Abstract
Middle East carbonates frequently are heterogeneous in nature, encompassing variable pore types, strong
diagenetic overprints, variable wettability and fracture networks amongst other effects. Resistivity borehole images
have long been an integral constituent to understanding their complexity and unlocking volumes. High resolution
LWD resistivity images were first introduced in the 1990’s, however as downhole environments became
progressively more challenging, resistivity images suffered from the dynamic acquisition environment resulting in
severely degraded images. The Al Shaheen field has been developed with Extended Reach Drilling (ERD) wells, and wells of 30,000 feet are
commonplace. Early LWD resistivity image data suffered from excessive stick and slip, with approximately half of
the wellbore suffering from poor quality image data, degrading with depth. The outer portion of the wellbore is
prohibitive to impossible to access via conventional drill pipe conveyed tools, resulting in an absolute requirement
for high quality LWD resistivity images.

The new methodology redefines the acquisition and processing methodology, resulting in images unaffected by
stick slip with a 100% success rate in the most challenging of ERD environments.

This paper illustrates the improvements in logging while drilling images (LWD) and subsequent fracture network
characterization as a result of implementing a new image acquisition strategy and processing algorithm. The paper
explores the close collaboration necessary to drive the innovation to dramatically enhance existing technology, and
demonstrates the results with comparisons of the LWD images using the old and new methodologies.

The development of the Al Shaheen Field
The Al Shaheen field was discovered in the 1970’s in connection with appraisal drilling of the underlying North
Field Khuff reservoir. It is located on the central axis of the Qatar Arch some 70 Kms N-E of the Qatar peninsula,
and covers an area of approximately 2080 km², Figure 1. The reservoirs were initially considered uneconomical
due to their thin oil columns. In 1992 Qatar Petroleum entered into an Exploration and Production Sharing
agreement with Maersk Oil Qatar and the Al Shaheen field has since been under development, (Thomasen et al,
IPTC-10854).

The field contains multiple stacked reservoirs, and the main producing targets are the Cretaceous Kharaib B and
Shuaiba carbonate formations and the Nahr Umr sandstone formation, Figure 1. The field is being developed using
extended reach horizontal wells (ERD), and is home to some of the longest wells in the industry. The application of
ERD technology has enabled the large areal accumulation to be developed using only nine production platforms.
Horizontal well technology is particularly attractive due to thin producing columns. The length of these horizontal
wells has increased over time, pushing the limits of available technology to today where for example wells of
30,000 feet to 40,000 feet are geosteered within a 10-foot window (Sonowal etc al, SPE/IADC-119506). Increases
in well lengths also require continuous improvement in associated well technologies from completion technology
(Brink et al, SPE-134934), to new logging technology.
Importance of identification and characterization of fractures

Al Shaheen is being developed predominantly using water injection to maintain pressure support. The field contains a number of faults and associated fractures, together with areas of the field that are more extensively fractured (Zampetti et al IPTC-17612). The presence of faults and fractures can contribute to premature water breakthrough. Mitigation of the risk from faults or fractures is optimally done during the drilling phase using zonal isolation or conformance treatments. Therefore reliable LWD image logging that can successfully identify fractures and faults during drilling becomes a critical enabler in the planning of a robust completion design of the long horizontal wells (Brink et al, SPE-134934).

Imaging techniques in Al Shaheen

Historically a variety of imaging technologies had been employed to successfully and reliably image faults and fractures. However as well lengths increased, the technologies became less applicable for a variety of reasons. Conventional wireline technologies deployed via drill pipe conveyed logging are difficult to impossible to use in the outer sections of extended reach wells. In addition drill pipe conveyed logging of 30,000 feet wells is prohibitively expensive due to the time required for conveyance. Therefore reliable logging while drilling (LWD) imaging in extended reach wells is required in the Al Shaheen field. Historically LWD technology had proven reliable, but as well lengths increased and downhole data acquisition environments became more challenging, the LWD images became unreliable in the most inaccessible outer half of the wellbore. The poor data quality was determined to be the result of extreme irregular rotation of the bottom hole assembly (BHA), due to getting stuck at some point and then being released after a few moments known as stick and slip. As technology developments had allowed wells to become longer, the technology for image acquisition needed to adapt. Therefore a full review of the data acquisition strategy was initiated to attempt to extend the operating envelope of the tool in the high stick slip environments. If successful the potential impact on well completion decisions and reservoir characterization would be significant.

LWD Imaging Technology

The LWD laterolog resistivity tool provides five resistivity measurements — bit, focused ring, and three focused button resistivities that are azimuthal and an azimuthal gamma ray, Figure 2. The three button resistivity sensors are about 1-inch in size and have a depth of investigation of approximately 1, 3 and 5 inches from the borehole wall into the formation in an 8 ½ inch borehole. The button resistivity measurements acquire resistivity profiles as the tool rotates in the borehole. Data from the azimuthal scans are stored downhole and downloaded from the tool between bit runs. In addition, the azimuthal data may be averaged by quadrant and transmitted to surface in real time along with the ring and bit resistivity, and gamma ray measurements. All four resistivities use the same measurement principle: current from the upper transmitter flows down the collar and out into the formation, leaving the collar surface at 90° along its length. The return path is along the collar above the transmitter. The amount of current leaving the tool at the ring and button electrodes is measured by a low-impedance circuit. Axial current flowing down the collar is measured at the ring electrode and at the lower transmitter. These measurements are repeated for the lower transmitter. Focusing is achieved by a technique called Cylindrical Focusing. (Oilfield Review Spring 1996).

