the real-time information. As the tool is integrated into a geological model, the geologist is able to perform updates on the model while drilling and can visualize the status of the diagnosis rules along the drilled and project-ahead sections. Two lateral wells drilled within the field were used as examples with the real-time environment simulated by receiving the MWD/LWD data at regular time intervals. The rules are automatically applied anytime new information is received, allowing analysis at the LWD and bit location and prediction ahead of the bit.

The high concentration of wells on the Troll field leads to challenging directional planning. This includes the crossing of existing wells, while staying within the productive reservoir zone. As part of the analysis, the rule methods defined for monitoring trajectories are Cross It or Stay within. The Cross It rule is used to help avoiding drilling too close to surrounding trajectories, whereas the Stay Within can be used to keep the well close to its plan trajectory.

Figure 10 shows Geosteering Diagnosis at 3856 m. The first rule is monitoring the oil water contact (OWC) vertical distance. The second rule is monitoring the shortest distance from the bit to the drilled well A. The third rule is monitoring the resistivity (Thevoux-Chabuel and Fejerskov, 2006)

	TVD from Bit to OWC	Shortest from Bit to Well A	2MHz Res
Category	OWC	Trajectory	LWD Properties
Monitoring			
Monitored Object	Bit 8 1/2	Bit 8 1/2	Resistivity 7
Monitored Object MD [m]	3855.77	3855.77	3840.33
Monitored Object TVD [m]	1560.86	1560.86	1560.72
Monitored Object Property	-	-	0.7710
Targeted Object Type	Horizon & Contact	Well trajectory	Well property
Targeted Object Name	OWC2	Well A	RPCEHX
Targeted Object Scanning	Up / Down	Shortest	Measured Depth
Targeted Object Property	-	-	0.5
Targeted Object Distance [m]	2.76 Up	6.27	-
Analysis			
Rule method	Stay Above	Cross it	Stay Within
Prediction			
MD from Monitored Object [m]	150.01	20.01	-
MD from Monitored Object [m]	400.01	160.01	-

Figure 10

Conclusion

There are a number of key elements to incorporating real-time drilling into the geological model. These include, among others, an understanding of the position of each of the LWD tool's sensors behind the bit within the geological model; the ability to monitor in real-time the proximity between the well and objects in the model; and a workflow-based approach to update the model while drilling.

The result is a robust, real-time, integrated geosteering software tool which will have a major impact on reducing uncertainties in well planning and drilling.

References

Saleri, N.G. and Muallem, A.S. [2006] Haradh III: A Milestone for Smart Fields. *Journal of Petroleum Technology*, November.

Thevoux-Chabuel, H. and Fejerskov, M. [2006] Geosteering Diagnosis, a New Approach to Monitor the Well Position within a 3D Geological Model. *SPE Annual Conference and Technical Exhibition*, SPE 102602.

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