How to Determine Stress in the Earth from a Borehole: Using Imaging Methods with Some Examples

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David Gray has contributed a great deal to the detection and visualization of seismic anisotropy using azimuthal variations in seismic reflectivity. In many cases, this anisotropy is induced in the rock mass by the prevailing in situ state of stress and, consequently, is one attribute that may tell us about the principal stress directions. This has enormous consequences for the eventual production of fluids as the directions of the anisotropy (and hence stresses) are often related to preferred directions of permeability and degrees of natural fracture sets, and are necessary to optimize the designed production strategy. This presentation approaches the problem more directly by providing some examples of how stresses are determined when we directly interrogate the earth from a borehole with a particular focus on borehole image analysis. Geophysicists rely heavily on visual interpretations of complex data sets and this topic will appeal to our community.

A variety of techniques exist for estimating stresses with the most popular ones being extended leak off testing (mini-fracking), dipole sonic shear wave anisotropy analysis, and borehole wall imaging. All of these techniques rely on the fact that the borehole cavity concentrates the existing natural state of stress in the earth. These stress concentrations are sufficiently intense that the rock will fail in either shear or tension. Indeed, one could argue that drilling and mud engineers spend a substantial fraction of their time trying to prevent or mitigate the failure induced by stress concentrations. That said, the failure patterns themselves reveal a great deal to us about stress directions and, perhaps, magnitudes. The use of borehole ‘elongations’, now usually called borehole breakouts, provides information on stress directions. Failure of the borehole wall rock in shear causes these features that point in the direction of the least compressive stress. Tensational failure of the borehole wall can also occur and these ‘drilling induced tensile fractures’ of which a variety can be found.

The only way to obtain this information is through image logging. High resolution electrical resistivity images of the borehole wall are very popular in industry. These can provide good information but they do not provide full coverage around the circumference of the borehole. Further, the tool employs pads that must touch the borehole wall and sometimes cannot fully touch the rock in zones of high rugosity. Ultrasonic borehole imaging is an alternate method that

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1 Borehole breakout analysis was pioneered in Alberta by Geologist Dr. Sebastian Bell at the Geological Survey of Canada and Geophysicist Prof. Ian Gough at the University of Alberta.
does give full 360° coverage. Various software have been developed to interpret these images although the tools commercially available do not allow for much in the way of additional image processing for enhancement that Geophysicists might desire.

A few examples of different cases of such borehole features encountered in the drilling and research projects I have been involved with will be shown with a tutorial aspect. Examples will come from a deep borehole near Fort McMurray and the Duvernay formation of Alberta. I will combine this with the results of laboratory strength measurements to provide some constraints on stress magnitudes.

It is impossible to provide for such studies their direct commercial value. However, such stress related studies provide important information that can prevent failure of boreholes or assist in the design of more efficient production strategies. Further, having knowledge of the state of stress is perhaps more crucial to industry with regards to the social license to operate. This information should be part of proper due diligence in assessing the risks associated with induced seismicity due to hydraulic fracturing or disposal of waste fluids.