Image acquisitions in high stick slip conditions

Stick and slip is an irregular rotation of the bottom hole assembly (BHA), caused by the BHA getting stuck momentarily, then being released after a few moments. This effect leads to high fluctuation of the downhole rotation that affects the image data quality. The tool acquires images through an acquisition cycle that can be customized to extend over 3, 5, or 10 seconds. To maximize resolution while minimizing stick and slip effects, the 5 second option is used as default in Al Shaheen, with the following acquisition cycle:

1. Tool fires the upper transmitter (T1) for 2 seconds, then the lower transmitter (T2) for another 2 seconds
2. During the next 1 second, the measurements are stored in 56 bins using the magnetometers
3. Sleeps 1 sec
4. Repeat acquisition cycle

From this acquisition cycle, 3 measurements for each electrode in the tool are generated one from the T1 one from the T2 and a compensated image, Figure 3. In order to optimise downhole memory usage by default only the compensated image was stored. A minimum rotation of 30 RPM is required to acquire an image. In high stick slip environments the fluctuation of the rotation is high, meaning that the minimum requirement of 30 RPM is not honored at all times. Failure to meet the 30 RPM requirement results in missing data within some of the 56 bins of the rotation, known as missing bins. Missing bins on the images are indicated in green. The stick slip is indicated by the variation of RPM in the depth track, Figure 3.
Image improvements in high stick slip conditions
The consequence of the high stick slip was improper binning of data to generate images. The compensated image is a combination of the T1 and T2 images. If one of the images is affected due to high stick slip then the compensated image was also affected. The result was un-interpretable image, Figure 3. The image acquisition and processing algorithm was redeveloped (not a part of this paper) and applied to the challenging ERD wells in Al Shaheen. The improvement of the image quality was immediately evident, Figure 4. The improved image quality has enabled a high confidence interpretation of the data. This in turn enables a high confidence completion design strategy which has a dramatic impact on the life of the well.

Case Study 1
A well was drilled into an area know to be fractured and susceptible to premature water breakthrough. The well was drilled to a TD of approximately 19,000 feet, where total losses were encountered. The LWD images were acquired using the new acquisition and processing algorithm. The new LWD images indicated a large fracture zone at the TD of the well, in addition minor fracturing was observed in selected intervals in the wellbore. A conventional wireline image log was acquired in combination with a formation pressure and sampling tool across the inner section of the wellbore where wireline log acquisition is feasible. This enabled a high confidence assessment of the image with the new acquisition and processing algorithms both in terms of image quality and dip accuracy, Figure 5.

The new processing algorithm was 100 percent successful in removing all stick and slip related artifacts from the image in the challenging extended reach environment. The dip accuracy was also qualified as being as good as the traditional wireline well bore imaging tool. In addition the packer from formation pressure and sampling tool was positioned across one of the fractures visible on both the FMI and the GVR. The inflow was assessed across the fracture, and nearby in matrix that appeared to have no fractures present. The inflow from the test where the packer was positioned across the fracture was higher than that of the nearby test where no fracture was present. This enabled a high confidence assessment that the LWD images were reliably and accurately characterizing fractures that impacted productivity. This enabled a high confidence completion strategy to be developed to optimise development within the offset area. A plug was set at the end of the well and a zonal isolation was installed. Following the zonal isolation the well produced as expected.

Case Study 2
A well was drilled to TD of over 33,000 ft MDRT. Images were acquired using the new acquisition and processing algorithm, which resulted in high resolution images throughout the wellbore to TD. This enabled a detailed analysis of fracture intensity, and resulted in the installation of a high confidence completion design. The well currently produces as expected.

Case Study 3
A well was drilled to a TD of approximately 26,000 ft MDRT. High losses were experienced close to TD of the well. LWD images were acquired using the new acquisition and processing algorithms, and high quality images were successfully obtained. A review of the images determined that the cause of the losses was most likely not in the interval where losses were experienced, and in fact caused by an interval in the inner section of the wellbore. A zonal completion was installed that isolated an inner part of the wellbore. The well currently produces as expected.

Conclusion
Continuous technological improvements have occurred throughout the well delivery process. These technological advances have lead to increasing well lengths, and the ability to successfully complete the long wells to optimize production. Historic LWD image acquisition suffered as a result of the harsher data acquisition environments that the tools were progressively subjected to. Once again, a successful collaboration with the vendors of technology has enabled the operating envelope of existing technology to be significantly extended. Historically LWD image acquisition would be challenging beyond 15,000 ft MDT. Today as a result of the successful collaboration high quality LWD image data can be recorded in any wells we drill, enabling high confidence completion decisions, and improved reservoir characterisation.

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Figure 1 Al Shaheen Field Offshore Qatar, Stratigraphy of Al Shaheen field
Figure 2 Tool configuration and image acquisition overview

Figure 3 Image acquisition cycle overview and quality in high stick slip conditions, erratic RPM is displayed in the depth track. The image is virtually uninterpretable.
Figure 4 on the left hand side is the images with the old processing and acquisition algorithm. On the right are the images with the redeveloped algorithm. Full improvement of the images in high stick slip conditions.

Figure 5 A comparison of a traditional wireline borehole image together with the improved LWD image and the original LWD image taken from the outer section of the wellbore. Also shown a comparison of the dips calculated from the two different tools confirming high confidence data.