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# Geo-mechanics in Shale-gas Reservoirs: Undoubtedly a Must

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## Summary

Geomechanics plays a critical role in successfully optimizing shale gas exploitation. During the plan of shale gas development one has to understand the essential aspects of geomechanics in such unconventional reservoirs in order to make better operational decisions. What is needed is a unified approach combining theoretical, laboratory (core study) and field aspects of exploring and exploiting shale gas reservoirs.

The geomechanical study of a shale gas reservoir essentially requires the measurement of rock mechanical properties and strength parameters in order to better identify the intervals which can be effectively fractured. This requires measurement of such properties from logs (dynamic) and their calibration with laboratory derived properties on cores (static). In addition, the strength and orientation of in situ earth stresses (overburden and horizontal) are also required to be estimated in order to calculate the fracture pressure and also to orient the well (inclined and horizontal) in a preferred direction for wellbore stability. Pore pressure of shales is another aspect which requires an accurate estimation for effective stress measurement. This parameter also assumes importance from the aspect of wellbore stability and producibilty of the shale gas reservoir. For example, an over-pressured shale section may create wellbore instability problems during drilling because of spalling and splintering but the same may be helpful during the production phase of the reservoir.

A comprehensive hydraulic fracturing model is solicited to be in place before undertaking any fracking job in shale gas reservoir. This may include expected fracture gradient, fracture growth and geometry, fracture height and width, preferred direction and expected barriers. Multiple wireline mini-frac tests and LOT's are encouraged for this purpose.

Finally, shale anisotropy is another important aspect which is to be considered for any shale gas stimulation program. Shales exhibit anisotropic mechanical properties and strength because of presence of clays which are intrinsically anisotropic. This variation in mechanical properties and strength in vertical and horizontal directions was hitherto beyond the scope of measurement of any logging tool until the introduction of sonic scanner. The anisotropic behavior of Poisson's ratio affects the fracture gradient and thus requires modeling of this parameter depending on the trajectory of the well. This is an important aspect while designing for stage fracturing.

At the end, monitoring of the stimulation job with micro-seismic technique is equally important for the assessment of completion strategy and firming up of the critical elements for future jobs.

## Introduction

Well placement and well completion jobs are essentially going to be the major consideration once a decision is taken to drill a well for shale gas exploitation, and geomechanics plays a crucial role in both these activities. Shale-gas wells are often drilled horizontal or high-angled to maximize the reservoir exposure. Given the fact that drilling a normal vertical well itself is difficult in a shale section, it is going to be very problematic to drill a horizontal well unless we have a robust mechanical earth model in place. In a normal or extensional fault regime like Cambay basin, horizontal or high-angled wells drilled in the direction of minimum horizontal stress are likely to remain more stable. However in a compressional or tectonic regime, these wells show more stability when drilled in the direction of maximum horizontal stress. Hence stress direction (which is a component of geomechanics) plays a major role during well placement.

Estimation of pore pressure in shale is another major factor because of two reasons: first, it sets the lower limit of safe mud-weight window for wellbore stability and secondly it is required for the estimation of fracture gradient. Pore pressure in shales is often found high because of poor rate of water expulsion and non-acknowledgement of this fact leads us to drill these sections with lower mud weights which ultimately results into splintering and spalling of wellbore wall. Pore pressure also affects the fracture gradient due to stress coupling and a high pore pressure results into high fracture gradient.

Due to high fracture gradient of shales, it is often required to look for stiffer zones in the lateral section which can be isolated and subjected to hydraulic fracturing. These stiffer zones can be easily identified if we have a measure of Young's modulus in the lateral section. This further entails the necessity of geo-mechanical studies. Additionally, in a normal faulting regime, the preferred fracture plane is vertical and it lies in the direction of next greatest stress which is the maximum horizontal stress. Since the recommended direction of drilling is parallel to the direction of minimum horizontal stress for wellbore stability, the hydraulic fracturing job is also going to be the most effective one with wide and deep penetrating fractures. Hence with the knowledge of stress orientation we can optimize both the well placement and the hydraulic fracturing job.

