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Recognizing Horizontal Stress Orientation for Optimizing Well Placement and Well Completion Jobs

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Summary

Knowledge of horizontal stress orientation can be utilized for addressing issues related to wellbore stability in any fault regime. Inclined wells drilled in the direction of minimum horizontal stress tend to be more stable in a normally faulted basin compared to those drilled in any other directions. Further, they also have the advantage of cutting through the natural fractures as these fractures tend to align themselves with the direction of maximum horizontal stress. On the contrary, inclined and horizontal wells drilled in the direction of maximum horizontal stress are likely to be more stable in a strike-slip fault regime or thrust fault regime. Well stimulation jobs like hydro- fracturing are preferred in the direction of maximum horizontal stress as all the induced fractures eventually tend to align themselves in this direction and fracturing in other directions will unnecessarily increase the tortuosity. Likewise, in unconsolidated sand reservoirs, initiation of sanding starts in the direction of minimum horizontal stress and hence if the perforations are carried out in the direction of maximum horizontal stress only (oriented perforation), the problem can be postponed for some time. We can therefore say that knowledge of the orientation of horizontal stresses is not only important for well planning, it is equally important for well completion.

The direction of horizontal stresses can be located with the help of some of the logging tools like 4-arm caliper, formation imaging tool and dipole shear sonic tool recorded in cross-dipole mode. In this paper we propose to exhibit all these methods to firm up the direction of horizontal stresses in a couple of fields operated by ONGC so that future strategy regarding the trajectories of upcoming wells can be drawn. The information will be also useful when well stimulation activity like hydro-fracturing is considered.

Keywords: *Importance of Horizontal Stress Orientation*

Introduction

Earth is a stressful place and the sub-surface too is equally stressful. The weight of the ever-depositing sediments increases the over-burden and since the rocks are not allowed to expand laterally because of confinement, there arises a strain in lateral direction which gives rise to horizontal stresses. If there is no post-deposition tectonic activity in the basin, the over-burden is the only reason for the horizontal stresses and the basin is known as normally faulted. However, if there occurs some post-depositional tectonic activity in the basin, a tectonic factor will get added to the horizontal stresses and depending on how big is this factor, the basin may either undergo strike-slip faulting or reverse faulting. In both the cases the compressional force is large enough to exceed the over- burden. If the overburden happens to be the intermediate stress and the maximum and the minimum horizontal stresses are the largest and the smallest respectively then the fault system will be strike-slip and if both the horizontal stresses surpass the overburden then the fault system will be reverse or thrust.

Before undertaking any drilling activity in any area it is prudent to know the prevalent fault system as well as the magnitude and direction of stress tensors. For example, in a normally faulted basin a vertical well requires the least mud weight from wellbore stability point of view whereas in a strike-slip or reversed fault regime an inclined or horizontal well in a preferred direction will have the least mud weight requirement. Further, the knowledge of the magnitude of these stresses enables us to estimate the hoop stress acting on the periphery of the wellbore so that

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one can predict whether the rock with a given strength and given mud weight will fail or not. Besides magnitude, the direction of horizontal stresses becomes all the more important when we plan to drill deviated and horizontal wells. In a normally faulted basin, the preferred well azimuth is the orientation of minimum horizontal stress whereas in strike-slip or thrust fault basin the preferred direction is that of maximum horizontal stress. In this work we will limit our study to the direction of horizontal stresses.

In cases of stress related anisotropy if the rock is not drilled with appropriate mud weight, breakouts starts appearing in the direction of minimum horizontal stress direction where the compressive hoop stress is maximum. We can also see drilling induced fractures in the maximum horizontal stress direction in which case the hoop stress becomes negative and the rock fails in tension. Both these phenomenon can be very well seen on an image log. The directions of these activities can also be located on the image log as these tools are always run with inbuilt navigational package. A simple 4-arm caliper with navigational tool can also indicate breakouts leading to the direction of minimum horizontal stress. These breakouts and drilling induced fractures may not, however, appear in all circumstances and depending on the used mud weight, differential stress magnitude and the rock strength, they may fail to appear on the image log or caliper log even though the stress anisotropy exists. In that case shear sonic recoded in cross-dipole mode is the most trusted way to know the direction. Even the nature of anisotropy (whether due to fracture network or stress difference or thin bed laminations) can also be established with this tool with the help of frequency dispersion plots. The processed data from the tool gives the fast shear azimuth which in case of stress anisotropy is nothing but the maximum horizontal stress azimuth.

