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Drilling of Multilateral Wells in Kuwait Aided With Geochemical Analysis

The Burgan reservoir consists of vertically stacked channel sands along with a fault network connected to the aquifer and contains highly viscous reservoir fluid. This dramatically enhances the water mobility and results in severe premature water breakthrough, bypassing zones of oil. This paper describes the use of real-time geochemical analysis to support geosteering of a smart multilateral well located in one of the highest-potential-flow areas of Kuwait.

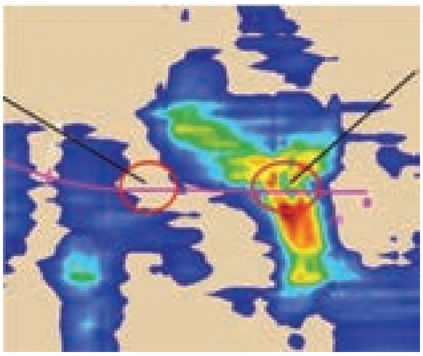

Fig. 1—Seismic coherence map along a horizontal section of a Burgan producer is used to locate areas of faulting. The coherent beige areas in the cross section show no faulting. All other colors (incoherent areas) show faulted areas ranging through dark blue, yellow, orange, and red colors (less faulting to more faulting, respectively).

Introduction

The Minagish field in Kuwait was discovered in 1959 and is located in the southwestern part of the country. It contains several reservoir intervals in its stratigraphic column, varying from Early Jurassic to Late Cretaceous. The field is situated 12 km northwest of the west Umm Gudair field. The field has been penetrated by more than 180 wells, to contact not only the middle and lower Minagish reservoirs of the Lower Cretaceous but also other shallow reservoirs such as the Mishrif/Rumaila carbonates and the Wara/Burgan sandstone. The Minagish field structure of the Wara and Burgan formations is a closed elongated asymmetrical anticline oriented in a north/south direction. The top of the Burgan structure is located at approximately 5,500-ft true vertical depth subsea.

Burgan Reservoir. This reservoir is informally divided into the upper and lower Burgan sections. Lower Burgan sands are more extensive and blocky in nature, with few variations in their properties. The lower Burgan reservoir section lies above the oil/water contact (OWC) and is of significance from a hydrocarbon-bearing perspective. Upper Burgan sands are mainly in the form of channel sands, ranging in thickness from a few feet to nearly 45 ft, and they have extensive lateral facies variation. The lower part of the Burgan has active bottomwater drive, whereas the upper part of the reservoir has an edgewater-drive system. The reservoir contains high-permeability sands on the order of a few darcies associated with active faults and has highly viscous reservoir fluid (approximately 40 cp at reservoir conditions). This heterogeneous nature of the reservoir accelerates water movement inside the reservoir and results in premature water breakthrough in the existing vertical wells and in horizontal wells, in spite of maintaining the highest standoff from the OWC.

Scope of Work. Located in the crestal part of the Minagish field, the Burgan reservoir offers limited surface locations for drilling many vertical wells to deplete the reservoir effectively. Because of the nature of the reservoir and its oil quality, horizontal wells or multilateral wells are viable options. The upper part of the Burgan reservoir consists of complex laminated thin channel sand, and interchannel silts and shale that are associated with fault networks pose several drilling and geosteering challenges (**Figs. 1 and 2**). Also, geosteering in the upper Burgan sand, with lateral facies changes associated with

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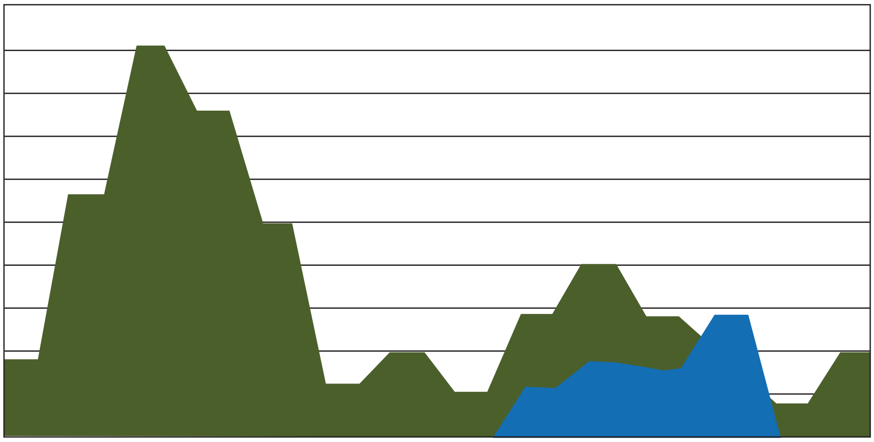

