[PS]Borehole Stability and Field Stress Analysis with Azimuthal Logging-while-Drilling Technology: A Case History*

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Abstract

North Kuwait Asset uses integrated Geomechanical modeling activity in multiple stacked reservoirs, which pose severe drilling complications. The model is updated and refined with diverse data and used in planning for drilling horizontal and multilateral wells to accelerate production from mature pays and thin sands. Real-time azimuthal acoustic measurements introduced recently in the logging-while-drilling (LWD) industry was used as part of the bottom hole assembly (BHA) to acquire information related to principal stress orientations and geological information in the deltaic to marine Zubair clastic sequence of Raudhatain Field in North Kuwait. A deviated 8.5-in. hole section of the well was planned through sand-shale sublayers with a borehole inclination ranging from 46 to 88°. This section is characterized by time sensitive borehole deterioration and significant variations in pore pressure, which results in severe hole instability and ultimate stuck ups and require relatively high mud weights to maintain wellbore stability. LWD azimuthal acoustic technology, free from chemical sources, was used for the first time both in drilling and wipes modes to facilitate time-lapse field stress and wellbore stability analysis. Principal stress orientations were identified from three different sources; namely, borehole breakouts from azimuthal acoustic caliper, compressional and shear slowness images, and acoustic anisotropy evaluation. The results were then compared with the existing offset geomechanics data and existing 3D Geomechanical model. Variation in observed stress orientation, seismic reflection pattern and pressure history in offset wells were used to map a fault, which is responsible for bypassed oil and occurrence of tar and gas. The interpretation was extended to other low throw strike slip faults and more fault compartments were identified which could affect the pressure maintenance scheme of the field. This paper discusses the planning, design, and execution of LWD azimuthal acoustic technology and the viability, integrity, robustness of interpreted results and its use in detailed geological interpretation in terms of stress orientation, fault trapping and areal fluid variation. Optimization of real-time drilling operations and petrophysical data acquisition requirements were investigated to improve future field development and overall reservoir management strategies.

Borehole Stability and Field Stress Analysis with Azimuthal Logging-while-Drilling Technology: A Case History

Shaikh Abdul Azim, Sankar Chowdhuri and Salah Al-Anezi: Kuwait Oil Company

Anar Abdulkarim, Ahmet Aki, and Mohamed Samie: Halliburton

Abstract

Real-time azimuthal acoustic measurements were introduced recently in the logging-while-drilling (LWD) industry. For the first time, this technology was used as part of the bottomhole assembly (BHA) to acquire information related to principal stress orientations in the deltaic to marine Zubair clastic sequence of Raudhatain Field in North Kuwait. The effort supports the Geomechanical modeling activity of the asset.

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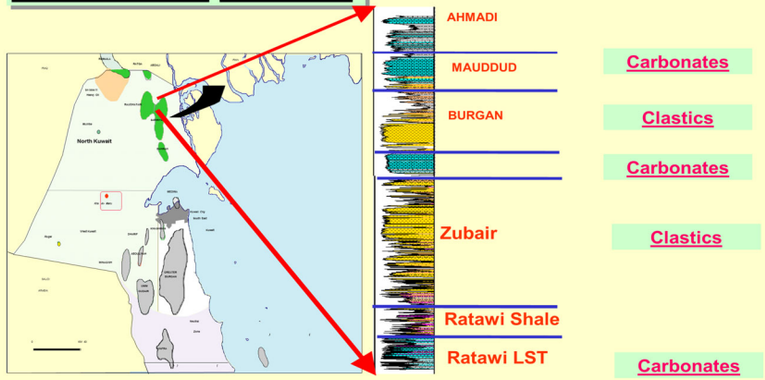
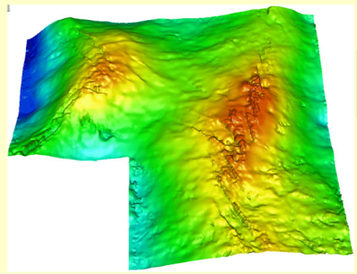
This paper discusses the planning, design, and execution of LWD azimuthal acoustic technology in this case history well and the viability, integrity, robustness of interpreted results and its use in detailed geological interpretation in terms of stress orientation, fault trapping and areal fluid variation. Optimization of real-time drilling operations and petrophysical data acquisition requirements are also investigated to improve future field development and overall reservoir management strategies.

