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Updating the Tectonic Stress Map of Alberta Using Borehole Breakout Method

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Summary

The stress state of a medium is disturbed when a hole is drilled. This leads to stress concentration around the borehole wall, and consequently leads to borehole failures. One of such failures is borehole breakout which occurs along the minimum principal horizontal direction. Since this failure is completely due to stress effect, it provides information about the orientation and magnitude of the minimum horizontal stress in the disturbed medium. This work is part of the Helmholtz Alberta Initiative geothermal project one part of which is focused on updating the Alberta stress map particularly with a longer term view to supporting potential engineered geothermal systems that could provide thermal energy in N. Alberta. Average stress orientation computed from 41 wells shows that the major stress orientation is NW-SE, with some minor trends in NE-SW. Also, it is observed that these orientations vary with borehole depth, when individual wells are considered.

Introduction

The three principal stress directions (figure 1) are the vertical (S_v), and the horizontal maximum (S_H) and minimum (S_h) compressive stresses (Bell and Gough, 1979). These directions are perpendicular to each other, and the knowledge of their orientation and magnitude has proved to be very useful at improving the safety and cost-effectiveness of drilling and hydrocarbon production. Stress anisotropy can result in borehole failures such as keyseats, washouts, and breakouts. Keyseats and washouts provide no information on the stress orientation because they are usually induced by solely mechanical wear or from a combination of both technical and stress concentration at the borehole (Brudy and Kjørholt, 2001). However, borehole breakouts are solely due to stress concentration at the borehole wall and can thus provide information about principal stress orientation.

Breakouts are zones of failure of the borehole wall in response to high compressive tangential stresses. Such failure causes the elongation of initial circular borehole wall in the direction of minimum horizontal principal stress (Brudy and Kjørholt, 2001). Scientists (e.g., Bell et al. 1994) have used the breakout method among other methods to determine the stress orientation and magnitude within Alberta. The purpose of this work is to update the Alberta stress map using new available data.

Theory and/or Method

When a hole is drilled in the earth, the equilibrium stress state is disturbed, resulting in stress concentration around the borehole wall. Analytical solutions for the stress field around a borehole wall that was drilled parallel to a principal stress direction are given by Kirsch (1898) for the case of an elastic and isotropic material and extended by Detournay and Cheng (1988) for a poroelastic, isotropic material. The extension of these solutions to arbitrary borehole orientations for both elastic and poroelastic materials was carried out by Fairhust (1968) and Cui et al. (1996) respectively. High compressive stresses occurs along the minimum horizontal stress direction, while low compressive stresses (sometimes even purely tensile) occurs along the maximum principal horizontal direction. As a result, borehole failures such as breakouts and induced fractures occur.

Borehole breakouts are elongations due to shear failure of the rock (Figure 1a) along the circular borehole wall in the direction of minimum principal horizontal stress. These elongations can be measured by dipmeter tools. In this project, borehole breakout orientations for 41 wells have been computed so far, using WellCad (figure 1b). The Orientation of the breakouts (figure 1b-1) were measured using information from curves such as deviation, hole azimuth, Pad 1 azimuth, and relative bearing. If the deviation angle of a well is less than 9^0, the value of the Pad 1 azimuth curve was used as the orientation of the minimum horizontal stress, if not, the hole azimuth and relative bearing curves were used. The Length of the breakout was also computed as the interval between the beginning and end of the breakout structure.

