We Can See Clearly Now –

Geosteering in ConocoPhillips’ Brodgar Field

using LWD Deep Reading Resistivity.

Presenter: Christopher Grieve

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Field discovered in 1985 and brought on production in 2008.

Reservoir is turbiditic Lower Cretaceous Britannia Sandstone.

Hydrocarbon type is gas condensate.
Objectives, Challenges and Constraints

• The well was originally planned with a pilot hole the **objective** of which was to confirm top reservoir and the post-production position of the Hydrocarbon Water Contact (HWC) – both key predrill uncertainties.

• The pilot hole would confirm whether sufficient hydrocarbon column existed to allow a horizontal producer to be drilled and maintain the required 40 ft production stand-off from the HWC.

• A **constraint** on the planned 1600’ horizontal section was to limit the dogleg severity to less than 3°/100’ to allow sand screens to be successfully run.
Well Profile (for Main bore following Pilot Hole)

- Challenging 13,000’-long, 57°, 12 ¾” section.
- Step-out to top reservoir is 3 km / 10,500’
- 9 5/8” set in the top Britannia at 16,400’ MD.
- Well LWD only – no wireline.
  - 12 ¾” section: 12.5 ppg OBM, Rotary steerable assembly + PWD + GR + RES.
  - 12 ¾” landing: Rotary steerable assembly + PWD + DEN/NEU + RES + GR, wellsite biostrat.
  - 8 ½” section: 11.1 ppg WBM, Rotary steerable assembly + PWD + DEN/NEU + RES + GR.
- Planned TD of well = ~18,000’ MD.
Lower Cretaceous Britannia ‘A’ Reservoir

- Thick, high net-to-gross package of amalgamated turbiditic sandstones
- Resistivity contrasts at 1, 2, 3.
- Contrasts produce events on a resistivity image.
- The Britannia reservoir has with very few shale interbeds, which would severely reduce the DOI (depth of investigation) of the resistivity tool.
Pre-well Modelling

Model created from reservoir surfaces populated with resistivity data from 21/3a-4 well
• The Geosphere® transmitter is 10m / 30’ behind the bit.
• The receivers measure the differences in the electromagnetic field.
• Receiver 1 inversion is ca. 16m / 50’ behind the bit.
• Receiver 2 inversion is ca. 22m / 70’ behind the bit
• The two-receiver inversion produces the best image (lowest SNR), but is ca. 34m / 112’ behind the bit.
• Use deep-reading resistivity tool to land well and optimise the horizontal section.
• Maintain 40’ vertical standoff from the HWC. Do not penetrate water-bearing Britannia Sandstone.
• Maintain a 15’ – 20’ stand off from the Kilda roof, minimise exits into the roof.
• The maximum allowable dog leg severity (DLS) is less than 3°/100’ to allow the sand screens to be run.
Landing the well – 12 ¼” Hole

- Drilling proceeds from left to right. The wellpath is in yellow.
- The “blind zone” behind the bit is shown in red.
- The horizontal exaggeration is 1.3
- The first horizon is expected to be the Kilda with a resistivity of 8 ohmm - this should be revealed as ‘green’.

“Kilda” response ~45ft TVD below tool
Landing the well – 12 ¼” Hole

“Kilda” response improving but not fully resolved

horizontal exaggeration = 1.3
• Expecting to see a ‘green’ 8 ohmm Kilda or a ‘red’ 100 ohmm Britannia.
• The ‘orange’ indicates that although there is an apparent single reservoir response – the tool is unable to render 2 separate horizons at this distance.
• There is however a hint of a conductive feature at the base of the plot.
Landing the well – 12 ¼” Hole

Resistivity decreases with depth and resolves into separate Kilda and top Britannia. Conductive feature becomes clearer, although tool not yet in reservoir.
Well Landed in Top Britannia Reservoir.

- Water contact detection confirmed sufficient column height to case the well in preparation for drilling the 8 ½” horizontal section.
8 ½ Hole Section – Start of Drilling.

- 9 5/8” casing set.
- Drilling proceeds from left to right. The wellpath is in black.
- The “blind zone” behind the bit is shown in red.
- The vertical exaggeration is 2.5
- A “dumb iron” assembly was used to drill out the cement and the shoe.
- Well landed at 88° and built geometrically to horizontal (90°).
Geosteering Decision #1 and #2 – Build to 91°, Build to 92.3°

- Roof rising at, at least 2°.
- Build angle in hope of positioning well 15 ft to 20 ft below top.
Roof Dipping Towards Well

Vertical exaggeration = 2.5
Geosteering Decision #3 and #4 – Drop to 91°, Drop to 90°.
Roof Climbing

~40 ft

Vertical exaggeration = 2.5
Geosteering Decision #5 and #6 – Build to 92°, Drop to 90.5°.
• Note the apparent rugosity of the water contact caused by lack of resolution due to the distance of the tool from the contact.
• Note also - as well is near the top of the reservoir – the tool doesn’t render the expected reduction in resistivity down through the lower part of the reservoir.
Geosteering Decision #8 and #9 – Drop at 2°/100 ft to avoid roof.
Vertical exaggeration = 2.5

21 – 22 ft
Exited Roof into Kilda

- The dip of top reservoir 8° - 9° was too steep to avoid especially given the dogleg severity constraint of 3°/100 ft.
- Note the apparent downward displacement of the water contact now that the tool is above the reservoir and is unable to resolve this feature.
Decision #10 – Drop at 2°/100ft to regain reservoir

Difficult to interpret what the top structure will do next.

Plan to land out at 90° with a sufficient standoff above the predicted HWC.
Re-entered Reservoir (after 400 ft). Decision #11 – Build to 91° and Hold

- Re-entered reservoir at 85° inclination. Decision to build to 91° and hold.
- Decided not to chase the roof up for fear that the added tortuosity at the toe of the well, might prevent the sand screens getting to bottom.
Reached Well TD at 91° inclination.

- Note, as the toe of the well is more centrally positioned within the reservoir that the water contact as appears flatter at the toe due to the proximity of the tool and the better imaging.
- Screens successfully run and landed.
Conclusions and Learnings

• A high level of Planning, Teamwork and Communication are essential to the success of any geo-steered well.

• The Brodgar reservoir was an ideal application of this tool. Though this or any other technology must be assessed on a reservoir-by-reservoir and well-by-well basis.

• The tool could see both the top reservoir and the water (from 120 ft above) before entering the reservoir in 12 ¼” hole. It could image both the roof and the water in the horizontal 8 ½” section.

• You must be prepared to respond to actual data you receive in real time, rather than overly focussing on pre-drill expectations of structure.

• The well is a success, the cost of a pilot hole was saved.
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