GEOLOGICAL SETTING



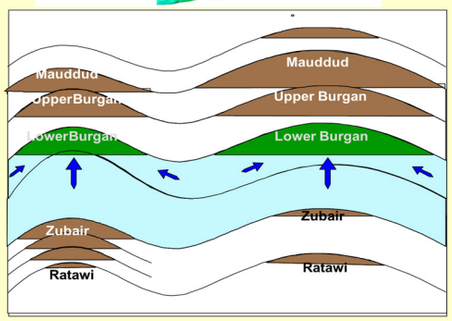
STRUCTURE



Raudhatain and Sabiriyah are the main fields in North Kuwait with Multiple reservoirs

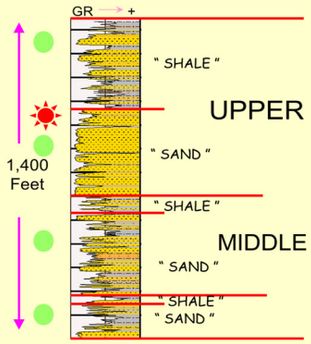
Structure Mapped from 3D Seismic
Doubly Plunging Anticlines
Highly Faulted
- Dominant Trends:
  - NE-SW
  - ESE-WSW

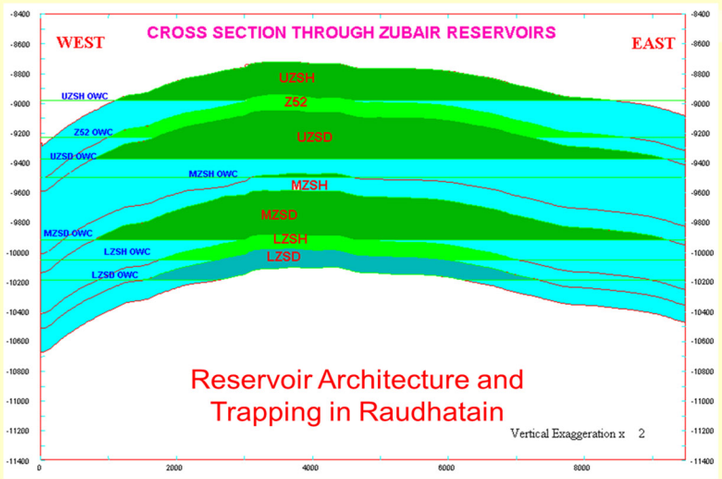
Faults Affected Palaeo fluid flow



A Schematic E-W cross section across the field showing multiple pools

Main Reservoir Intervals in Zubair





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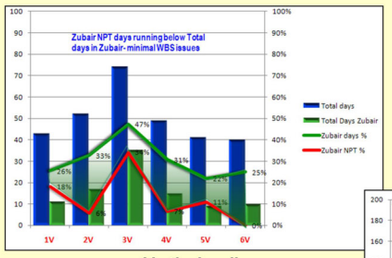
Drilling Issues and Geomechanical Modeling

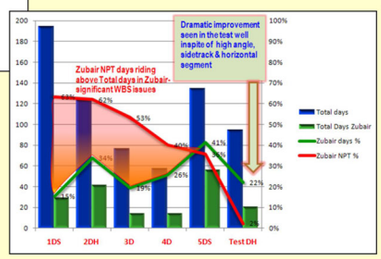
DRILLING COMPLICATIONS THROUGH ZUBAIR

- Drilling through Zubair has always been a challenge.
- Consistent Wellbore Instability
  - Stuck pipe / logging tools,
  - Tight zones, Additional reaming,
  - Sometimes cavings similar to over pressured shales.
- Drilling any type of well (vertical/deviated) is associated with significant wellbore instability.
  - Higher the deviation, higher the risk.
  - Vertical wells have low risk, but not free from instability.

