Seismic Method to Mapping Geomechanical Properties

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Summary

A workflow is examined which takes laboratory geomechanical tests to help calibrate seismic interpretation of structure and elastic properties.

Introduction

Interpreting seismic data for geomechanical applications in unconventional reservoirs is normally a function of mapping Young's modulus (E) and/or Poisson's ratio (v). In doing this, there is an inherent assumption relating reservoir elastic properties to their failure properties. A popular relationship was proposed by Rickman (2008) which combines both E and v to assess brittleness of reservoir rock. Although quite useful there is often no calibration to substantiate the brittleness claims of 1) linearity with both E and v, 2) insensitive to in-situ stress conditions and 3) independent of rock fabric or fractures.

In this workflow, laboratory data is used to construct a brittleness index (BI) relating the increase in permeability associated with increases in BI. Finally, a correlation is found to establish a relationship between seismic attributes and BI. In conjunction with a general understanding of subsurface variations through fault mapping and inferring stress anisotropy from AVAZ anomalies seismic can be used to highgrade potential drilling locaitons.

Theory and/or Method

A model of rock failure is needed in order to determine what geomechanical tests should be performed. The Mohr-Coulomb theory for rock failure is a relatively standard and simple model that has applications to many different disciplines and is suitable for seismic petroleum geomechanics purposes. The model describes the conditions under which a material will exhibit both shear and tensile failure as a function of the material strength and confining stress.

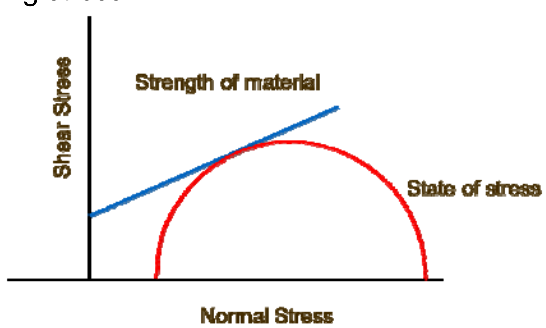

Figure 1. Mohr Coulomb space relating stress to material strength and failure conditions.

Laboratory testing performed is designed to determine the material strength. Geophysicists can then correlate strength data to elastic (E and v) or reservoir properties (porosity ϕ, Vclay, etc) so as to infer geomechancial parameters from seismic attributes.

Plugs are taken from core over different reservoir intervals of interest to perform geomechanical tests. The basic strength test measures the unconfined compressive strength (UCS) - a sample is uniaxially stressed until failure. The stress at failure is known as the UCS. The same experiment with the sample confined at different stresses in the transverse direction demonstrates a confining stress dependency on material strength. In addition, higher confining stresses changes the manner in which the materials fail. In the context of seismic applications this would correspond to the brittle to ductile transition. Ductile materials should exhibit lower BI values.

Stress strain experiments also yield static values of elastic properties. Compressional and shear ultrasonic velocities at different confining pressures allow for a dynamic to static correlation of velocities. Ultrasonic velocities measured at different orientations also can detect presence of reservoir elastic anisotropy.

In this workflow, instead of using Rickman's brittleness index ($BI_{rickman}$) a brittleness index (BI_{strain}) derived from the ratio of elastic strain to total strain (elastic plus plastic) before failure is used as per Holt et al. (2011). For each interval within the reservoir a BI is calculated to be used in subsequent seismic mapping.

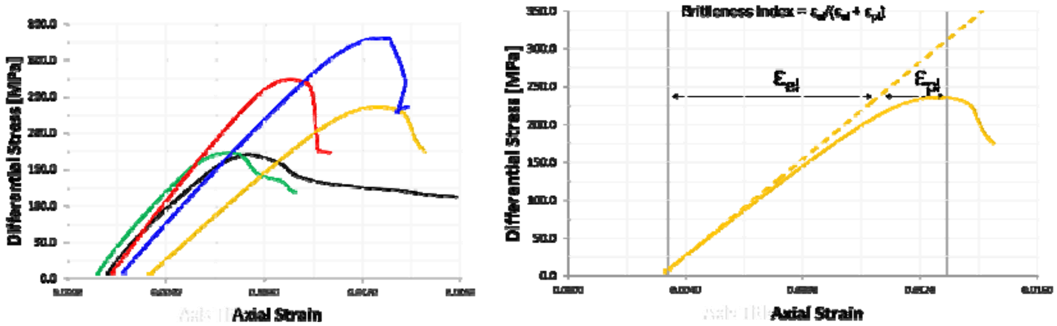

Figure 2. Stress strain plots (left) for different reservoir intervals and brittleness index calculcation (right).

Examples

Lower Manville core plugs are taken and subjected to the aforementioned geomechanical experiments. The results lead to the following empirical trends relating mineralogical trends to stress dependent velocity and corresponding permeability variation.

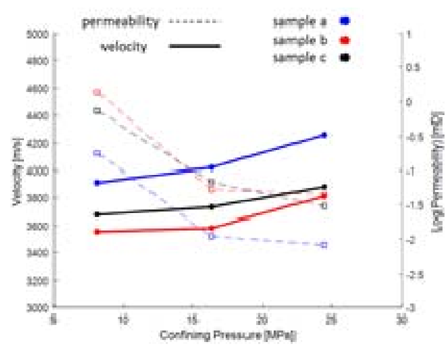

Figure 3. Velocity and permeability variation as a function of confining stress.

Unsurprisingly, increasing confining stress increases compressional velocity and decrease permeability. What is instructive is the decrease in permeability by two orders of magnitude.

