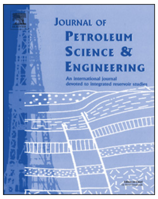
Journal of Petroleum Science and Engineering 122 (2014) 318–330

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol



Evaluate the borehole condition to reduce drilling risk and avoid potential well bore damages by using image logs

Movahed Zohreh [a,b,1], Radzuan Junin [a,*], Peter Jeffreys [c]

[a] Universiti Teknologi Malaysia/Faculty of Petroleum & Renewable Energy, Malaysia
[b] Schlumberger, Malaysia
[c] Schlumberger, United Kingdom

ARTICLE INFO

Article history:
Received 3 December 2013
Accepted 24 July 2014
Available online 14 August 2014

Keywords:
high stresses
borehole instability
borehole failure
Ultrasonic Borehole Imager
wellbore instability
well condition
wellbore damage

ABSTRACT

By drilling a well, i.e. removal of a cylinder of rock from the subsurface, a disturbance of the natural stress state is created. Where the horizontal stresses are strong and unequal, then the borehole will be subjected to an imbalanced horizontal stress condition. Drilling mud is weighted to create a hydrostatic pressure to balance the formation stress. However, in Iran there are high stresses then stressing anisotropy will remain. After drilling it is important that the borehole stays in good shape if it is to successfully perform its intended function, e.g. produce hydrocarbons. Borehole instability will severely compromise this function and reduce the working life of the well. An evaluation of the borehole condition and the mechanism of borehole failure by using image log tools would clearly help. The tool referred to is the Ultrasonic Borehole Imager (UBI). Currently it is a standard practice to use this tool for a comprehensive structural analysis and fracture characterization; however interpretation of borehole shape analysis needs a lot of improvement. In this study found solution regarding borehole stability by early warning of wellbore instability and improve information about the well condition by working on advanced borehole shape analysis. Image logs showed exactly where the losses are happening and allowed the remedial action to be precisely made.

1. Introduction

Borehole instabilities pose significant challenges to drilling and completion operations, particularly in regions with weak bedding planes and pre-existing fractures where formations have strong anisotropies (Zhang, 2013). Orientations of regional stresses in most part of the Arabian Peninsula (Akbar and Sapru, 1994) is NE-SW for the maximum horizontal stress and NW-SE for the minimum horizontal stress, which is considered as Zagros stress. All Iran and particularly the Zagros mountain front have a strong in-situ stress. The dominant type of horizontal stress is compressive in the direction SW to NE. In this direction, drilling fractures will tend to develop, and is perpendicular to the direction of borehole collapse or breakout due to shear failure in the orientation of minimum horizontal stress, i.e. NW to SE. The Zagros tectonic activity is still continuing to the present day, hence the earthquake activity that is occasionally experienced resulting from movement along faults and folds (Jeffreys, 2005). Present day in-situ stresses acting on the freshly drilled borehole is therefore likely to be substantial (Fig. 1). After drilling in this area, it is important that the borehole stays in good shape if it is to successfully perform its intended function, e.g. produce hydrocarbons. Borehole instability will severely compromise this function and reduce the working life of the well. The acquisition of UBI either at an intermediate stage or immediately following drilling provides an early warning of wellbore instability. If you know what the problem is then you can start to fix it. For example, what type of fracture system is present? Are the fractures dispersed throughout the interval or related to faults? Are they aligned parallel or oblique to the direction of maximum present day in-situ stress? In this study we are going to find a solution regarding borehole stability by working on advanced borehole shape analysis. Image logs will show exactly where the losses are happening and allow the remedial action to be precisely made. So, in this study, our objective is to gain following advantages: (1) early warning of wellbore instability; (2) identification of fractured zones (mud losses), mechanically weak formations and sections where the well is enlarged or restricted; (3) early quick-look data as insurance in the event of subsequent deterioration of borehole conditions; (4) measurement of the mud

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[*] Corresponding author.
E-mail addresses: zmovahed@gmail.com (M. Zohreh), radzuan@petroleum.utm.my (R. Junin).
[1] Tel.: +60 104298052.

http://dx.doi.org/10.1016/j.petrol.2014.07.027
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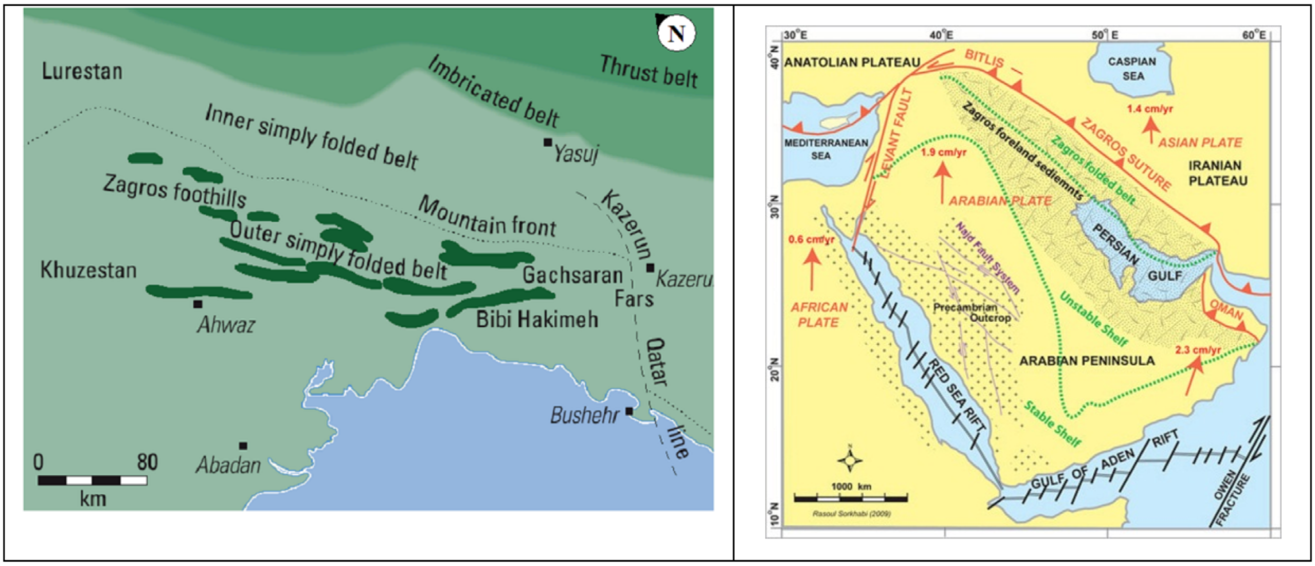


Fig. 1. NW-SE trending major anticlinal structures in the Foreland basin of the Zagros Mountains (left) and Foreland folding in the south west of Zagros convergence and large-scale strike–slip faults are indicated in Iran (right) (Motiei, 1995).