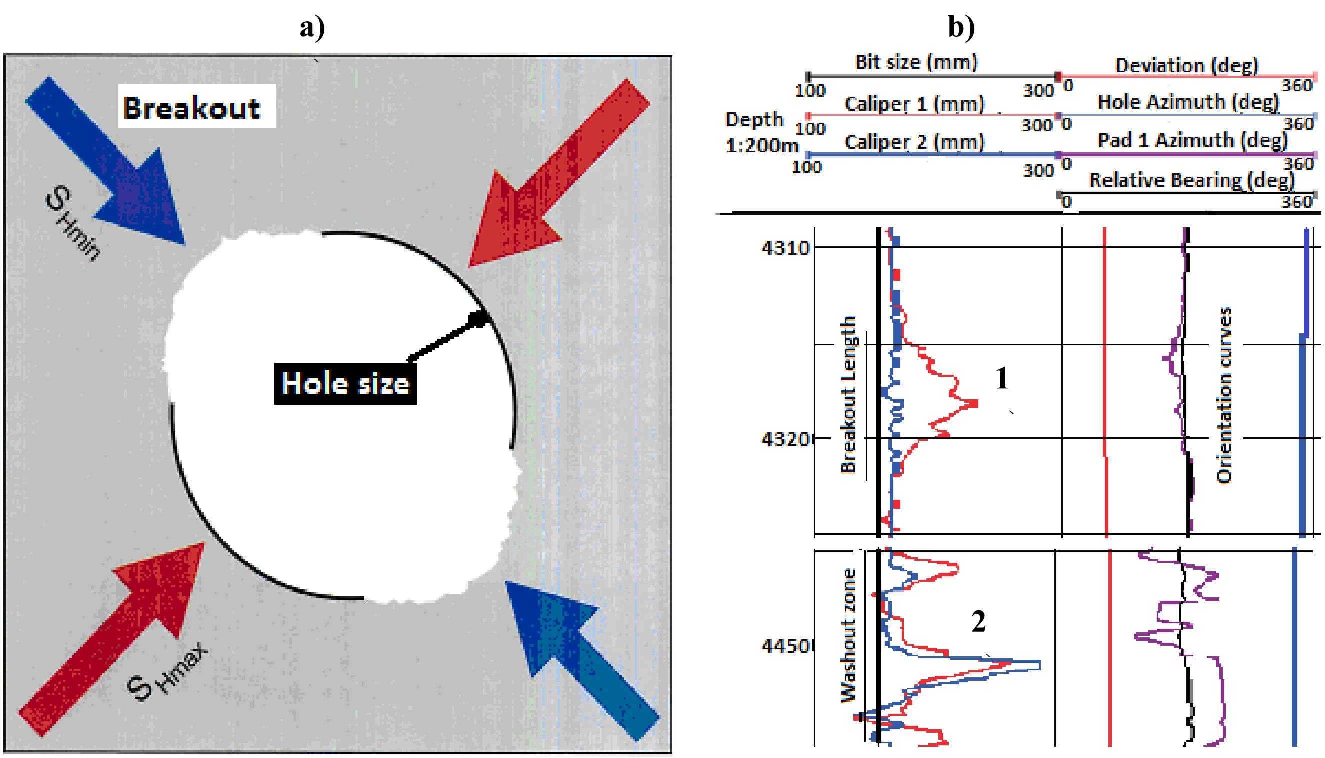

Figure 1: showing a) cross-sections of borehole breakouts along the wall of a wellbore (Bell et al, 1994) . Borehole breakouts occur when the stress concentration around the wellbore exceeds the compressive shear rock strength. The breakout is parallel to the minimum horizontal stress direction b) Typical identification and measurement of borehole breakouts. b-1 gives a good example of a borehole breakout in which caliper 2 diameter measurement is the same as the bit size, while caliper 1 measures the diameter along the elongation direction. b-2 shows borehole failure that looks like a breakout, but in which the two caliper measurements show elongation in two directions. This could be as a result of washout than breakout.

Example

Measurements have been made from 41 wells so far in Alberta. The breakout intervals in the wells range from 1 m to 70 m, and the frequency of their occurrences ranges between 1 and 12. The average breakout orientation for each well was computed and the results were plotted for all the 41 wells. It is observed from the rosette diagram (figure 2) that the average stress orientation for the majority of the wells trend NW-SE, which is in agreement with previous studies (e.g Bell et al, 1994). However, there are some slight variations in some wells in which the orientations trend NE-SW (0^0 to 10^0, and 80^0 to 90^0).

In most of these wells, variations in stress orientation with depth were observed. An example of such variation is observed in well 7-32-89-10W4. In this well, 9 breakout intervals were examined between 1182.3 m and 2143 m. The start depth, length, orientation, and error associated with each interval are seen in Table 1. Also, the orientation plot is seen in figure 2a. The table and figure show two significant stress orientations in NE-SW direction. The high magnitude stress orientation that occurs between 1182.3 m and 1818.84m and the low magnitude stress orientation between 1879.44m and 1922m. This information could give a good indication of changes in tectonic forces in Alberta.