Thus knowledge of complete stress tensor along with pore pressure, fracture pressure, rock mechanical properties and rock strength are required for planning for wellbore stability, well placement and hydraulic fracturing job in shale-gas reservoirs. Additionally the knowledge of shale anisotropic properties are also required to know the rock mechanical and strength properties with respect to direction so that an anisotropic stress modeling can be done for a better stage fracturing job. This is a relatively new concept in the area of shale gas stimulation job.

## Discussions

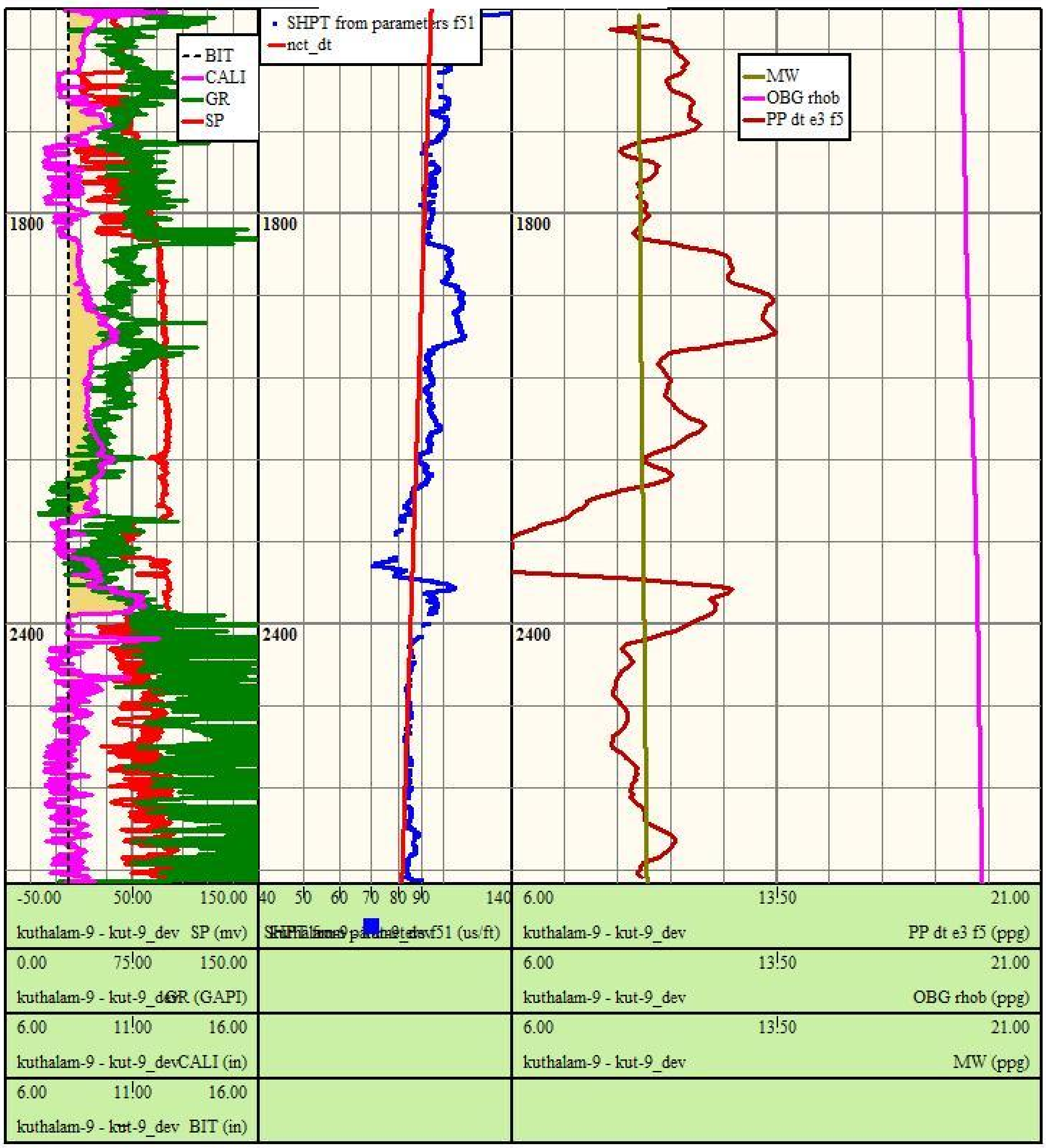
There are a number of important critical parameters which need to be worked out for creating a robust geomechnical model for a shale gas reservoir. A few amongst them are: Young's modulus (for brittleness), Poisson's ratio (for fracture gradient), pore pressure (for effective stress, wellbore stability and reservoir producibility), stress orientation (for well placement and fracture job optimization) and shale anisotropic properties (for optimization of stage fracturing design). All these properties can be estimated for logs, however they need calibration from laboratory measurements. The elastic and strength properties of the rocks computed from logs are essentially dynamic and they need to be calibrated from laboratory generated results for any engineering application. Similarly the fracture gradient from logs is required to be calibrated either with LOT's or with the results of mini-frac tests done on wireline.

