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Seismic Derived Geomechanical Properties for Shale Gas Exploitation

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Summary

An integrated geoscience approach is applied in a Montney shale gas example. Using wide azimuth, wide angle of incidence seismic data principle stresses and rock strength parameters such as Young's modulus and Poisson's ratio can be estimated. It will be demonstrated that with this fundamental information well location, horizontal drilling direction, and fracture stimulation can be optimized.

Introduction

Drawing on petrophysics, seismic inversion and carefully constrained data processing a 3D survey specifically designed to extract geomechanical attributes targeting the Montney formation was acquired. The results show that the Upper and Lower Montney formation have distinct geomechanical properties which in turn are very consequential to drilling and well completion operations.

Theory

Hook's law describes the relationship between strain and stress. The stress induced during hydraulic fracturing causes sufficient strain on the formation leading to rock failure. Stress and strain are functions of the elastic properties of the rock. Seismic inversion for rock elastic properties has been in use since Goodway et al (1997) introduced LMR™, which derives Lamé's moduli (λ – Lambda, μ – Mu) and density (ρ – Rho) using AVO (amplitude versus offset) techniques. Simple linear mathematical transformations of these parameters allow the estimation of other elastic moduli, such as Young's modulus, Poisson's ratio, bulk modulus, compressibility, etc. These moduli are important in estimating how rocks will fracture and they are needed to estimate principal stresses.

Stress and strain are tensor variables so we need to make use of any azimuthal variations in travel time and amplitude observed in wide azimuth seismic data. Iverson (1995) showed that including azimuthal anisotropic measurements can improve stress estimates. Schoenberg and Sayers (1995) showed that under certain assumptions, Hook's Law can be modified to obtain azimuthal anisotropy from surface seismic and hence obtain azimuth stress – strain estimates. Since the stress state is generally assumed to be anisotropic, this leads to an estimation of two principle horizontal stresses; σH and σh. The vertical principle stress at any particular depth is calculated from density logs or from density calculated from seismic inversion. From these three principle stress values other pertinent stress values can be calculated.

Examples

These concepts will be illustrated using a 3D survey acquired over a Montney shale gas prospect. The 3D was designed with particular attention given to azimuthal fold and offset distribution at the zone of interest. This dataset is 200 sq. km., single component, shot line spacing 420 m., receiver line spacing 360 m., and 30 X 30 m. natural bin size.

An important result concerning the geomechanical properties of the Upper and Lower Montney will be shown. Young's modulus is directly proportional to the brittleness of the rock and stimulated fracture length. Taken together both maps show confined regions where better fracture quality is expected. The results show a variance in Young's modulus of 15%. Fracture modeling indicates that this variance magnitude will significantly impact the size of the stimulated reservoir volume. Comparing these maps show that although the reservoirs are vertically aligned, the geomechanical properties are not. This would have implications on producing both reservoirs from a single pad. It must be noted that these values still require calibration to static values before being used in quantitative calculations. The calibration is first determined from well logs and then applied to the inverted seismic results.

Turning to stress estimates, given the depth to the top of Montney is 2600m. the largest principle stress is the vertical stress. Consider the horizontal stresses for the Upper Montney shown below. The minimum horizontal stress is an important rock property because it is related to the fracture closure stress. Again there are significant variances across the Upper Montney which will have material impact on well completion operations. The maximum horizontal stress is significant because it indicates the direction of fracture propagation. Vertical fractures will propagate aligned with the maximum horizontal stress. At locations where the differential horizontal stress ratio (DHSR) calculated as ($(\sigma H - \sigma h)/\sigma H$) is low, tensile fractures will form in any direction creating a fracture swarm. If $\sigma H \gg \sigma h$ then fractures parallel to σH will form.

Conclusions

We have shown that geomechanical properties and principle stress estimates can be made from wide azimuth wide angle surface 3D seismic. These estimates are qualitatively useful and must be calibrated to static estimates before use in any quantitative calculations. Further we note that these estimates can vary significantly over short distances which will have implications for well completion.

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References

Goodway W., Chen T., and Downton J., 1997 "Improved AVO fluid detection and lithology discrimination using Lamé parameters; lr, mr and l/m fluid stack from P and S inversions" CSEG National Convention Expanded Abstracts 148-151.

Iverson, W.P.,1995, Closure Stress Calculations in Anisotropic Formations, SPE Paper 29598

Schoenberg, M and Sayers, C.M., 1995, Seismic anisotropy of fractured rock, Geophysics, 60, 1, 204-211.