Method & Examples

We will now elaborate the ways discussed above with suitable examples from fields operated by ONGC.

1. Breakouts and Drilling Induced Fractures on Image Logs:

Image logs like UBI or FMI or STAR can be recorded to see breakouts or drilling induced fractures. The breakouts are seen as conductive out of focus zones on the image logs as depicted in Fig-1. They appear on the opposite pads which are 180 deg apart. As the azimuth of Pad1 (reference pad) is known, the orientation of the breakout can be established. The direction of breakouts in this figure is 50/230 deg, which also is the direction of minimum horizontal stress.

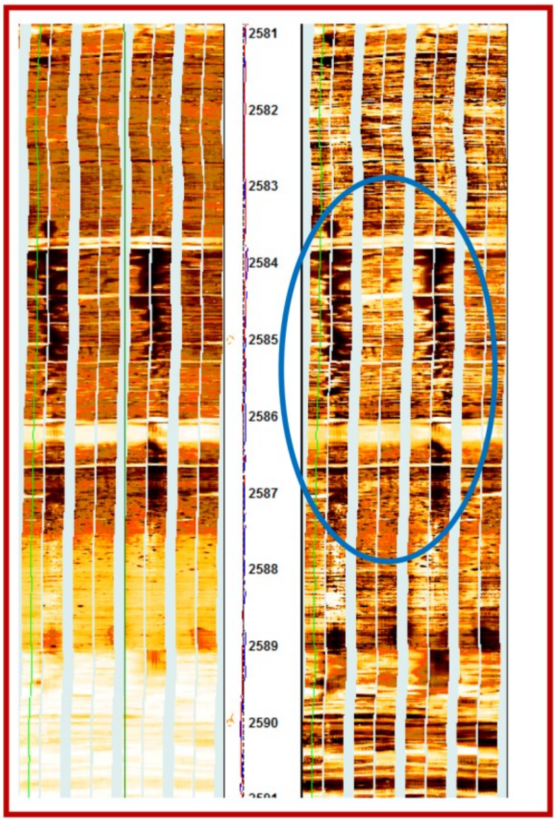

Fig-1: Breakouts on resistivity image log

In vertical wells, drilling induced fractures appear as vertical dark lines on two opposite pads, as shown in Fig-2. These fractures remain confined to wellbore wall only. Natural fractures can be distinguished from induced fractures keeping in mind that natural fractures appear on all the pads as a sinusoid whereas induced fractures appear only on two opposite pads. Like in case of breakouts, the direction of drilling induced fractures can also be established with the knowledge of Pad1 azimuth. The direction of drilling induced fractures in this case is 140/320 deg, which is the direction of maximum horizontal stress. It may be noted here that since both breakouts and drilling induced fractures have been picked up here from the same well, the difference in their orientation is 90 deg.