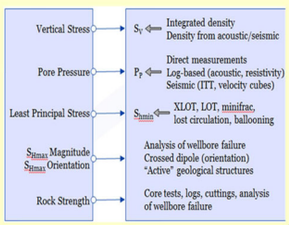
WELLBORE INSTABILITY STATISTICS IN ZUBAIR

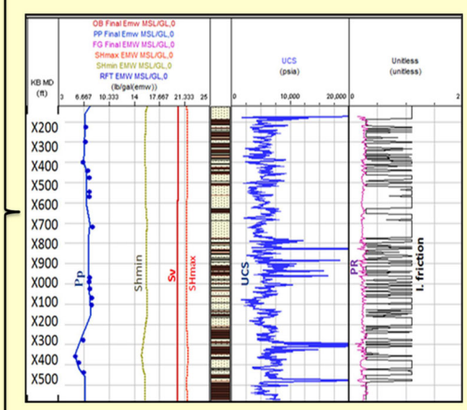


Vertical wells



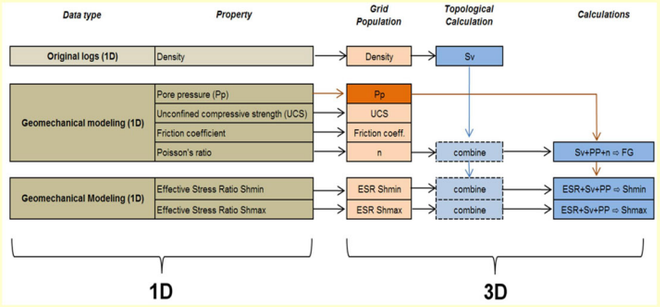
PHASE-1: BUILDING 1D GEOMECHANICAL MODEL





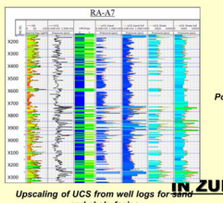
1D Geomechanical Model for Zubair

PHASE-2: 3D STATIC GEOMECHANICAL MODELING WORKFLOW

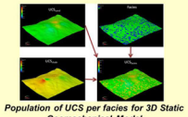


Calibrated 1D Geomechanical models are key input before moving to 3D Geomechanical modeling.

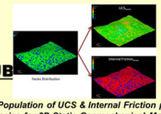
UPSCALING & POPULATION OF ROCK STRENGTH PROPERTIES



Upscaling of UCS from well logs for sand and shale facies

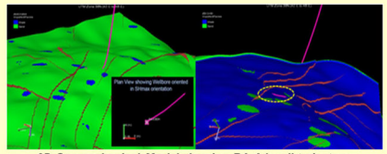


Population of UCS per facies for 3D Static Geomechanical Model

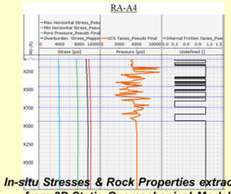


Population of UCS & Internal Friction per facies for 3D Static Geomechanical Model

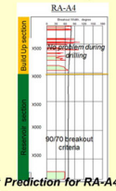
CALIBRATION OF 3D GEOMECHANICAL MODEL



3D Geomechanical Model showing RA-A4 well trajectory

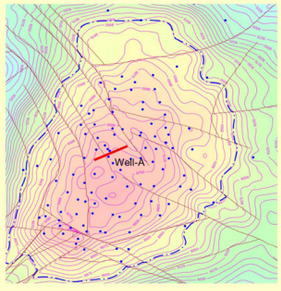


In-situ Stresses & Rock Properties extracted from 3D Static Geomechanical Model



Breakout Prediction for RA-A4 showing predicted failure less than allowable failure

Well drilled in crestal part of Structure
Well type: Horizontal
Build Section in Zubair
Crosses a Major Fault
Variation in observed stress orientation
Azimuthal Logging-while-Drilling Technology used



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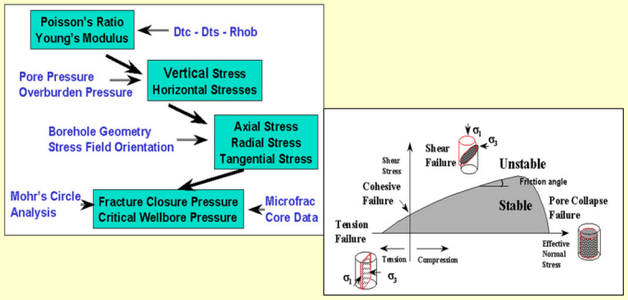
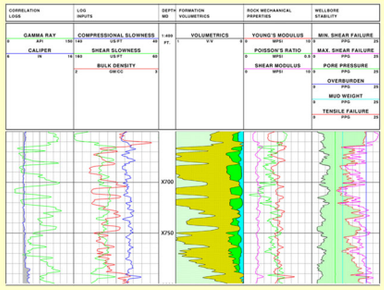
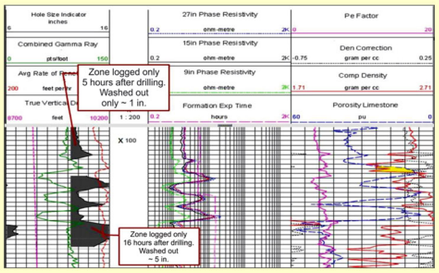
Rock Mechanical Analysis