Fig. 2—The production log shows incoherent areas on seismic having a very high potential for water coning. This zone is interpreted as a fault zone connected with the aquifer. The water coning is mainly caused by a very high mobility ratio and oil-wet reservoir characteristics.

faulting and with deformation or drag, is a major challenge. The multilateral well was drilled by integrating logging-while-drilling and X-ray-fluorescence (XRF) data and petrophysical interpretations in real time to geosteer the horizontal well successfully in the zone of interest with maximum possible reservoir contact. However, in the current paper, only the XRF component of Well MN-A (multilateral) is highlighted. After successful implementation of the work flow in the lower lateral (LAT-0) placed in the lower Burgan, the same work flow was used to geosteer the upper lateral (LAT-1) in the upper Burgan.

In the current work scope, the prejob modeling consisted of a geochemical model based on XRF analysis of core chips from offset wells. For a discussion of prejob modeling, including geochemical and petrographic analysis and an offset-well study, please see the complete paper.

Multilateral-Well-Location Optimization

The well locations for smart multilateral wells are optimized by integrating data from multiple disciplines, from the macroscale (seismic) through the microscale (petrography). Furthermore, data from seismic, geology, petrophysics, reservoir engineering, and well surveillance were incorporated into the predrill characterization program. The lower lateral, LAT-0 (main bore) of the smart multilateral well, is placed in the lower Burgan, consisting of a braided river system with stacked sand bodies. The sediment ranges from fine to coarse grain sizes, with the porosity ranging from 20 to 30% and with permeability values on the order of a few darcies. The bottom part of the massive, thick sand bodies is connected directly to the bottom aquifer.

The upper lateral, LAT-1 of the smart multilateral well, is targeted in the upper Burgan reservoir, which ranges from silt to medium sands. The porosity is relatively low (between 15 and 18%), and the permeability values are on the order of 100 md because the reservoir still retains its fluvial-sand character. Shaly sediments between the lower and upper Burgan can act as a permeability barrier or baffle for vertical migration of fluids. This complex channel geometry makes these reservoirs very challenging for implementation of smart multilateral wells.

Real-Time Geosteering Aided With Geochemical Analysis

High-resolution 3D-seismic-data interpretation has enabled refining of the geological model in terms of faults and reservoir boundaries. Real-time geosteering is performed by use of advanced and innovative technologies, including high-resolution XRF geochemical analysis, to identify "geochemical proxies" and to allow geochemical steering. In the present scope of work, near-real-time XRF geochemical analysis complemented with log-based petrophysical evaluation was used to better geosteer the wellbore in the zone of interest and to maximize the reservoir contact. The authors present the details of an integrated interpretation based on a real-time data set for the LAT-0 and LAT-1 sections of Well MN-A (multilateral).

Multilateral-Junction Considerations. A crucial aspect in designing the smart multilateral well was the selection of an appropriate multilateral junction. After a complete screening of various multilateral junctions, the Level-4 junction was selected. During the well-trajectory optimization, the multilateral-junction depth was selected across excellent compact shale at the base of Wara layers to ensure junction stability during drilling and well completion, and to ensure junction integrity during long-term production. The high-resolution-XRF analysis shows a high-argillaceous siliciclastic zone on the basis of chemical behavior.

XRF-Aided Chemosteering in Lower Burgan Sand (LAT-0). The geochemical model built with offset-well data guided the chemosteering of the well, in integration with other information. In the absence of resistivity data, XRF-analysis data identified a fault at 7,340 ft, which was not observed by the near-bit gamma ray log. Elemental changes, supplemented with lithological changes, confirm the faults encountered at 7,490, 7,950, 8,450, and 8,700 ft. Cl could be used as a good marker before encountering the fault. The findings of XRF analysis are further confirmed, while drilling, from interpretation of azimuthal density images. Chemosteering thus aided in changing the well path on the basis of elemental analysis, helping to maximize the reservoir contact.

Identification of Faults/Fractures. Azimuthal lithodensity images were interpreted while drilling not only to understand the formation dip but, more importantly, to identify clusters of fractures/faults. Four fault zones were identified through the LAT-0 section of Well A, and these were quite evident from XRF analysis. Though the real-time density images were not of high confidence, they still were able to provide information about formation dip and helped guide the geosteering process in the upper and lower Burgan reservoirs.