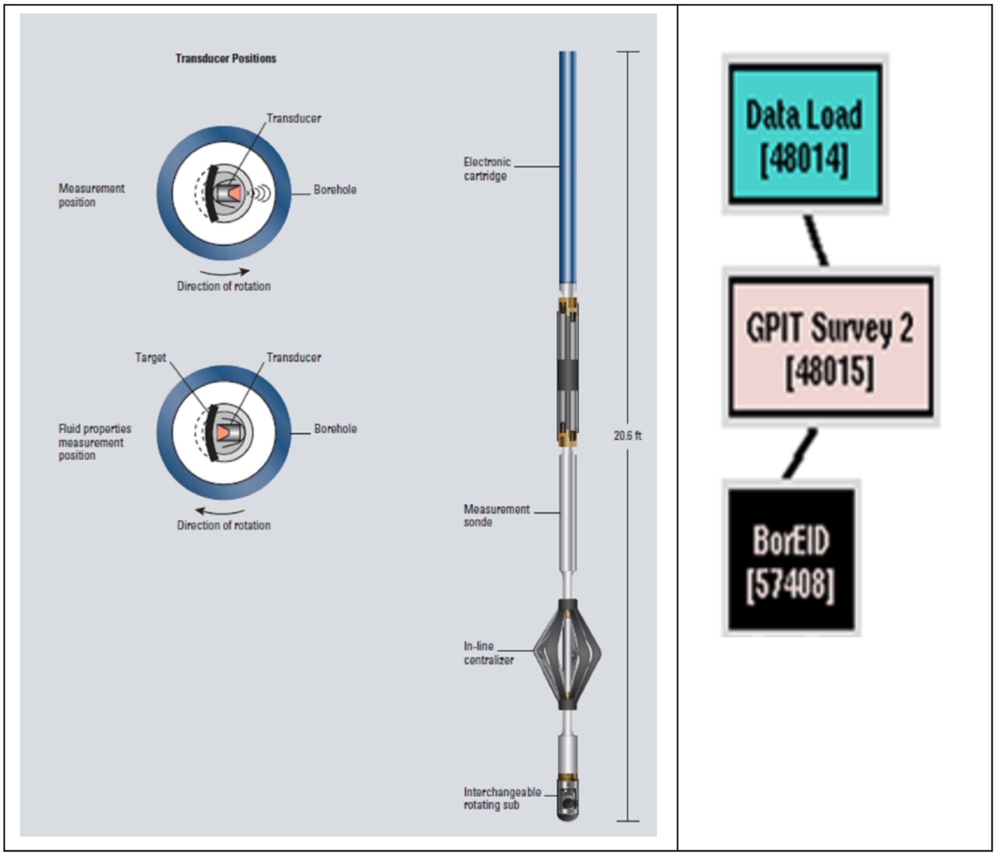


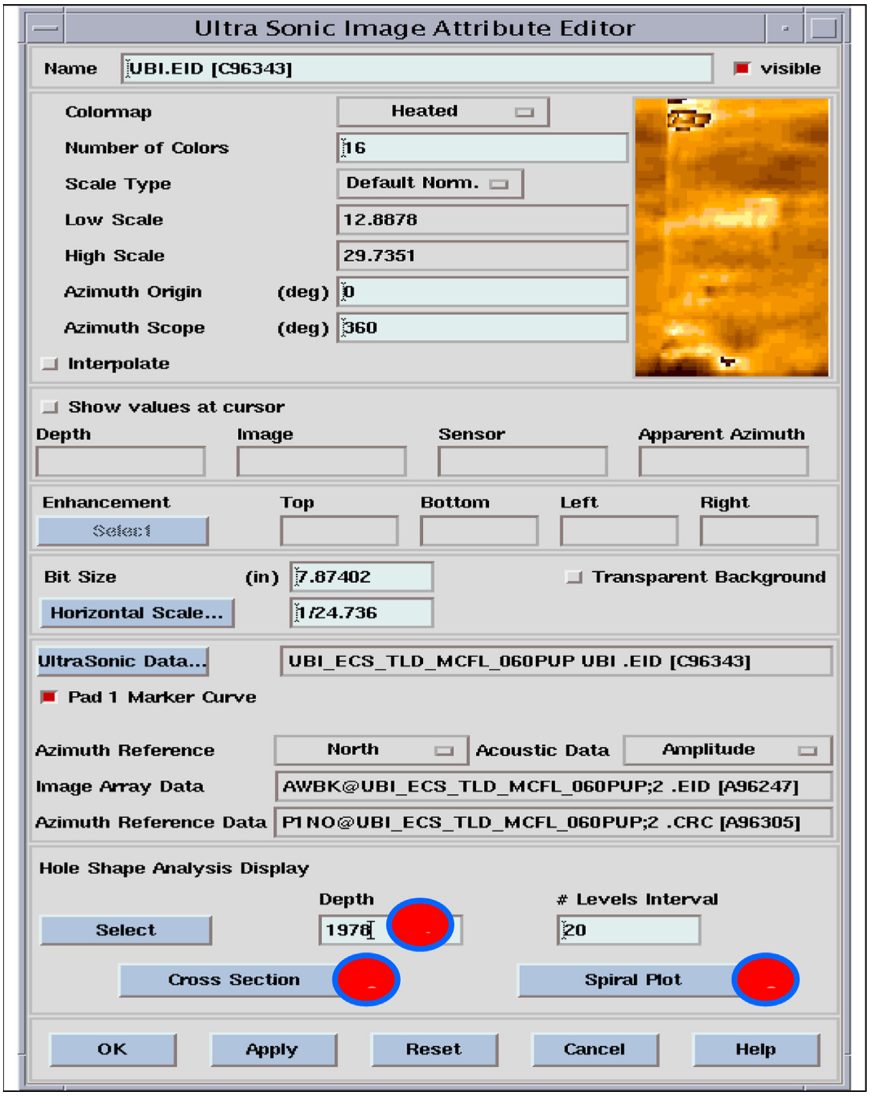
Fig. 2. Sketch diagram showing the direction of rotation of the transducer subassembly controls the transducer position (left) and UBI Image Processing Workflow (right) (Schlumberger, 2002).

slowness, i.e. down hole fluid density; (5) determination of in-situ stress direction and magnitude; and (6) continuous and high-resolution well deviation survey.

2. Used imaging tool and workflow

Geological image logs provide a down hole measurement of the actual borehole conditions. The acoustic tools (UBI) emit ultrasonic echoes that provide a full-bore caliper, i.e. 180 azimuthal samples per depth interval. The UBI tool accurately measures both amplitude and transit time. The processing technique provides improved accuracy, avoids cycle skips and reduces echo losses. The tool operates on two frequencies (250 or 500 kHz); the higher frequency yields higher image resolution, while the lower frequency provides a robust measurement in highly dispersive muds. Acoustic imaging tools utilize a rapidly rotating piezoelectric transducer to emit a focused, high frequency sonic pulse to the borehole wall (Asquith and

Krygowski, 2004). The sonde of UBI includes a rotating transducer subassembly, which is available in different sizes to log all standard sizes of open boreholes (Fig. 2). The direction of rotation of the subassembly controls the orientation of the transducer – counter-clockwise for the standard measurement mode (transducer facing the borehole wall) and clockwise to turn the transducer 180° within its


Ultra Sonic Image Attribute Editor

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Number of Colors: 16
Scale Type: Default Norm.
Low Scale: 12.8878
High Scale: 29.7351
Azimuth Origin (deg): 0
Azimuth Scope (deg): 360
☐ Interpolate

☐ Show values at cursor
Depth / Image / Sensor / Apparent Azimuth

Enhancement: Select / Top / Bottom / Left / Right

Bit Size (in): 7.87402 ☐ Transparent Background
Horizontal Scale...: 1/24.736

UltraSonic Data...: UBI_ECS_TLD_MCFL_060PUP UBI .EID [C96343]
☒ Pad 1 Marker Curve

Azimuth Reference: North
Acoustic Data: Amplitude
Image Array Data: AWBK@UBI_ECS_TLD_MCFL_060PUP;2 .EID [A96247]
Azimuth Reference Data: P1NO@UBI_ECS_TLD_MCFL_060PUP;2 .CRC [A96305]

Hole Shape Analysis Display
Select
Depth: 1978
Levels Interval: 20
Cross Section
Spiral Plot

Fig. 3. GeoFrame snapshot showing ultra-sonic image attributes editor panel.

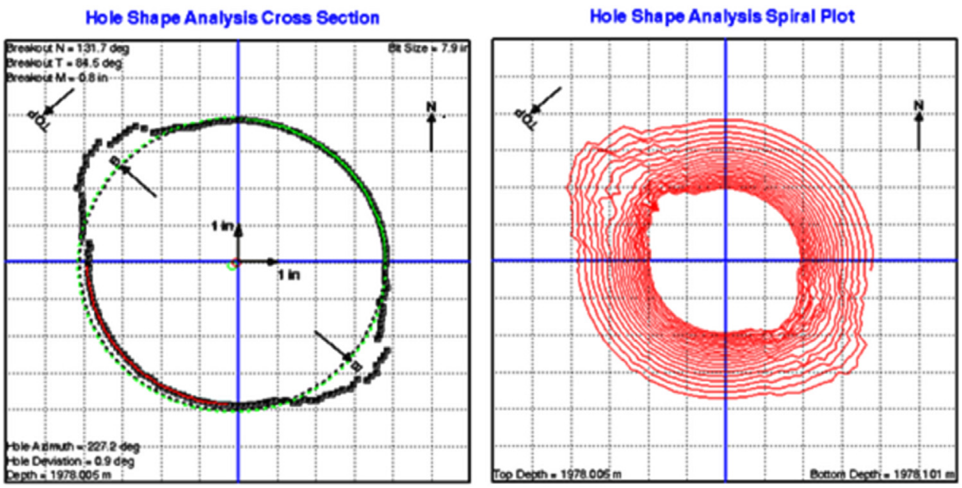


Fig. 4. Geoframe snapshot showing cross section plot (left) and spiral plot (right).

subassembly (transducer facing a reflection plate within the tool) to measure downhole fluid properties (Schlumberger, 2002).

Three steps are involved in the generation of UBI image and the cross-section plot based on GeoFrame in this study, load the raw dlis file by applying the Data Load module, run GPIT Survey 2 to quality check of the data, and run BorEID to generate the speed corrected image and cross-sectional radius data (Fig. 3).

We first run the Data Load module to load the UBI image and other open hole logs, and then run GPIT Survey 2 module to quality check of the data before running the BorEID module. GPIT Survey 2 is for repairing the bad inclinometry data and for computing the data channels. BorEID is the key GeoFrame module to generate speed corrected UBI images and create borehole cross-section from radius data. After passing major steps to run the BorEid, hole shape analysis, cross section easily generated from the BorEIDplayback window by following these steps:
(1) double click the BorEID image (amplitude or centered radius) on the BorEIDplayback panel to activate the Ultrasonic Attribute Editor (Fig. 3), and enter the depth for cross section generation and click Cross Section button to generate the hole shape analysis, the cross section for the selected depth (Fig. 4); and
(2) multi level interval spiral plot can be generated at the same time by simply click Spiral Plot button (Fig. 4).