Shale pore pressures can be easily estimated with the help of compaction trends seen on acoustic logs. This method works for thick monotonous shales which we expect in cases of shale gas. Shales often exhibit high pore pressure due to extremely slow rate of water expulsion compared to the rate of sedimentation, resulting into excess water trapped in the pores. On the other hand, as shales are impervious, even drilling them with a mud-weight less than their pore pressure does not lead to any well kick or blowout. This often results into oblivious under-balanced drilling of the shale sections. However, drilling a shale section in under-balanced conditions may lead to severe wellbore instability problems. In such cases, a zone of tensile radial stress will exist near the wellbore and if this stress exceeds the tensile strength of the rock (which is often very small for sedimentary rocks compared to their compressive strength), spalling will occur. Over-pressured shales will also create splinters when crushed under a drill bit. These spalling and splintering of shales will lead to enlarged wellbore and may also result into stuck pipe due to hole pack off. Thus prior estimation of shale pore pressure is important from wellbore stability point of view.

Rock mechanical properties and rock strength can be estimated from logs if we have rock compressional velocity, rock shear velocity and rock density in place. These parameters can be had from a dipole sonic log and density log. However, as mentioned earlier, these properties are essentially dynamic and need calibration with static measurements for any engineering application.

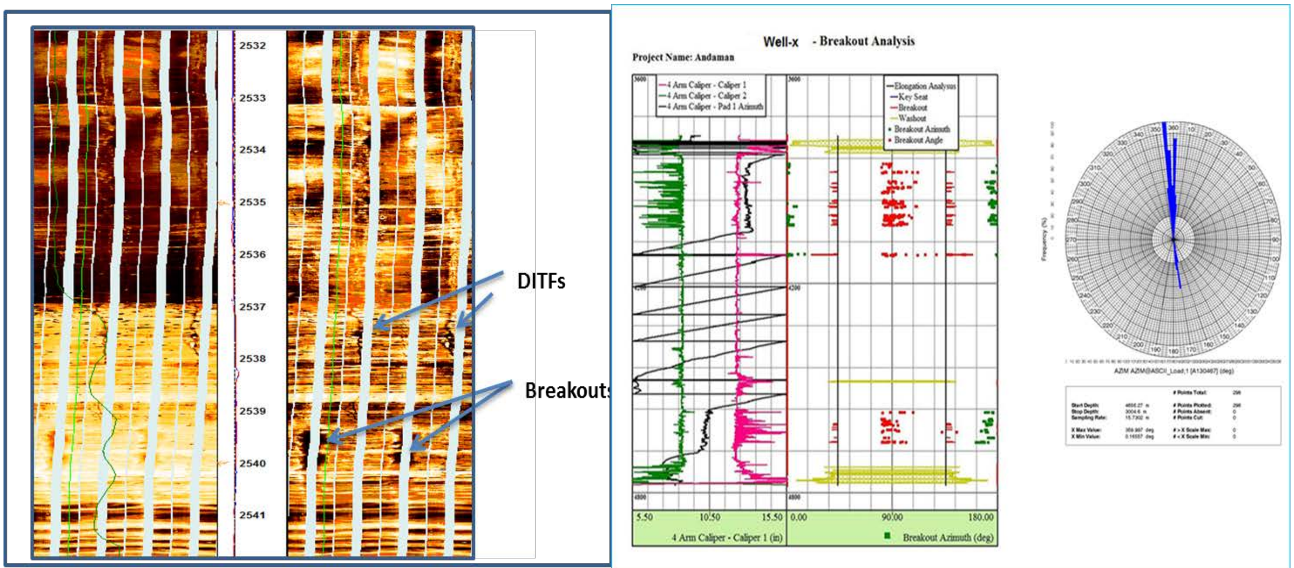
**Fig-1**

## Pore Pressure in Shales




Estimation of magnitude and direction of earth stresses is yet another important aspect of geomechanics of shale gas. In normal faulted basins with insignificant tectonic movements, the earth stresses may not play an important role for wellbore stability and well placement, provided the wells are vertical and difference between the two principal horizontal stresses are not very large. However, drilling an inclined or horizontal well in such situations will demand a higher mud-weight and that will also depend on the direction of the well. 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. Thus it is all the more important to know the orientation of horizontal stresses to optimize the well placement job.

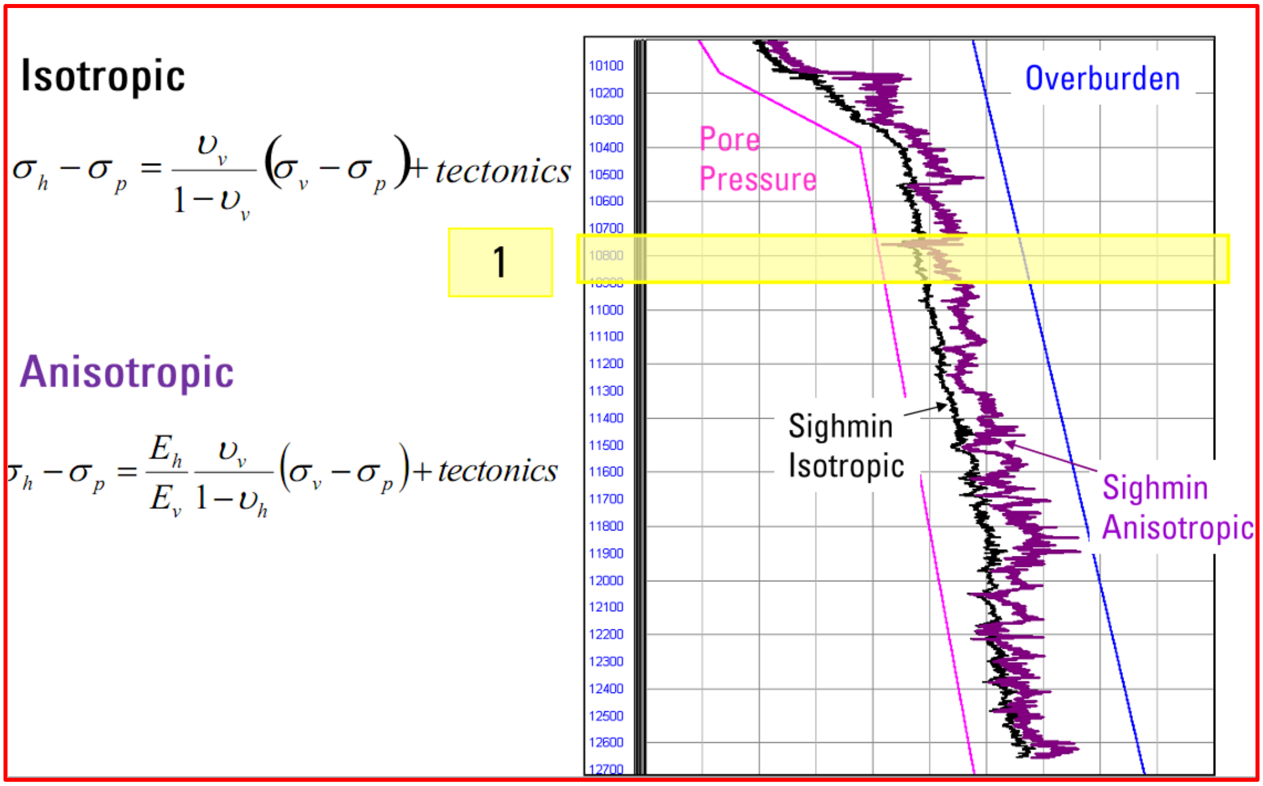
The orientation of horizontal stresses can be estimated with the help of some of the logging tools like 4-arm caliper, formation resistivity or acoustic imaging tool and dipole shear sonic tool recorded in cross-dipole mode. The 4-arm caliper with navigational package gives the direction of breakouts which occurs in minimum horizontal stress direction. The formation resistivity or acoustic imaging tools indication the breakout zones or drilling-induced fracture zones with their directions, thus indicating the orientation of minimum / maximum stress direction. The dipole sonic when recorded in cross-dipole mode gives the azimuth of fast shear in case of stress anisotropy, thus providing the direction of maximum horizontal stress.