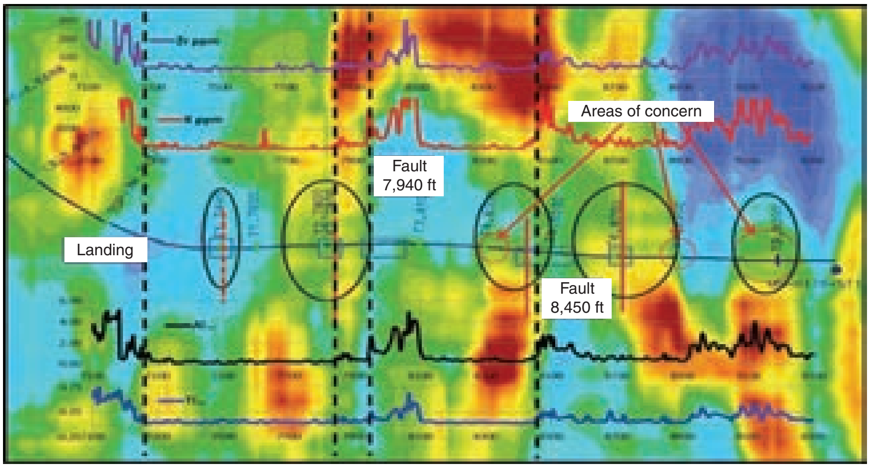

Fig. 3—Superimposed seismic section with key elemental markers.

During geosteering, in the LAT-0 of Well A in the lower Burgan reservoir unit, increments of K, Al, Ti, and Zr are observed, indicating dirty sands. The target is to keep these elements at a minimum to ensure contacting good sand, thereby retaining a higher value of silica (Si). XRF geochemical analysis showed a clean sand/sandstone over the drilled interval, with Si values between 18 and 35% and minimum concentrations of Al, Fe, K, Ti, S, Zr, Co, and arsenic.

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XRF-Aided Chemosteering in the Upper Burgan Sand (LAT-1). During landing of the well at the top of the upper Burgan sand, XRF geochemical analysis based on elemental signature showed a sharp positive increment of Si; heavy minerals Ti, Zr, Al, Fe, and K had a downward trend, with other elements, such as Cl, Mo, Cr, Ag, Co, and Sn reaching zero values at the top of the Burgan sand. These proxies are considered excellent markers and had very good correlation with the offset well MN-X. The Si values decreased after displacing the oil-based mud (OBM) with calcium carbonate mud because of the contamination and high percentage of Ca. The correlation with MN-X degraded, and other elements were selected for correlation. There are 10 proxies with elemental signatures in clean-sand lobes of the upper Burgan. While geosteering in the sweet zone, an increase in heavy-mineral contents (Ti and Zr), particularly in the middle part of the main clean-sand channel, then an increase in Mg content, has been noticed while penetrating downstructure, followed by Fe and Al maximum elevated values while moving further down at the lowest part of the Burgan, indicating dirty sand and shaly sections. The evidence of faulting in the upper lateral (LAT-1) showed elemental changes, supplemented with lithological changes, very similar to the faults encountered in the Lower Burgan lateral section (LAT-0). The pilot XRF model and offset Well MN-X were used with high confidence to steer the well on the basis of clear geochemical fingerprints and markers associated with Burgan sublayers. This technique has resulted in successful chemosteering in the clean-sand lobe with less than 10-ft thickness and has maximized the reservoir contact, even with the structural complexity associated with faults and significant dip changes.

Collaborative Work Flow: A Key to Success

The current work scope was a success because of the merger of independent data sets from different analyses through a collaborative approach, extracting the right information at the right time. The first data to be gathered were seismic data, providing a vital reference framework—such as identifying the most likely faulted sections and the type of dislocation they can cause. The seismic image in **Fig. 3** shows the horizontal-well section superimposed by an abundance of main elemental markers obtained through XRF analysis. Clear changes in the abundance of these elements are associated with the main features of the well section. Al also provided an early indication of the approaching fault, showing an increase at the start of the disturbed section at 7,836 ft.

Similarly, elemental markers are also matched with the measuring-while-drilling azimuthal-tool response. Al began to increase with the first minor fault and peaked at 7,940 ft. It remained high until 8,100 ft, where its values lowered. Ti had similar behavior, with the difference that it appeared significantly only when the main fault was encountered at 7,940 ft. The indication from Al is particularly important because it came as an early sign of the fault. The azimuthal information arrived later and confirmed that a fault had dislocated the well trajectory, which was corrected as a consequence.

However, the use of chemical elements measured in real time with high-density points is not the only application of this technology. In fact, the same data can be used during the production phase to isolate the faulted interval. In the case outlined in the complete paper, Al concentration was used as a proxy along with permeability measurements to mark and isolate zones of potential trouble that would be very detrimental for water production. **JPT**