3. Discussion

3.1. Solution 1: detailed borehole shape analysis

The subsurface of the continental crust rarely stays at hydrostatic stress condition, the stress state under which all points in the crust are subjected from all directions to equal stresses ($\sigma1=\sigma2=\sigma3$). However, such stress conditions are rarely met in the Earth's subsurface as many structural movements keep taking place in it. The largest portion of the disturbance in the equilibrium in the stress state is contributed by the plate's movements that ultimately result in the formation of a regional stress system for the area bounded by them. However, sometimes the regional stress is completely overprinted due to stresses localized to a certain area (Mount and Suppe, 1987; Bell, 1990). The source of the local stress system may be associated with faults, folding, diapirism and so forth. The orientation of such local stresses may be changed abruptly over short distances in any area. The wells drilled in areas subjected to such kind of unbalanced stress system often exhibit two types of borehole failures, shear failure and tensile failure, when the rocks drilled by them are replaced with the drilling mud (Lehne and Aadnoy, 1992; Aadnoy and Bell, 1998). The rocks can bear both compressive and shear stresses, but the fluid filling the borehole can bear only compressive stress and not shear stress. Consequently, the concentration of stresses takes place around the borehole in the form of hoop stress or tangential stress. By drilling a well, i.e. removal of a cylinder of rock from the subsurface, a disturbance of the natural stress state is created. Where the horizontal stresses are strong and unequal, then the borehole will be subjected to an imbalanced horizontal stress condition. Drilling mud is ‘weighted’ to create a hydrostatic pressure to balance the formation stress. When the mud weight is too low (i.e., radial stress=mud weight minus pore pressure), the maximum hoop stress becomes much higher than the radial stress. Consequently, a shear failure of rocks exposed to the borehole takes place, which is exhibited in the form of borehole elongation on the orthogonal calipers of dip meters (Cox, 1983) or borehole images (Ma, 1993; Aadnoy and Bell, 1998) as long dark regions on the borehole images that are 180° apart.

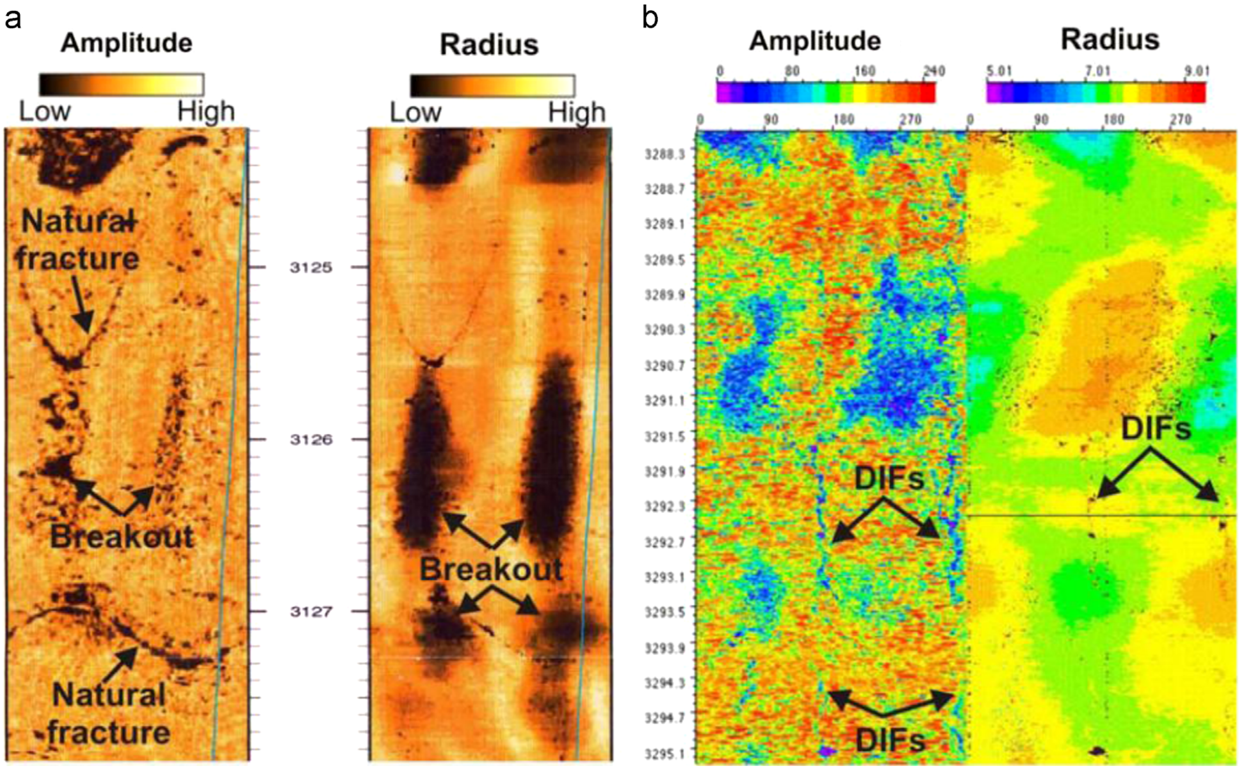


Fig. 5. Example of breakouts and drilling-induced fractures (DIFs) observed on acoustic image logs. (a) Borehole breakouts observed in the Ultrasonic Borehole Imager log. Borehole breakouts are broad zones of high borehole radius and, to a lesser extent, low reflection amplitude oriented towards 095–275°N. The borehole breakouts indicate that the present-day maximum horizontal stress is oriented approximately N–S. (b) BoreholeTeleviewer log showing DIFs oriented towards 165–345°N. DIFs are observed as zones of low amplitude (left image) and, to a lesser extent, higher radius (right image). The DIFs indicate that the present-day maximum horizontal stress is oriented (approximately SSE–NNW) (Tingay et al., 2008).

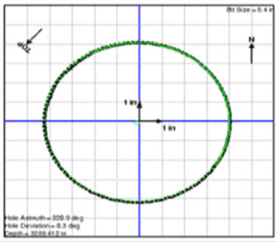
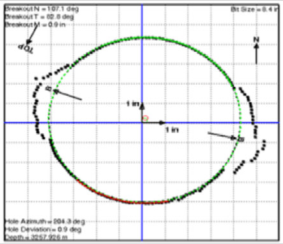
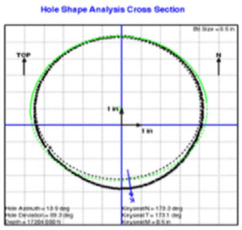
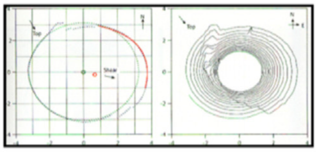
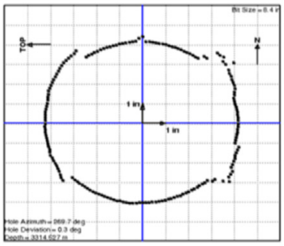
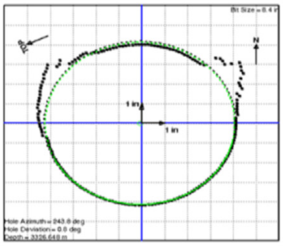
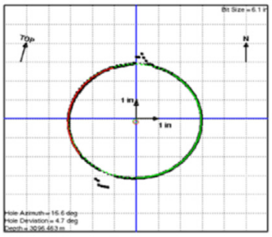
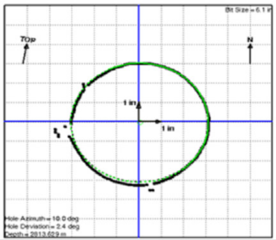
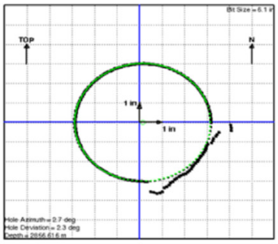
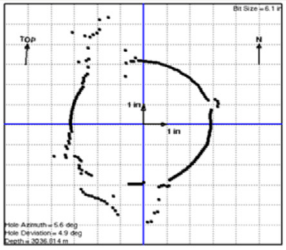
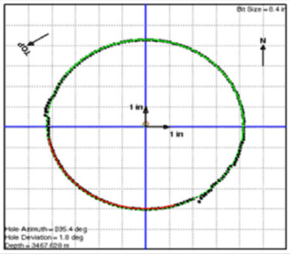
In-gauge borehole	**Borehole Breakout**	**Keyseat**
		