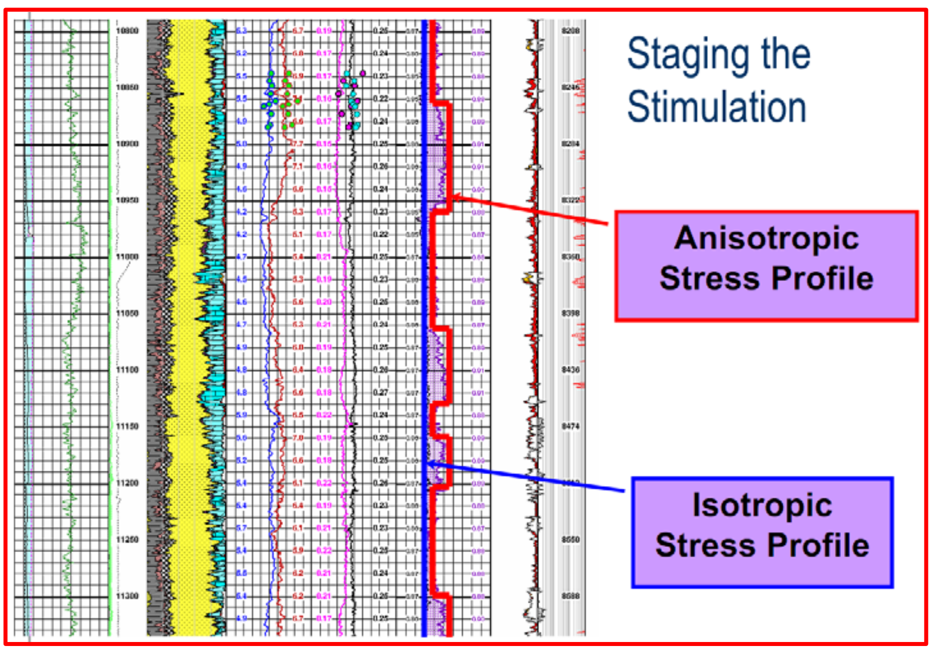



**FMI images and 4-arm caliper showing breakouts and DITFs**

Estimation of magnitude of earth stresses can also be done with the help of logs. The estimation of overburden is comparatively straightforward and simply needs the integration of density log. The minimum horizontal stress can be estimated provided we have already estimated overburden, pore pressure and Poisson's ratio. Application of Eaton's transform can give a fairly good estimate of this stress gradient although it is highly recommended to calibrate it either with available LOT's or with wireline minifrac test results. Estimation of maximum horizontal stress gradient is not straightforward and it can only be done by modeling of observed well failures.

The most important of all is the anisotropic stress modeling for improved completion design. This modeling is particularly important if stage fracturing is envisaged. The model can be built on sonic scanner information but the anisotropic rock mechanical properties need calibration from laboratory derived anisotropic properties wherein they are derived not only by axial loading of the core plug but also by loading the plug with different rotations measuring the properties. A comparison of fracture gradient considering isotropic modeling and anisotropic modeling is shown in figure below (courtesy Schlumberger). The perforation and staging strategy may change if anisotropic stress model is considered over isotropic one.




**Shale anisotropy and staging design (Figures courtesy Schlumberger)**

## Conclusions

A comprehensive geomechanical study comprising of magnitude and orientation of earth stresses, pore pressure and rock mechanical properties and strength (both isotropic and anisotropic) along with laboratory support is essential for effective well placement and well completion jobs in a shale gas reservoir. A precise estimation of these calibrated properties is possible from the logs, thus giving us a continuous measurement.

## References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