The benefits of directional drilling are widely known – increased reservoir exposure and greater production. However, the practice can pose formation evaluation challenges in high angle and horizontal wells, making traditional petrophysical interpretation techniques harder to apply because of geometric effects on the data. Modern wellbore software can provide a viable solution.

Increasing numbers of wells are drilled horizontally or at high angles for a number of reasons: to improve reservoir exposure, avoid or target particular features, and in relief-well scenarios. The practice has been proven to significantly increase production, even the first commercial horizontal well delivered twenty times the expected production of a vertical heavy oil well (Bossio, 1986). Modern drilling technology, geosteering, and logging while drilling (LWD) tools allow high angle and horizontal wells, particularly the resistivity logs, to be acquired under these conditions, such as coil tubing and drill pipe assisted logging, and the development of LWD tools and assemblies which have become the primary means of acquiring logging data in Hahz wells.

The difficulty begins with the fact that LWD data acquisition strategies in horizontal wells are often designed for geosteering purposes and can be unsuitable for petrophysical evaluation. Even when full LWD logging suites are available in Hahz wells it is often difficult to apply vertical well petrophysical interpretation techniques because of bed boundary effects and proximity of the well. If available, LWD logs are also used to calculate formation dip and azimuth along the trajectory. The formation model is then verified, refined, and updated. Each layer of the formation model crossed by the well is populated with formation properties based on selected well logs. For layers not crossed by the well, properties are manually entered based on offset well responses. If necessary, lateral property boundaries are inserted in the layers, allowing for property variations to exist in a layer which the well intersects more than once. Forward model simulations of the logs are then compared with the measured logs, and the layered model and property layers are manually refined until the best agreement between simulated and acquired logs is reached. Validated layer properties from the workflow form the basis for the new petrophysical evaluation, which is compared with the original evaluation performed using raw acquired data. Substantial differences are evaluated and understood, before final validation and updating of the geological model.

Lastly, a final hydrocarbon-in-place calculation update is performed.

Example well A showing the target layers and faults. Note the extreme vertical exaggeration: 10 ft (200 ft true vertical depth sub-salt) vs. 6,000 ft THR (true horizontal length).

The workflow checks LWD logs and measured logs against a geological model which was built using measured logs, and the layered model is then verified, refined, and updated. Each layer of the formation model crossed by the well is populated with formation properties based on selected well logs. For layers not crossed by the well, properties are manually entered based on offset well responses. If necessary, lateral property boundaries are inserted in the layers, allowing for property variations to exist in a layer which the well intersects more than once. Forward model simulations of the logs are then compared with the measured logs, and the layered model and property layers are manually refined until the best agreement between simulated and acquired logs is reached. Validated layer properties from the workflow form the basis for the new petrophysical evaluation, which is compared with the original evaluation performed using raw acquired data. Substantial differences are evaluated and understood, before final validation and updating of the geological model.

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Analysis-Ready Data

In one of the wells, where it crossed three thin layers at a high angle, extended shoulder bed effects are observed. The resistivity measurements responded to the multiple layers within their volume of investigation, causing the measured resistivities to read higher than they would in a single layer. Consequently the standard interpretation would deliver a water saturation which was too low. By accounting for these shoulder bed effects, the new interpretation delivered higher and more precise water saturation in the thin shaly beds, avoiding undeliverable hydrocarbon volume in a substantial non-reservoir section. In this interval the effect of the carbonate-cemented concretions was clearly observable on the density image.

Two further effects were observed. The standard petrophysical analysis delivered a water saturation which was too low, as the input geometrically uncorrected resistivity was affected by a combination of the nearby thin bed which was shaly and conductive, and an underlying high resistivity reservoir layer. In this case the density image suggested that the wellbore just touched the layer. The resistivity response is affected by a combination of the layers, all of which lie within the resistivity volume of investigation. The contributions from each can only be determined from a tool-specific response equation, available in the Techlog software platform. The overall result indicated that the apparent resistivity is slightly higher than would be recorded. The new water saturation calculated with the geometry-corrected layer resistivity in the petrophysical analysis indicated water saturation of almost 100% in the shale (as expected in this area) and revealed higher hydrocarbon saturation in the layer near the exit and entry points. This resulted in improved water saturation determination.

Optimised Analysis

Although bringing a number of significant benefits, the increasing prevalence of Hultz wells has highlighted some of the limitations of traditional petrophysical interpretation techniques in these wells, due to geometric effects on the data. This challenge calls for new approaches and modelling workflows to improve the reliability of interpretation results. Digital drilling and interpretation technologies will form part of a wider theme to be discussed at the 2014 SIS Global Forum, in Barcelona on April 15–17. This biennial industry conference will focus on the future of digitally mitigating E&P risk, using simulation and software technology.

The workflow in the above project efficiently confirmed and refined the geological environment from the static reservoir model, and provided true formation layer properties for use in the petrophysical analysis. The comparison of log responses between vertical and deviated wells was helpful for quality control, and in the well log modelling phase to assess the correct record of petrophysical properties for the input logs and the model logs. Log measurements were updated and a resulting improvement in petrophysical answers was observed.

References:

Bosio, J., 1986, Horizontal Wells are Now Used for Industrial Development. SPE Paper 14614