Indicates that no significant stress anisotropy exists and/or that the rock at this point in the well is strong.	Indicates that there is a clear imbalance in the horizontal stresses. The stress in one direction is clearly greater than that in the orthogonal direction.	Most common in deviated wells where the drillpipe has worn a groove on the lowside of the well. Clearly this is an assymmetrical hole enlargement
Slip displacement	**Asymmetrical damage**	**Assymmetrical damage**
		
Where the well crosses a planar dipping feature along which shear displacement can occur that results in the creation of an assymetrical holeshape.	Where fractures, faults or sedimentary planes of weakness intersect with the wellbore and cause a irregular distortion of the ideal cylindrical holeshape.	As previous …..
Single discrete fracture	**Multiple minor fractures**	**Fracture adjacent to well**
		
The borehole irregularity can be traced across the wellbore. It is associated with a clear moderately deep depression on the borehole wall.	An assemblage of minor shallow fractures can be identified on the borehole wall from this single depth 'slice'.	A single planar fracture is observed sub-parallel to the borehole axis, towards the SE and striking SW-NE.
Single deep fracture	**Multiple deep fractures**	**Fracture with micro-slip**
		
The fracture plane has an associated deep depression at the borehole wall, ie it is a major open fracture type.	The fracture striking NNW-SSE is associated with borehole wall collapse and a deep wide depression.The fracture striking SW-NE is more subtle.	The intersection of a fracture at the borehole wall in this case is associated with the development of minor slip displacement, see red flag on SW part of borehole cross-section

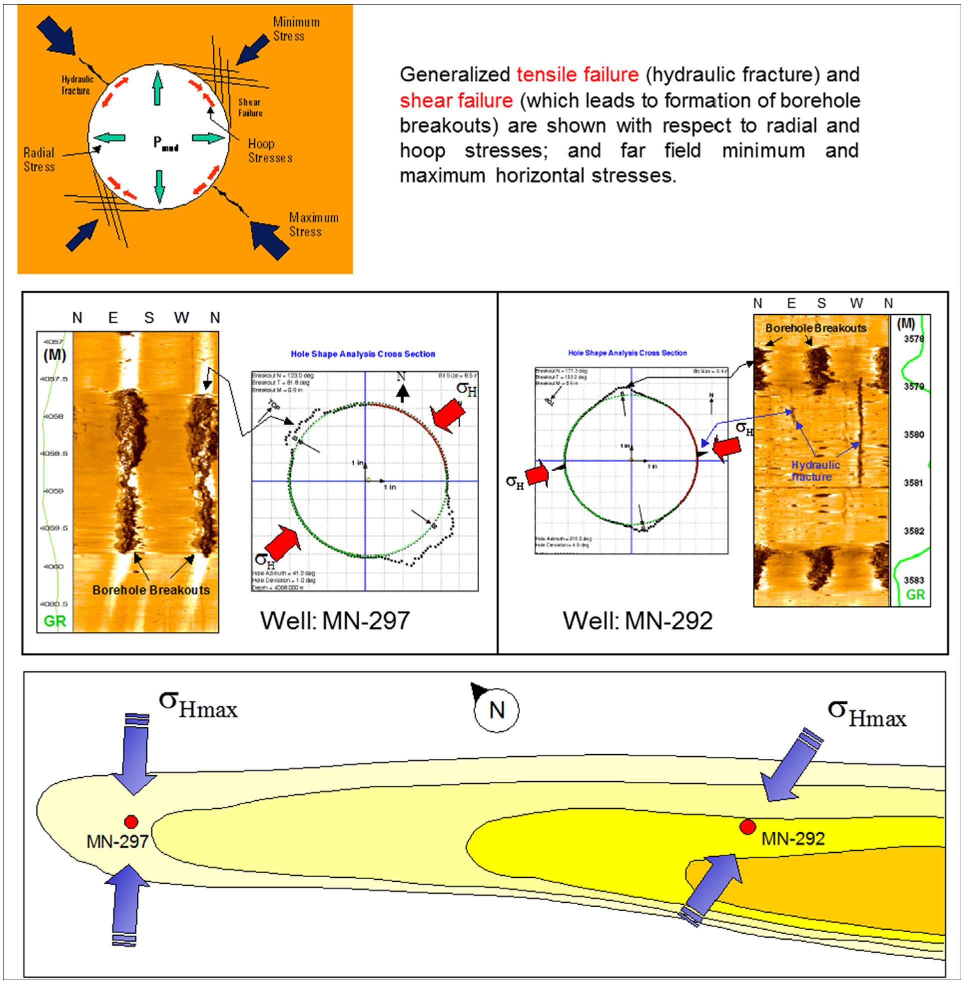
Fig. 6. Fracture patterns on UBI cross-section plots in some wells in Iran.

On the contrary, when the mud weight is too high, the radial stress increases and the hoop stress, decrease; consequently rock around the borehole comes under tension and fails in tension; the fractures so created are called drilling induced fractures. It is manifested in the form of a fracture seen by the images oriented at 180° from each other. Generally, in vertical wells and those with smaller deviation, the orientation of borehole elongation is aligned with the trend of minimum horizontal stress. Similarly, the strike of drilling induced is aligned with the trend of maximum horizontal stress. However, it may not be the case with the deviated wells and particularly those wells that are not aligned with either of the two horizontal stresses.

Borehole breakouts are typically interpreted from acoustic image log data using the borehole radius (or travel time) image in combination with images of the reflected amplitude. Borehole breakouts appear as broad zones of increased borehole radius (or travel time) observed on opposite sides of the borehole (Fig. 5a). However, breakouts typically have rough and variable surfaces and thus can also often be observed in reflected amplitude images as broad zones of low amplitude (Fig. 5a). Drilling-induced fractures are primarily observed in the reflected amplitude image. Both natural and drilling-induced fractures are poor reflectors of acoustic energy. Hence, drilling-induced fractures appear as narrow zones of low reflectivity separated by 180° and typically sub-parallel or slightly inclined to the borehole axis (Fig. 5b). Drilling-induced fractures are not commonly associated with any borehole enlargement and thus are often not well exhibited on borehole radius images. However, both natural and drilling-induced fractures may appear on borehole radius images as narrow zones of increased borehole radius (Fig. 5b) (Tingay et al., 2008).

The UBI provided full-bore images which are sensitive to fractures and other borehole wall irregularities as well as provide the caliper data. In addition to the conventional acoustic amplitude and borehole radius image displays, the UBI data also used to construct borehole cross-sections in plan view at any selected measured depth in the borehole. These cross sections are interpreted to give a very detailed account of the in-situ stress conditions. Structural cross-sections were built by using image logs to verify and update the geological maps and to identify the fracture systems at the well location. It is used for the well completion and to explain the observed reservoir behavior. The data also give a detailed description of the borehole condition following completion of the drilling process (Fig. 6).

For example, acoustic imaging has been used to determine orientation of in-situ stresses in a number of fields of this area. For instance, two wells MN-292 and MN-297from the studied field, well MN-292 being located near the crestal region and well MN-297 in the northwestern plunge area, show a 30° change in the orientation of the maximum horizontal stress. Well MN-297 follows the regional stress while well MN-292 does not. The change in stress orientation in well MN-292 is possibly a result



Generalized tensile failure (hydraulic fracture) and shear failure (which leads to formation of borehole breakouts) are shown with respect to radial and hoop stresses; and far field minimum and maximum horizontal stresses.

Fig. 7. Acoustic image and borehole radii plots show NW-SE trending borehole enlargements (due to shear failure of the rocks exposed on the NW and SE sides of the borehole) in well 'Y' of the studied Field. Similar plots show nearly N–S trending borehole enlargements in well 'X', which is located about 19 km away from well 'Y'. Hydraulic fractures trending E–W are also indicated by the acoustic image in well 'X'. Borehole breakouts and hydraulic fractures indicate that orientation of the maximum horizontal stress is changing across the studied field.