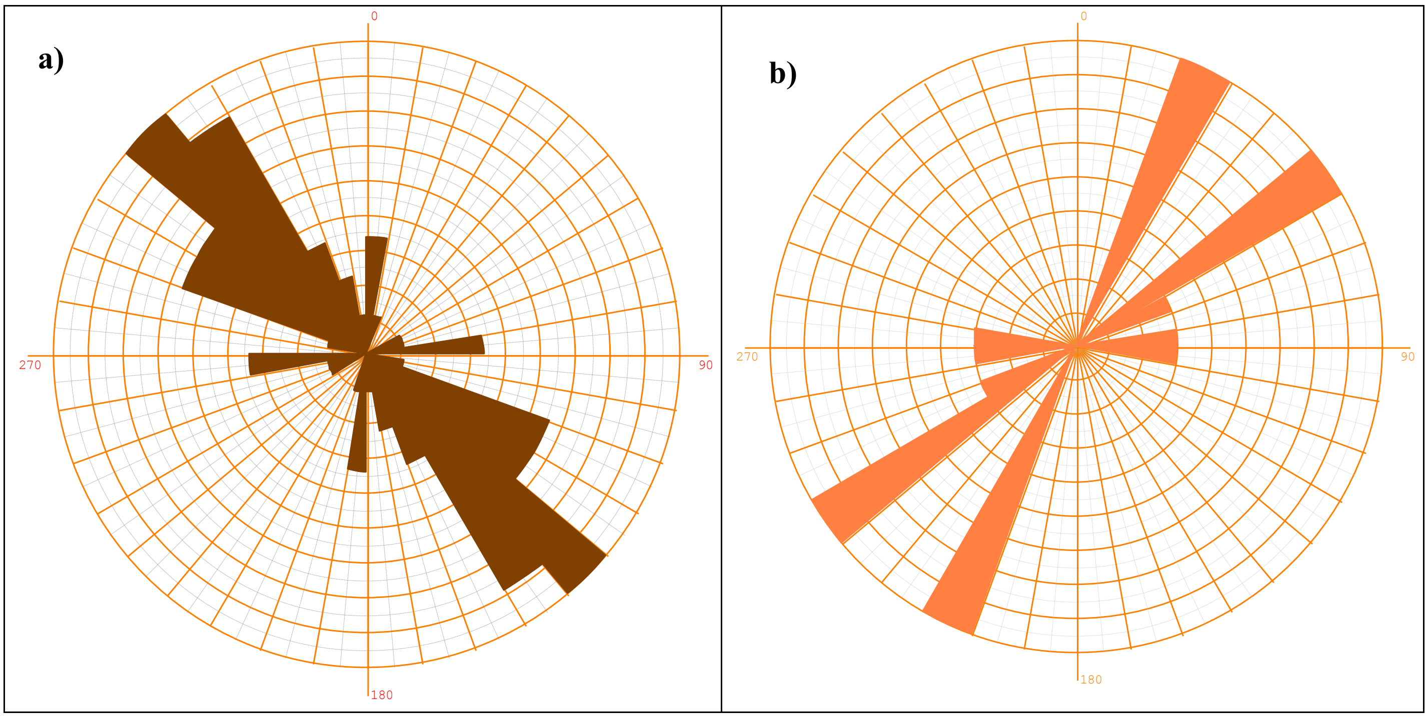

Figure 2: A rosette diagram showing a) the minimum horizontal stress direction (breakout) for all the 41 wells, the dominant stress direction is NW-SE b) the minimum horizontal stress direction for all the breakout intervals in wellbore 7-32-89-10W4; good example for variation in stress orientation with depth.

S.N	Start depth (m)	Length (m)	Aver. Azimuth (deg)	Std. deviation (deg)
1	1182.3	24.8	250.4	24.8
2	1383.4	21.0	279.6	7.8
3	1681.3	7.0	237.7	2.0
4	1818.8	10.0	237.1	2.4
5	1879.4	3.0	209.3	0.3
6	1894.2	6.0	207.7	4.6
7	1912.5	4.0	207.1	1.5
8	1922.0	4.0	205.3	0.7
9	2143.0	2.0	262.4	0.5

Table 1: showing values of depth, length, and orientation of 9 borehole breakout intervals in a wellbore (7-32-89-10W4).

Conclusion

This research is still ongoing, but based on the analysis that have been completed to date, we have been able to confirm that the major trend of the minimum stress orientation in Alberta is NW-SE, and that this orientation varies with depth along the borehole wall.

Acknowledgements

This work would not be possible without access to publicly available data sets through the IHS databases.

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