Rock Mechanical Analysis Plot



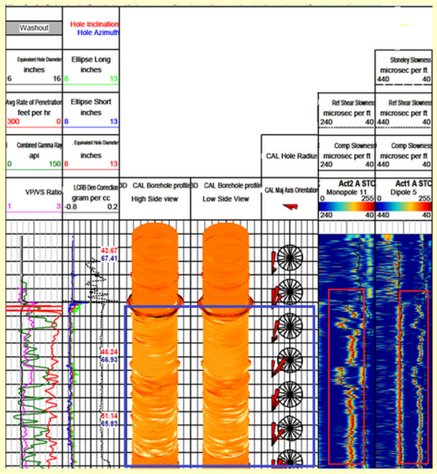
Hole Size Deterioration by Time



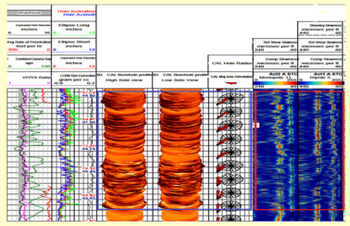
LWD Composite Logs

Breakouts resulting from borehole instability significantly affect log data quality. Previous observations and comparisons showed that extended formation exposure times in the Zubair formation can greatly affect borehole size changes. Logging while drilling (LWD) tools have a distinct advantage in terms of acquiring petrophysical data soon after the bit has penetrated the formations before borehole deterioration. Hole size could begin to deteriorate within a few hours. In this specific case, a hole washed out within approximately 16 hours by 5 to 6 in.

Hole Size Deterioration by Time



Logging in Wiper Run

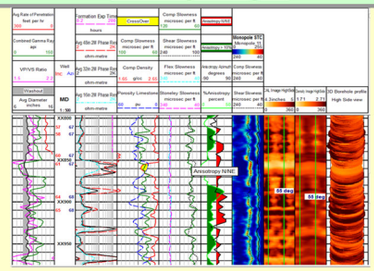


Caliper Measures a 2-in. Washout; Weak Sonic Semblances are Apparent on Last Two Tracks

Anisotropy Analysis From LWD Caliper

- A four-axis caliper measurement integrated with the anisotropy analysis feature and the density image is capable of providing information about stress orientation in the presence of breakouts. These functions also add confidence in information that is confirmed by all of them. The breakout direction is approximately southeast-northwest, which is a minimum stress orientation.
- In addition, the anisotropy analysis feature showed an average of 15 to 20%; its orientation function indicated northeast direction. This orientation is perpendicular to southeast.

Composite Logs With Anisotropy Indication and Breakouts on Ultrasonic and Azimuthal Bulk Density Images



Conclusions

- Azimuthal LWD time-lapse measurements have proven to be broadly useful for assessing the accuracy of previous geomechanical studies performed for the field. They are also valuable for the purpose of formation evaluation because they capture the clastic sequence of the upper Zubair layers in a near-virgin state.
- The acquired borehole acoustic data proved to be beneficial for the identification of compaction trends and in the establishment of more accurate estimates of pore pressure values across thick shale layers. Historically, washouts and breakouts resulting from borehole instability and deterioration often masked wireline sonic/acoustic data accuracy across these types of layers, rendering previous pore pressure prediction exercises inadequate.
- The authors expect a step change for understanding in-situ field stress and advancements when managing borehole stability to occur after a sufficient database of azimuthal acoustic LWD data across the field is gathered and analyzed. This change, in addition to newer methods of early target detection and geostopping technologies, will eventually help facilitate the elimination of pilot hole sections for horizontal wells.
- The wide-scale application of acoustic LWD technologies and the answers that these technologies provide could be key components of reaching NPT-free operations and sustainable well construction and oil recovery efforts.