Pre and post failure air permeability measurements are also conducted as a method to qualitatively determine if brittleness index does correlate to enhanced permeability upon hydraulic stimulation. As expected, a correlation between UCS, volume of quartz and brittleness index is present. Interestingly, the nonlinearity between the parameters makes data acquisition and parameter estimation very important. A UCS difference of 75 leads to a large difference in permeability.

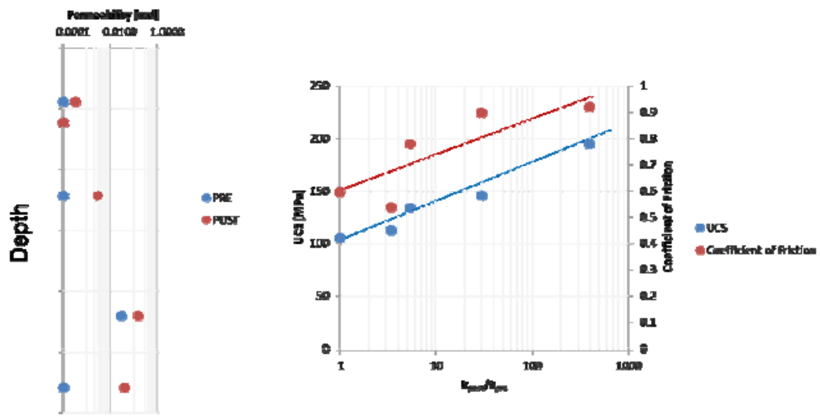

Figure 4. Relationship between permeability increase between pre and post failure and UCS and coefficient of friction.

The correlation between volume of quartz and permeability increase is then exploited by integrating inverted seismic data with a rock physics template to estimate map variations in stimulation efficiency, as determined by pre to post frac permeabiltiy increase.

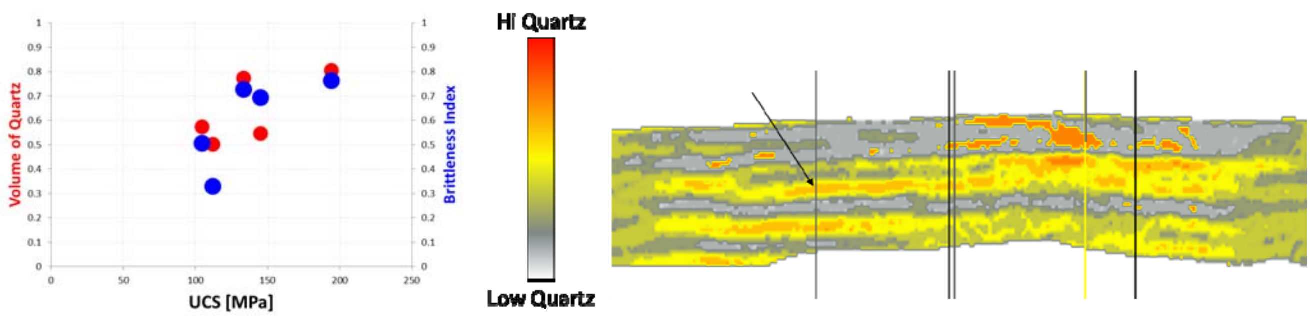

Figure 5. Relationship (left) between UCS and reservoir parameter volume of quartz and failure parameter BI_{strain} and seismic estimate of volume of quartz (right).

Finally, to integrate in-situ stress as it pertains to determining BI, careful fault analysis in conjuction with AVAZ measurements to assess relative increases in stress will add another layer of variability.

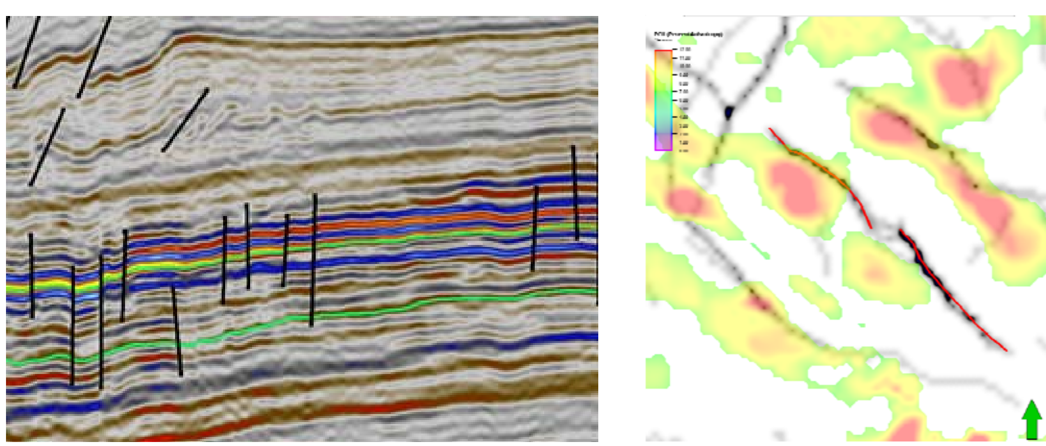

Figure 6. Section view with interpreted faults (left) and plan view of faults with AVAZ anomalies (right).

Conclusions

Acquiring geomechanical data from laboratory experiments can be used to build interpretation templates to map areas of increased hydraulic fracture effectiveness. A laboratory derived brittleness index associated to increase in permeability with hydraulic stimulation demonstrates the nonlinearity in potential reservoir productivity.

Acknowledgements

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References

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