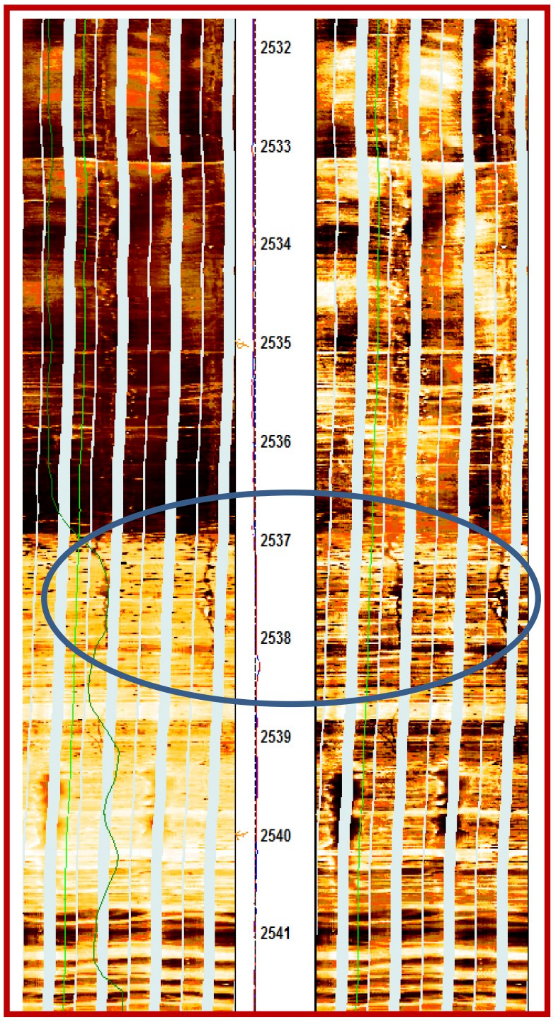

Fig-2: Drilling induced tensile fracture on image log

2. Breakouts on 4-arm caliper:

If we record two calipers in directions orthogonal to each other and if one caliper reads bit size whereas the second one reads more than the bit size then this event can be termed as a breakout provided the following conditions are broadly met:

- The tool rotation should stop in the breakout zone (can be checked from Pad1 azimuth curve or relative bearing curve). This is because the larger caliper falls in the breakout groove and does not allow the tool to rotate. If however the tool motion is not arrested then it may be a hole enlargement (washout) or key-seat, and not necessarily a breakout.
- The smaller caliper should be larger than or equal to the bit size. If it is larger, then it should not exceed 1.1 times the bit size.
- If the smaller caliper is larger than bit size (within the above prescribed limit), it should show less variations than the larger caliper.
- Both the calipers should be at least 5% different from each other.
- Length of breakout zone should be larger than at least half a meter.

Keeping these conditions in mind the breakout zones can be picked up from the caliper log (Fig-3) and its azimuth

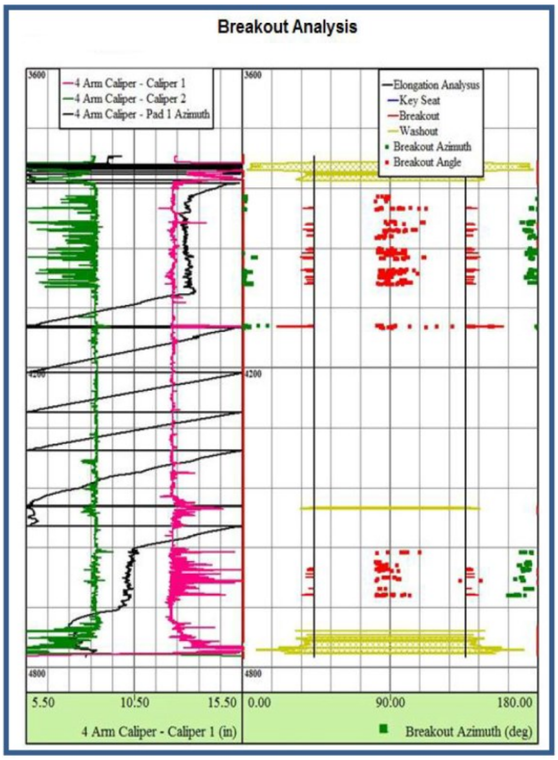

Fig-3: Breakout analysis from 4-arm caliper

can be plotted as a rose plot (Fig-4). As can be seen in Fig3, the tool rotation is arrested in the breakout zones (Pad1 azimuth is constant) in the bottom and top section. This example is from deep-water Andaman block where the minimum stress direction is established as N-S on the basis of breakout analysis (Fig-4).

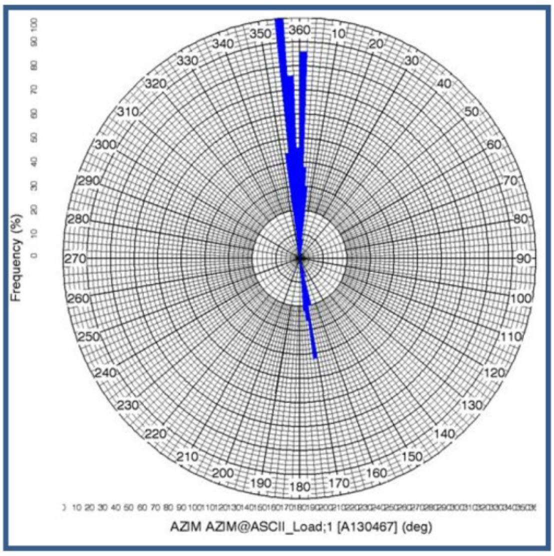

Fig-4: Rose plot for azimuth

Another example (Fig-5) is from a Mumbai Offshore field where the minimum stress direction is seen as 138 deg on the caliper breakout.