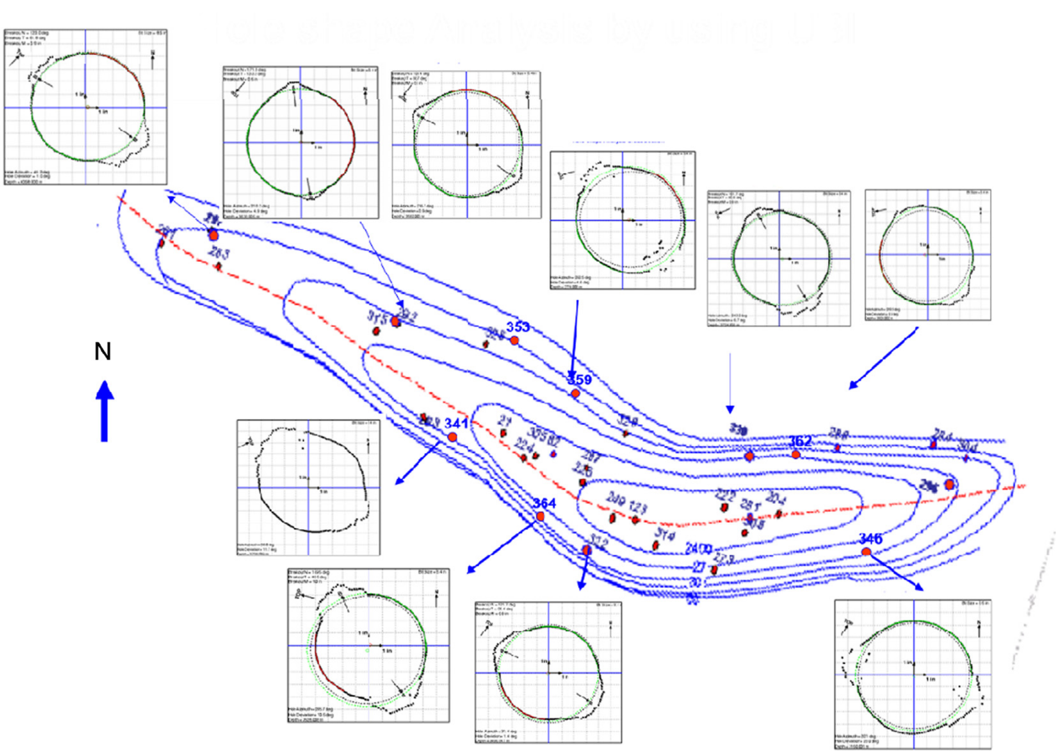


Fig. 8. In-situ stress analysis provided in different wells in Marun field.

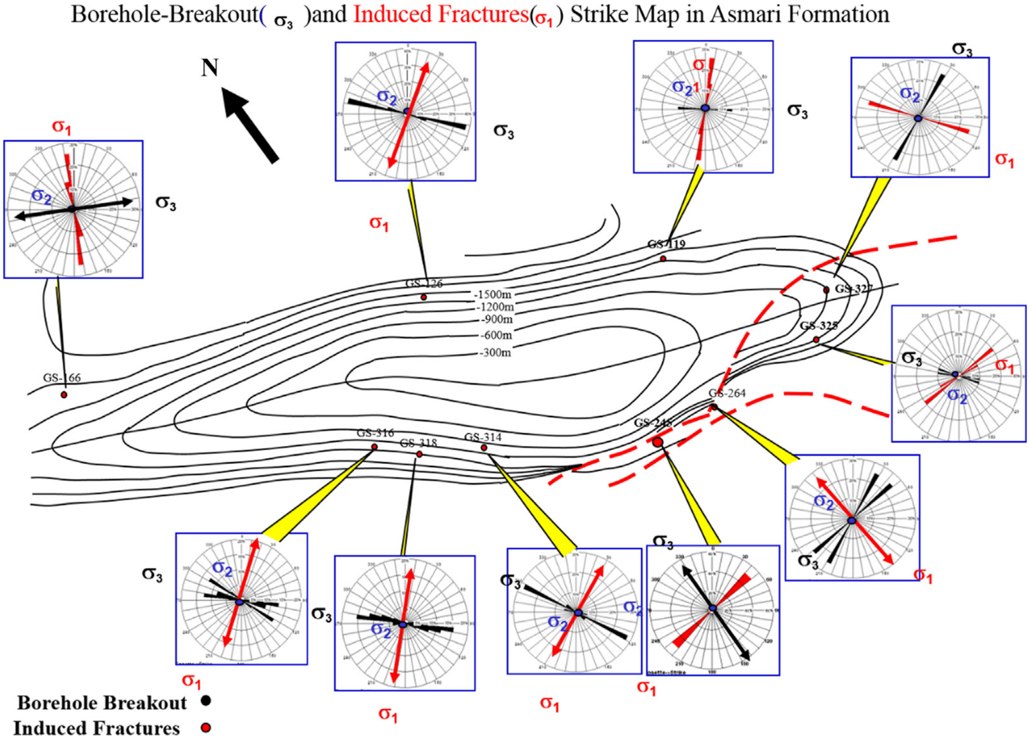


Fig. 9. In-situ stress analysis provided in different wells in Gachsaran field.

of local structural feature (Fig. 7). Borehole breakouts and hydraulic fractures indicate that orientation of the maximum horizontal stress is changing across the Marun field. It indicates that fractures formed during hydraulic/acid fracturing might extend in different directions across the Marun field (Fig. 8).

The information on stress orientation can further be used in well planning, oriented perforations, sanding control, and hydraulic fracture planning. In addition, in Gachsaran field, borehole image shows NW-SE trending borehole enlargements (due to shear failure of the rocks exposed on the NW and SE sides of the borehole) in all wells of Gachsaran field. Similar plots show nearly NE-SW trending borehole enlargements in well GS-264, which is located close to thrust fault. Borehole breakout and hydraulic fractures indicate that orientation of the maximum horizontal stress is changing nearby fault. It indicates that fractures formed during hydraulic/acid fracturing might extend in different directions across the Gachsaran field (Fig. 8). Most wells imaged with acoustic imaging showed that the present day stress orientation tends to follow the regional stress. However, variation in this trend is also observed (Figs. 8 and 9).

Since the hole shape can change frequently the analysis of hole shape should be made continuously with the generation of log curves to indicate the changing stress attributes with increased measured depth. Differences in rock strength and fracture gradient can be expected with increased measured depth. In addition, hole condition will change according to lithology type, the location of structural boundaries such as faults and unconformities, and according to the stratigraphic unit. The UBI is run in combination with a GPIT for orientation and with a GR for correlation. This GR log will show where the hole problems are lithologically related, i.e. where there is a mechanical stratigraphy effect. The GPIT data is used to orient the images and to correct for irregularities in the logging speed. It is also used to provide a measurement of the borehole drift, which can be an important factor related to any drilling hazard that is being encountered (Fig. 10).

In Fig. 10, Image log quality control flag color (coded flags indicate where data are degraded, e.g. as a result of adverse hole conditions (track1)). Drift and breakout width (continuous log of hole deviation (blue) along with a flag (black) indicating where breakouts have been identified and giving their computed width (track2)). Caliper display (two caliper curves (C1 and C2) from the orthogonal pairs of tool arms are displayed to highlight the variations in borehole size (track3)). Interpreted dips – bedding and fractures (bedding and Fractures interpreted from the image logs are displayed on a conventional dip track. Natural fractures

