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Uncertainty Updating in Real Time Drilling: A Probabilistic Approach to Model Updating While Drilling

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SUMMARY

The trajectory of the horizontal section is one of the most important factors in the siting and drilling of a horizontal well. If correctly guided into a “sweet spot”, the well can be tremendously productive and profitable. Measurement-while-drilling (MWD) technology provides real-time information from the drill bit that can be used to steer the well during drilling, a practice referred to as “geo-steering.” In a thin and highly stratified horizon, the ability to make mid-course corrections can be critical in maximizing the length of the interval from which a horizontal well bore can produce. The ability to navigate requires a map; a model that predicts what is immediately ahead of the drill bit. Geostatistical conditional simulation offers the ability to create a family of plausible scenarios, or realizations for any of the attributes measured by the suite of MWD tools. By constantly updating a large group of realizations, one has access to a probabilistic model of what the drill bit will encounter and where it should be steered. This paper demonstrates a practical and efficient method for improving “geo-steering” through continual uncertainty reduction of key properties along the drill path in 2D sections or thin 3D slices.

Introduction

The trajectory of the horizontal section is one of the most important factors in the siting and drilling of a horizontal well. If correctly guided into a “sweet spot”, the well can be tremendously productive and profitable. Measurement-while-drilling (MWD) technology provides real-time information from the drill bit that can be used to steer the well during drilling, a practice often referred to as “geo-steering” because it tries to tap into knowledge of the geological/geophysical environment at the drill bit to make subtle corrections to the well’s trajectory. In a thin and highly stratified horizon, the ability to make mid-course corrections can be critical in maximizing the length of the interval from which the horizontal well bore can produce. If the well sits too high in a fining upwards horizon, it will encounter poorer quality rock; if it drifts too low, it may run too close to the oil-water contact and suffer from water coning quickly into the well bore.

The ability to navigate requires a map, a model that predicts what is immediately ahead of the drill bit. Geostatistical conditional simulation offers the ability to create a family of plausible scenarios, or realizations for any of the attributes measured by the suite of MWD tools. By constantly updating a large group of realizations, one has access to a probabilistic model of what lies ahead, and where the drill bit should be steered.

Method

Figure 1 shows a vertical cross-section through the proposed path of a horizontal well. The vertical well bore on the right provides the kick-off location for the horizontal well, and also provides petrophysical data on the target horizon in the immediate vicinity of the horizontal well bore; typically, a gamma ray log will be available from the vertical well bore. The vertical well bore also provides an additional control point on the elevation of the top of the target horizon.

Using data from the vertical well bore, and any other nearby wells, conditional simulation is used to build a group of 100 realizations of the top and bottom of the target horizon. The tops and bottoms are important for defining the stratigraphic coordinate system, and will be unique for every realization. Realizations are also developed for the gamma ray response in the 2D slice of the cross-section, providing 100 different versions for what the drill bit might encounter as it enters the target horizon and travels through it.

After kicking off from the vertical leg, the horizontal well will soon encounter the top of the target formation, and this will be evident from the MWD tools. Once the exact elevation of the top is known at this new XY location, this new data point can be used to update the realizations of the reservoir tops. As the well continues on its approximately horizontal path, if it again encounters the top of the target horizon these undesirable (but not uncommon) events provide additional control points for the simulation of the top.

As the well advances into the formation, the MWD tools will provide a gamma ray response at the drill bit. This can be compared to the distribution of simulated gamma ray response from the 100 realizations. Some realizations will remain plausible, because they provide predictions that are close to the actual response; others will become increasingly implausible. Realizations that have become too implausible are deleted from the library of plausible scenarios and replaced with new realizations that use all of the available conditioning information at that point in time.

With access to 100 realizations that are being constantly updated, in real time, to remain consistent and plausible with the MWD data, a probability map can be created to assist the geo-steering. This map shows the probability that the gamma ray response will be below a threshold indicative of high- ϕ and high-k reservoir rock. The drill bit can be steered in the direction that has the highest probability of encountering high quality rock.

Figure 1 A cross-section through the path of a horizontal well bore. The drill bit has progressed to the location marked by the gray line. The horizontal well is marked with a solid line behind the drill bit (to the right), and its planned trajectory is marked with a dashed line ahead of the drill bit (to the left). MWD data from the horizontal well and petrophysical logs from the vertical well provide conditioning data for simulations of structure and petrophysical properties. 100 realizations provide estimates of the probability of encountering reservoir rock (as indicated by a low gamma ray response), with the favourable zones colored in green.

Conclusions

The procedure is fast, because the simulations are being generated in 2D, or in a thin 3D slice. It is sufficiently fast that it can keep up with the flow of MWD data, and regenerate in real time the probability maps required to assist with the geo-steering.