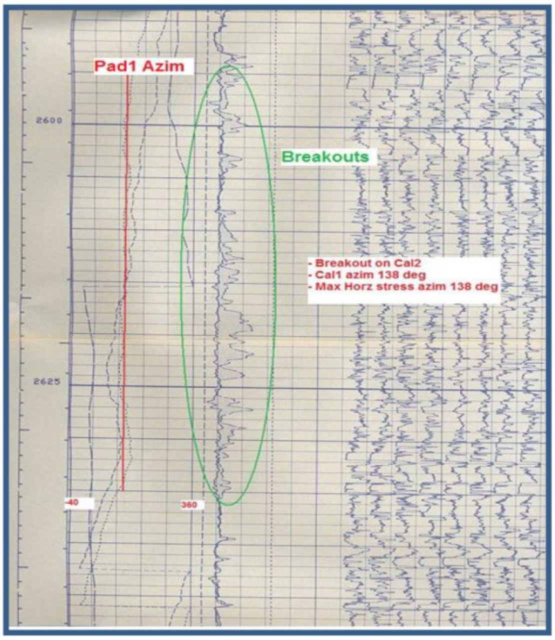

Fig-5: Breakouts seen on 4-arm caliper log

3. Fast shear azimuth from shear sonic in cross-dipole mode:

Tools like XMAC, DSI or Sonic Scanner respond to stress anisotropy if recorded in cross-dipole mode. When a polarized shear wave (generated by these tools) travels in an anisotropic medium, it splits into two polarized waves (also known as seismic birefringence). One of these waves is faster than the other and oriented parallel to the fractures or cracks if the anisotropy is caused due to presence of fracture network. If, however, the anisotropy is caused due to horizontal stresses, the fast shear wave will be polarized in the direction of maximum horizontal stress. It is may be noted here that in the common tool configuration where the tool axis is vertical and the beds are horizontal (zero dip), anisotropy due to thin beds or due to sand facies will not be picked by the tool. Hence in a vertical well with gentle bed dip the tool will either respond to stress anisotropy or anisotropy due to the presence of fracture network.

In the example shown here (Fig-6) from Mumbai offshore, the presence of any fracture network is ruled out, as the image log of this well does not indicate any. Therefore the anisotropy present in this case is due to horizontal stress differential and the fast shear azimuth is essentially the azimuth of maximum horizontal stress. The azimuth in this case is 320 deg.

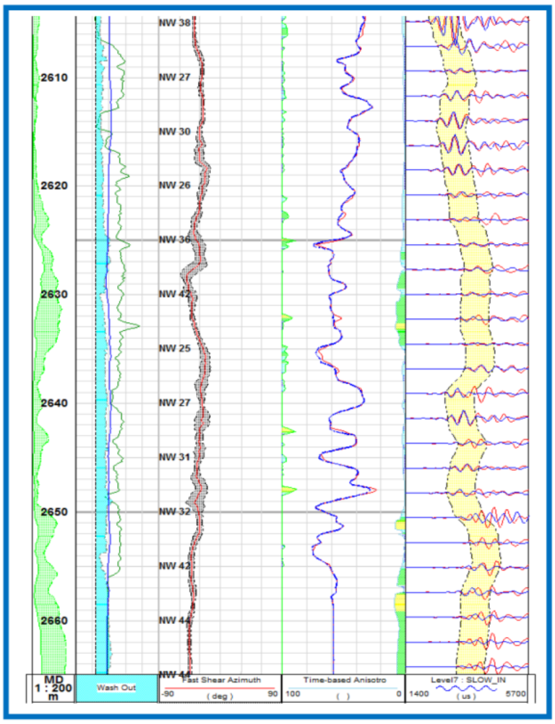

Fig-6: Shear log in cross-dipole mode showing anisotropy and fast shear azimuth

Conclusion

As horizontal stress orientation is an important parameter for trouble-free well placement, optimum hydro-fracturing jobs and sand avoidance completions with oriented perforations, a precise measurement of the same can be successfully achieved through logs like 4-arm caliper, resistivity or ultrasonic images and shear sonic recorded in cross-dipole mode. Such measurements can be planned in the appraisal or offset wells so that the information can be used during the development phase of the field.

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