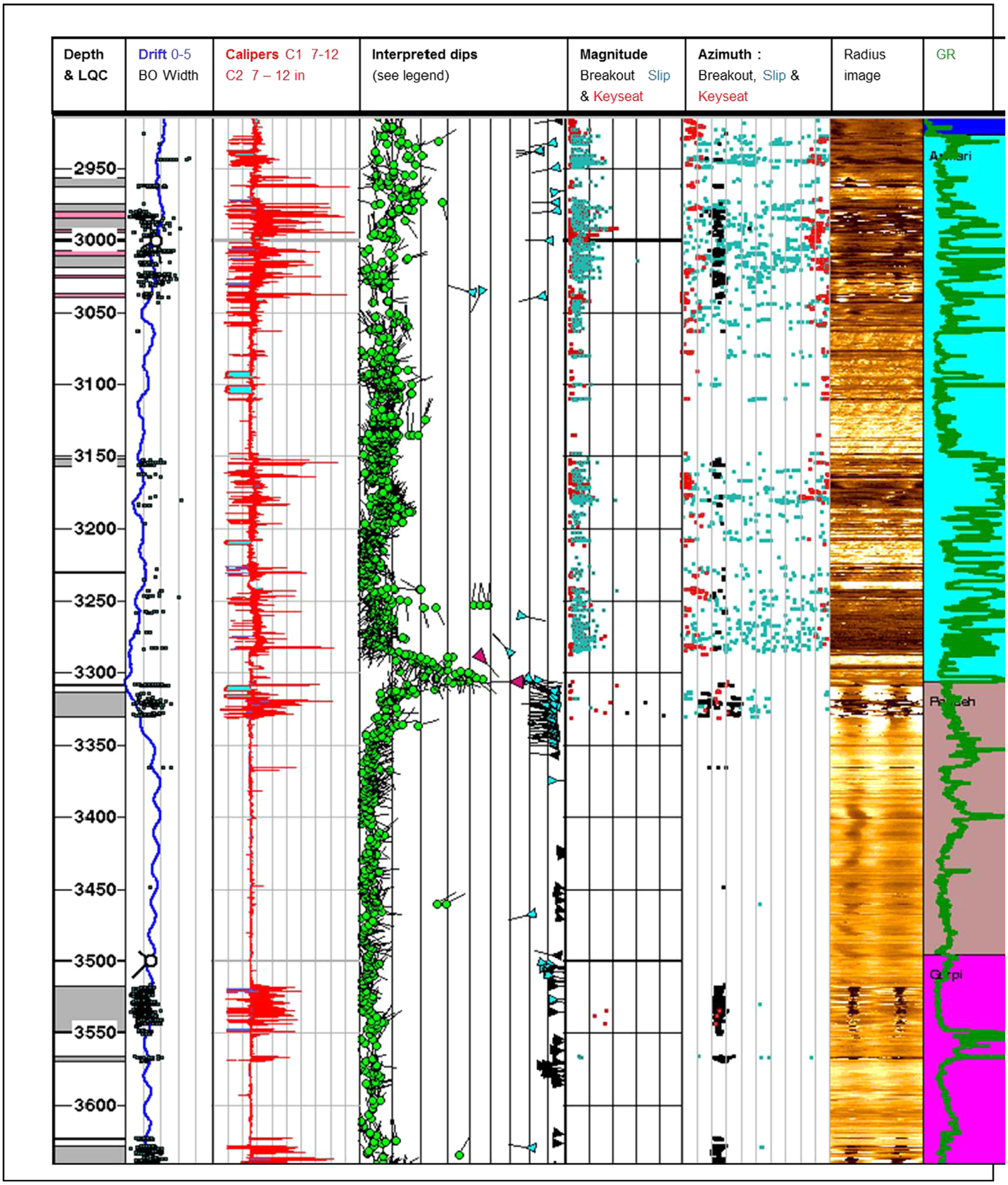
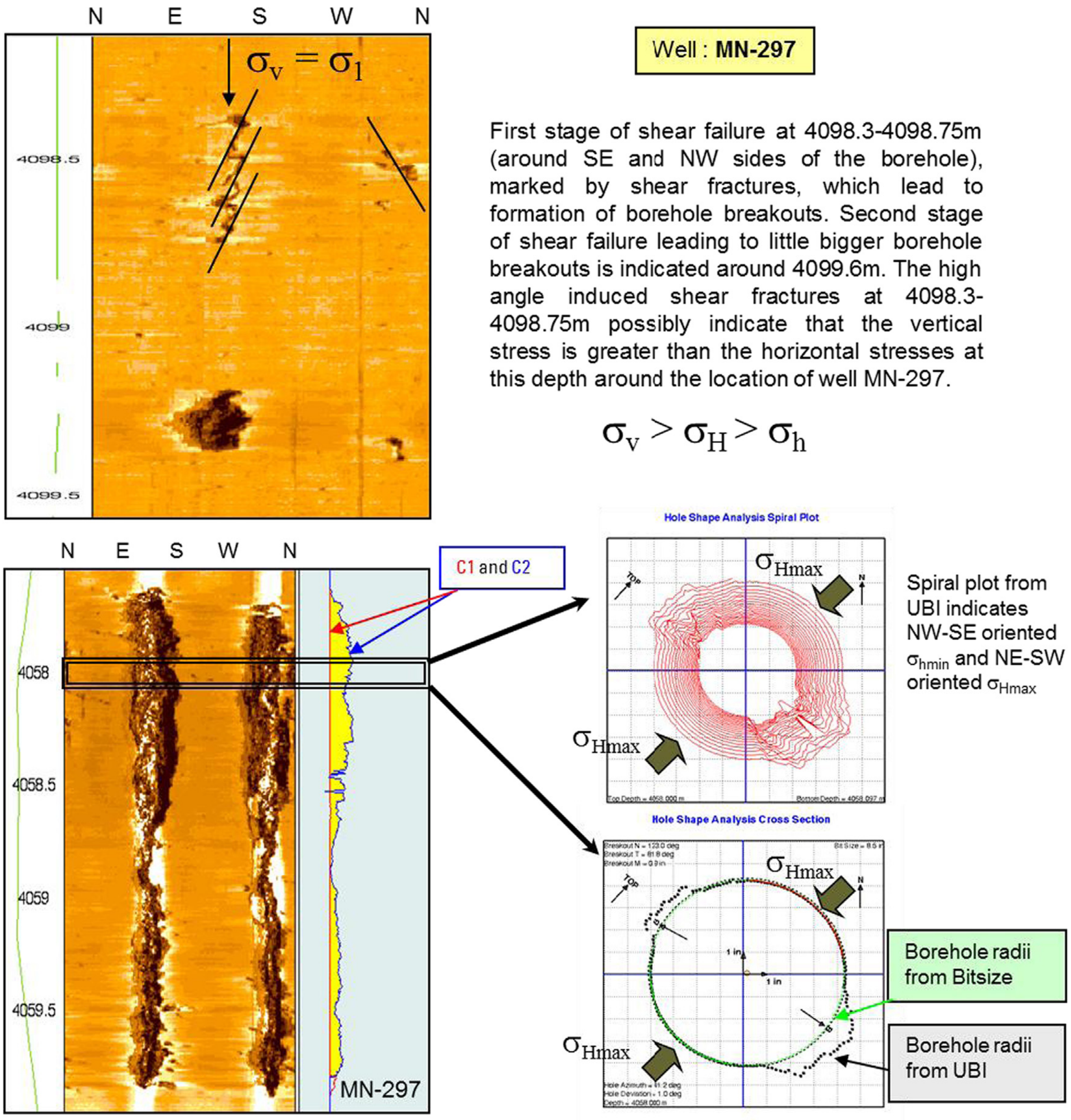


Fig. 10. Image log quality control flag color (coded flags indicate where data are degraded, e.g. as a result of adverse hole conditions (track1)). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

indicate the stress condition that existed at the time of fracture formation, whereas the drilling fractures indicate the present-day stress conditions (track4)). Magnitude of hole shape deformation (the three most commonly developed types of hole shape deformation are identified and plotted as color coded flags on a grid from 0 to 2.5 in. Borehole breakout is in black, key seats are in red and Slip displacement is in blue (track 5)). Orientation of hole shape deformation (the three most commonly developed types of hole shape deformation are identified and plotted as color coded flags on a grid from 0° to 360° to show their orientation). Borehole breakout is in black, key seats are in red and Slip displacement is in blue (track 6). Image log display the full bore UBI borehole radius image logs oriented to North and before normalization (track 7), stratigraphy, GR and reservoir tops (track 8).

So, this single image log runs as part of the final logging program provided information about the borehole condition at a single point in time, usually too late to have any impact on the current borehole l condition. It is proposed that the acquisition of image logs in multiple stages during the life of a well would bring significant new information and furthermore could in many cases allow some corrective actions to be taken which would benefit both the drilling and the formation evaluation. Wells drilled in this area commonly experience drilling problems. These can occur at various times during the life of a well, however, when they occur during drilling of the reservoir and cap rock sections, then they can be particularly problematic, i.e. due to associated damage to the main producing zones of interest. The acquisition of image log data immediately following completion of the drilling could bring significant benefits. Primarily they would help indicate both the type/cause of the problems and where the problem is most severe. As a result, remedial actions to minimize or cure the problem could then be taken. For example the continuous logs of hole shape deformation and the selected borehole cross-sections shown previously can be prepared and provided along with a quick look report within a short time.

The outputs of this interpretation are (1) location and orientation of drilling and natural fractures, therefore the in-situ stress direction; (2) location and orientation of structural boundaries



First stage of shear failure at 4098.3-4098.75m (around SE and NW sides of the borehole), marked by shear fractures, which lead to formation of borehole breakouts. Second stage of shear failure leading to little bigger borehole breakouts is indicated around 4099.6m. The high angle induced shear fractures at 4098.3-4098.75m possibly indicate that the vertical stress is greater than the horizontal stresses at this depth around the location of well MN-297.

Spiral plot from UBI indicates NW-SE oriented σ_{hmin} and NE-SW oriented σ_{Hmax}

Fig. 11. UBI image of the borehole radius showing borehole enlargements (breakouts – black vertical stripes) around NW and SE sides of the borehole. A cross-section at 4058 m of borehole diameter from UBI shows elliptical hole along NW-SE direction (black dots represent 180 borehole radii of the wellbore). Based on which the maximum horizontal stress orientation around the well is NE-SW and minimum horizontal stress orientation is NW-SE.

(faults and unconformities); (3) location and orientation of borehole breakouts, key seats and other damaged zones; (4) interpretation of where the fracture gradient is being exceeded, where rock strength is low; (5) indication of slip displacement, closure and other restrictions in the wellbore; (6) continuous well deviation survey to show doglegs and undulating well trajectory; (7) early indication of an unexpected geological structure, i.e. formation dip.

As a result of the information gained from the detailed analysis of image log it should be possible to undertake corrective measures to mitigate the drilling problems, for example:

3.1.1. *Borehole restrictions*

Are there indications of closure/restriction of the borehole to less than the bit size? If so, then these sections of the hole may be improved by reaming. Also, why is slip displacement and closure occurring, maybe it is due to insufficient mud weights! Slight alteration of mud weight may therefore prevent what can be a major cause of stuck pipe.

Are there any doglegs or undulations in the borehole where there may be excessive mechanical wearing? In addition to the image data that will identify the presence and severity of the mechanical damage, the image log also provides a well deviation survey that can be used to identify aspects of the well trajectory that may be causing the drilling hazard. Compared to the other well deviation surveys image logs well survey is a continuous and high-resolution measurement that will be far more sensitive to any minor irregularities in the well trajectory. Ledges due to interbedded lithologies of different strength can also cause the drill bit and later on the logging tools to become hung-up.

3.1.2. *Optimization of mud weight*

The type of well bore damage identified by these images will help to show if the well is being drilled underbalance or overbalance. It may be possible to adjust the drilling mud properties and thereby either reduce any further wellbore damage and/or allow faster drilling rates. The images may show indications of either (1) excessive mud weights, e.g., drilling induced fractures; (2) insufficient mud weights, e.g., borehole breakouts; or (3) a combination of drilling fractures and breakouts may indicate that there has been swabbed and surge, IE that pipe tripping speeds and/or drilling rate needs to be controlled!

By using borehole image provided information on the type of borehole failures, which are used to determine in-situ stress orientations and also the order of stresses.

In the studied well, different stages of shear failure were observed in the rocks exposed to the well. Early stage of shear failure in the form of shear fractures, possibly indicates that at depths around 4099.5 m, the vertical stress was greater than the horizontal stresses (Fig. 11). Borehole images show type of borehole failure taken place in the well. The observations can be used to optimize drilling parameters for future wells to be drilled in that field. The acoustic image indicated borehole breakouts over most of the interval in well MN-297, which is an indication that the mud weight used for drilling this well was lower than the required one.

3.1.3. *Efficient use of lost circulation material*

By finding the losses zone, you can recognize, then (1) more efficient placement of lost circulation slugs/pills; and (2) more careful drilling practices in these intervals, e.g. avoid circulation, slower tripping speeds.

3.1.4. *Alteration to well trajectory*

The UBI provides a continuous high resolution well deviation survey that will show if there are subtle doglegs and undulations in the well trajectory that may be causing drilling problems. This information will also show the relative direction of the well to the in-situ stresses and to the natural fracture systems. The relative orientation of the well deviation to the local in-situ stress and to the system of natural fractures and faults can have a very large impact on the drilling efficiency and wellbore stability. Wells drilled in the direction of the maximum horizontal stress will be affected differently to t wells drilled in the direction of minimum horizontal stress. In areas subject to high compression horizontal stress there can be a tendency for micro-slippage to occur along pre-existing and laterally extensive planes of weakness, e.g. faults and fractures. The structural geology of the studied area suggests that this type of borehole failure has a high likelihood of being developed in this area. The most likely type of borehole cross-section in these conditions is a reverse movement along the dip plane of an existing fracture (Fig. 12).

In Fig. 13, asymmetrical borehole wall damage resulting from mechanical wearing related to reaming and pipe rotation. Note how reaming causes a wide depression, whereas pipe wear causes a cyst groove (5 in. wide). The UBI cross-section provides the depth and width of the effect as well as its position on the borehole wall relative to North and/or top-of-hole. It shows how reaming causes a wide depression, whereas pipe wear causes a key seat groove (5 in. wide) (Fig. 13). Therefore, the UBI cross-section provides the depth and width of the effect as well as its position on the borehole wall relative to North and/or top-of-hole.

3.2. *Solution 2: time lapse imaging*

Geological image logs are usually acquired at a final stage of the logging programmed. This may often be a number of days after the initial first stage image log was run. By comparing the data from the various image log passes, then a range of new and very significant information could be obtained.

3.2.1. *Borehole stability*

Has there been any significant change in the condition of the well over the hours and days since the first log was made? Has the fracture count changed and has there been any change in the appearance/size of the natural features? Has borehole breakout developed or become more severe? For example, are there any indications that detached blocks and carvings have started falling into the borehole?

3.2.2. *Fracture characterization*

Time-lapse images will help to show which type of fractures is present. (1) Major natural open fractures: Some changes in apparent fracture width due to the effects of fluid movement can be expected. (2) Minor natural open fractures: No significant change in apparent fracture width. (3) Drilling induced fractures: Some changes in the apparent fracture width, either wider or narrower! Also extension of the fracture length, note that these fractures are usually aligned near parallel to the borehole axis and form discontinuous features. (4) Drilling enhanced fractures: Where the original natural fractures are extended/split to form a hybrid type of feature consisting of an assemblage of both natural and drilling fractures.

Production changes with respect to fracture orientation have also been noted in the carbonate reservoirs. As well as fracture orientation with respect to the well the other important fracture attribute that plays a big part in their permeability to drilling fluid is their apparent angle in the borehole. In general, there is a higher vertical permeability when a single set of high-angle fractures is encountered. Oil production is better with a mixed orientation of fractures (El Wazeer et al., 1990).

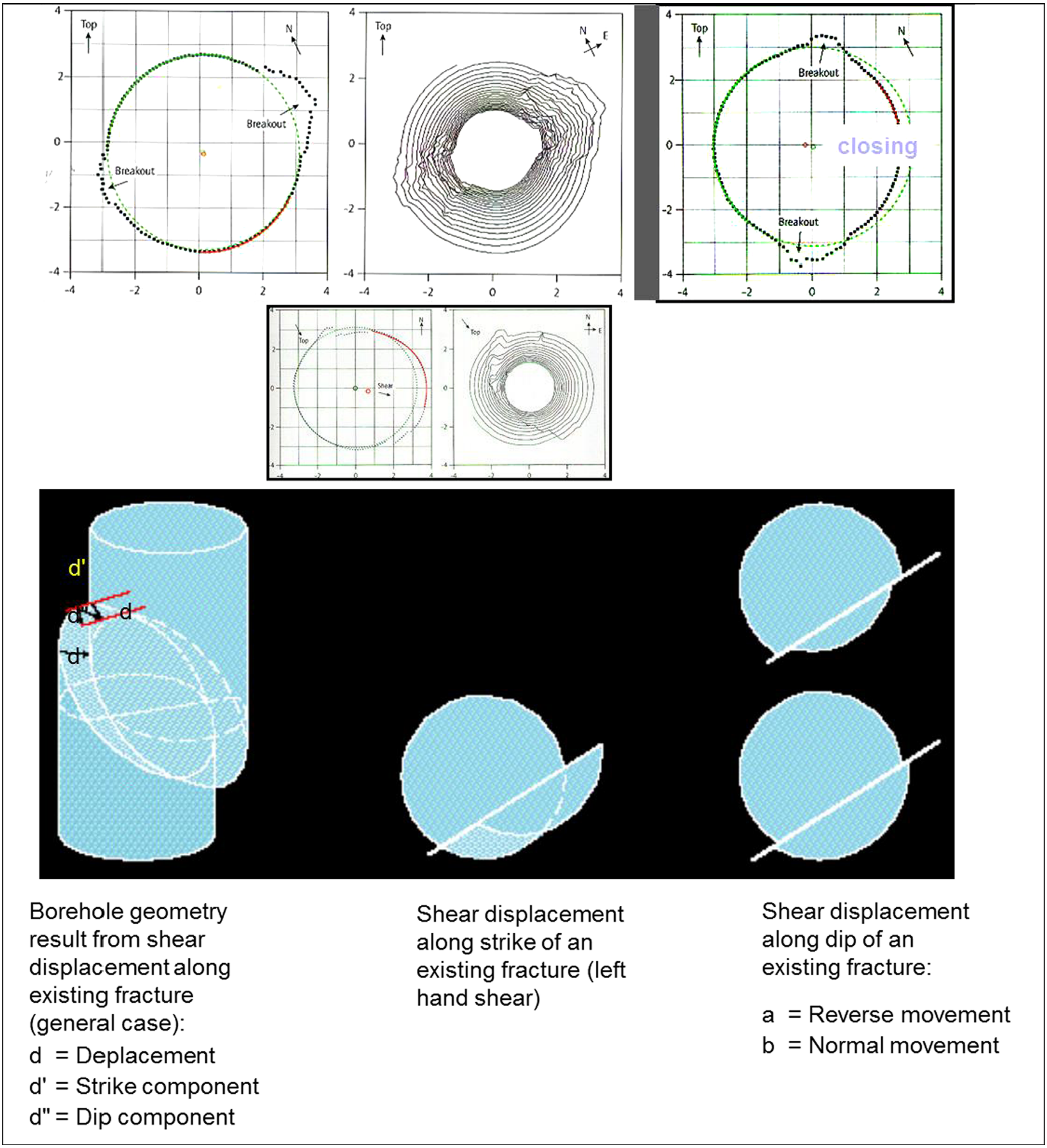


Fig. 12. Composite plot of calipers, logs, and borehole breakout azimuth and magnitude derived from the acoustic image analysis. On the average, the orientation of elongated borehole breakouts is E–W, which indicates E–W orientation for the minimum horizontal stress and N–S for the maximum horizontal stress orientation.

Low angle fractures will not generally be as permeable as high angle fractures are, because low-angle fractures recorded in the field are generally closed and filledwith calcite and quartz. The low-angle fractures, which are generally filled with either calcite or quartz, have apertures between 5 mm and 10 mm (Akbar, 1993). The relation between natural fractures and drilling fractures will also be clearer. Where they are both in the same direction, i.e. geological stress direction was the same as the present-day stress direction, and then it may be more likely that there will be enhanced and slip displacement along the natural fracture planes that can lead to drilling problems. Natural fractures with a direction that is different to the present-day stress may be more stable.

3.2.3. *Pressure and fluid sampling points*

Pressure and fluid sampling points should be visible in the final full-bore images, but it is absent on the stage 1 images.

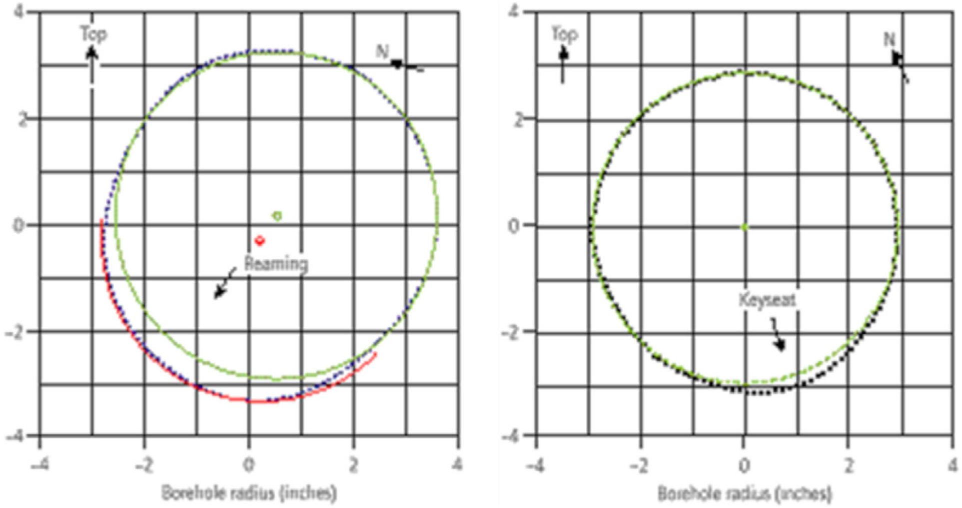


Fig. 13. Asymmetrical borehole wall damage resulting from mechanical wearing related to reaming and pipe rotation.

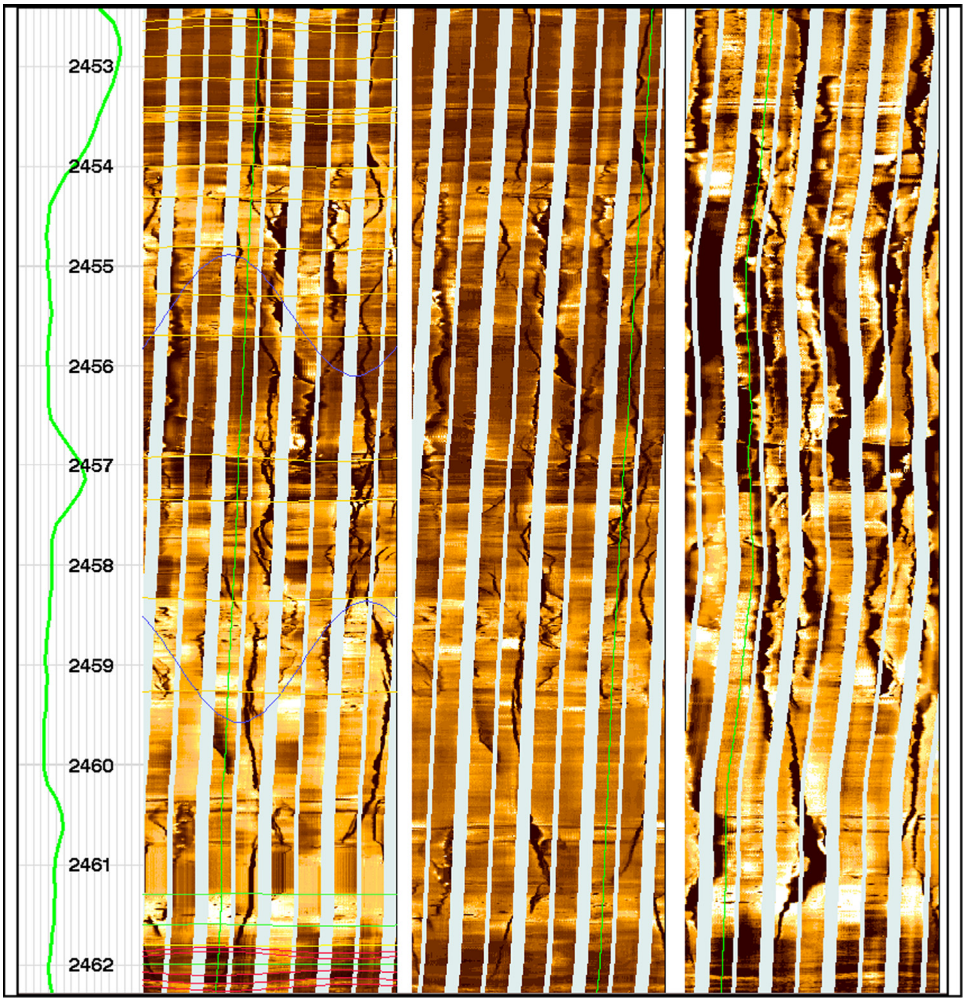


Fig. 14. FMI images acquired over a period of 7 days, the increase in aperture of drilling fractures and the development and/or enlargement of borehole breakouts (left to right).

3.2.4. Fluid movement

Large induced fractures perpendicular to the direction of borehole enlargement is usually long straight cracks in an axial position lying on opposite sides of the borehole. These induced cracks are extensional fractures which form and are propagated in front of the bit during drilling. Axial drilling induced fractures have a modified appearance when the axis of the borehole is not parallel to any of the principal stress directions. This kind of crack has a jagged appearance, resembling a lightning bolt, in contrast to the long and straight cracks which are perfectly parallel to the axis of the borehole (Fig. 14). Such cracks are more common in horizontal or highly deviated wells where the orientation of the borehole with respect to the stress field was not accounted for in positioning the well (Akbar, 1993). Recognizing and analyzing induced fractures is valuable in determining the orientation of the principal horizontal stress, which may vary within a reservoir. Either invasion of the borehole fluids or influx of the formation fluids into the well may be indicated! Both these effects are likely to alter the acoustic amplitude log response. A comparison between the minimum, median and maximum amplitude curves of the different image log passes should highlight where any changes have occurred. In this example, geological image logs were acquired over a time period of 7 days and provided valuable information to help decide on the appropriate well completion strategy. The data from three separate logging runs made over the same depth interval but after a time delay of many days were compared and clearly show the deterioration in well condition with time after drilling. They also show the behavior of both natural and drilling fractures with time as the borehole is left open. The influence of the present day in-situ stresses on the natural tectonic structures can be studied with such data. So, repeat logging of special processed wells has shown that borehole failure and breakouts occur within days of drilling (Fig. 14). In addition image logs acquired following MDT pressure tests can show the probe marks and thereby confirm the exact position of the station measurements.

4. Conclusion

Improved information about the well condition will enable lost circulation to be minimized therefore cutting the drilling mud costs and reducing the volumes of lost circulation material that are required. The type of well bore damage identified by these images will help to show if the well is being drilled underbalance or overbalance. It may be possible to adjust the drilling mud properties and thereby either reduce any further wellbore damage and/or allow faster drilling rates. Better borehole conditions produce higher drilling efficiency and fewer days to complete the wall. It may help to avoid sticking pipe and fishing trips to retrieve tools left down the hole. It will also ensure better log data quality and therefore a more accurate formation evaluation.

5. Recommendation

These logs are usually made as a final stage of the logging programmed, often many days after the drilling process has been completed, following wiper trips and drilling mud conditioning. However to gain the maximum benefit from the UBI caliper data it is here suggested that the log be run stand-alone either at an intermediate the drilling stage or at the latest then immediately following drilling. When the first run image log is compared to the final geological logs acquired days later then new information relating to wellbore stability, fracture type/origin will be obtained. Changes in the well condition during the time will be visible for fractures opening or closing, borehole breakout development, type and direction of drilling fractures.

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