Preparation and Use of Well Log Data to Identify Regional Rock Property Trends: Preliminary Results from the Mackenzie Delta - Beaufort Sea, N.W.T., Canada.

Jay A. Gunderson, Veritas GeoServices Ltd.

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Introduction

The Mackenzie Delta - Beaufort Sea region of the Canadian Arctic is widely recognized as having significant hydrocarbon potential and continues to attract exploration interest as we strive to replenish falling North American hydrocarbon reserves. It is estimated that up to 67 TCF of gas and approximately 5.5 Bbls of oil remain undiscovered in the Beaufort Mackenzie Basin (BMB). Successful exploration for these resources demands multi-disciplinary efforts to integrate all available data and utilize advanced technologies to mitigate the exploration and drilling risks.

Seismic reflection data indicate contrasts between elastic rock properties and can seldom be used to directly quantify reservoir rock and fluid properties, except when combined with other geological and/or petrophysical information (e.g. inversions to lithology or porosity). From well log data, we are able to derive reservoir properties such as lithology, porosity and fluids, as well as elastic rock properties, which are a function of velocity and density. Thus, petrophysics provides a critical link between reservoir rocks and fluids and their seismic response. However, the value we get from wellbore data is directly dependent upon the quality of the log data and our ability to interpret and understanding the formations being measured.

We carried out a regional study using well log data to investigate and quantify regional rock property trends for the BMB. An important aspect of this study is the preparatory work involved in creating a log data set with sufficient quality to be used with confidence for subsequent geophysical modeling and interpretation. Along with formation evaluation, this dataset forms the basis for calibrating seismic (elastic) rock properties to reservoir properties. This paper reviews the process for generating and using a high-quality geophysical log dataset. It will also present preliminary results of rock property trends across the area. These results broaden our understanding of the BMB and can be used to reduce exploration risk.

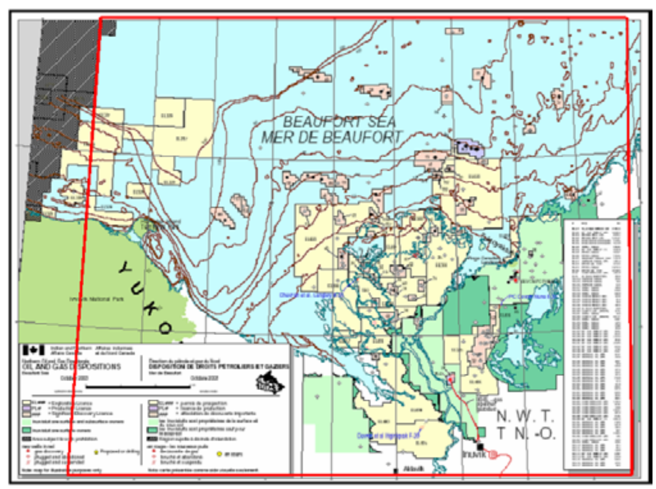

Figure 1. Map showing study area outlined in red

Methods

Since the early 1960's, nearly 300 wells have been drilled in and around the BMB. In this study, we reviewed data from 225 wells located between 68°-71° N. latitude and 131°-141° W. longitude (figure 1). Wells were grouped according to geographic location, play type (Dixon et al., 1994), stratigraphy, and pressure regime to define subsets of wells exhibiting similar geophysical characteristics (e.g. velocity and density). Crossplots showing compaction trends were used to help characterize the different areas, and to assess data quality and coverage (figure 2). Compaction trend curves were also used to indicate over-pressured zones (figure 2), structural displacement (uplift, burial), and relative properties of sands and shales (figure 3). From our well groupings, representative wells were chosen for detailed analyses. These analyses included log editing and reconstruction, standard formation evaluation, Gassmann fluid substitutions, pressure estimation, AVO modeling, and rock properties interpretation.

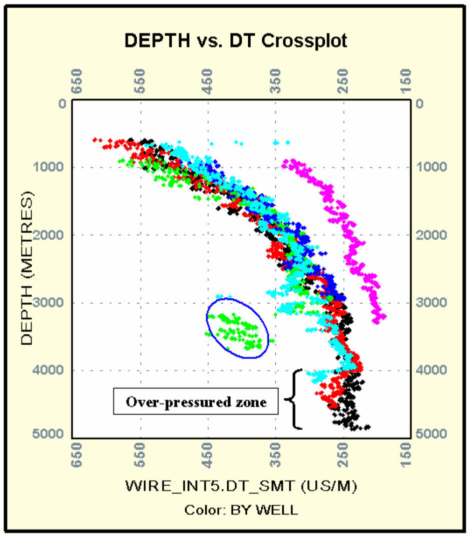

Figure 2. Trend plot of DT for 6 wells from the Taglu field. Note the scale (digitizing) problem with the magenta-colored well data. Green points represent bad sonic data. Over-pressure is present in lower Taglu.

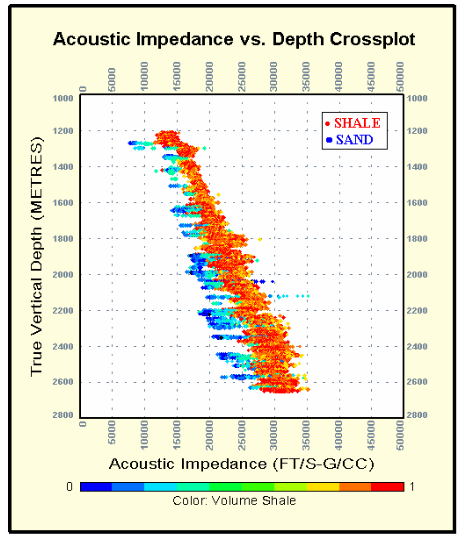

Figure 3. Acoustic impedance trends for Niterk L-19 show sands have lower impedance than shales

Data Preparation and Analysis

Log data acquisition for these wells spans four decades and exhibit a wide range of data quality due to advancements in wireline tool engineering, drilling techniques, and mud systems. Geophysical curve data – considered here as compressional sonic (Dt), shear sonic (Dts), and bulk density (Rhob) – were carefully checked for quality and completeness prior to use in geophysical modeling. Log quality problems are perhaps the single largest cause of poor log to seismic calibration. Three critical steps require expertise from the log analyst:

1) log editing and reconstruction
2) shear estimation, particularly for mixed lithologies
3) detailed formation evaluation and calibration to core data

Log Editing and Reconstruction

Depthshifts, digitizing errors, borehole conditions (e.g. washouts, rugosity, mud invasion), and tool problems all contribute to the generally poor log data quality in the BMB wells (e.g. figure 2). Log editing and reconstruction of sonic (Dt) and/or bulk density (Rhob) was necessary for nearly all wells. Appropriate curve editing requires knowledge of wireline tools, log interpretation skills, experience, and considerable effort. There are many published methods and equations for log reconstruction (e.g. Faust, Smith, Gardner, etc.), a discussion of which is beyond the scope of this paper. An example of editing to repair poor quality data is shown in figure 4. Sonic and density curve editing improves wellties and this should be an iterative process between the geophysicist and log analyst.

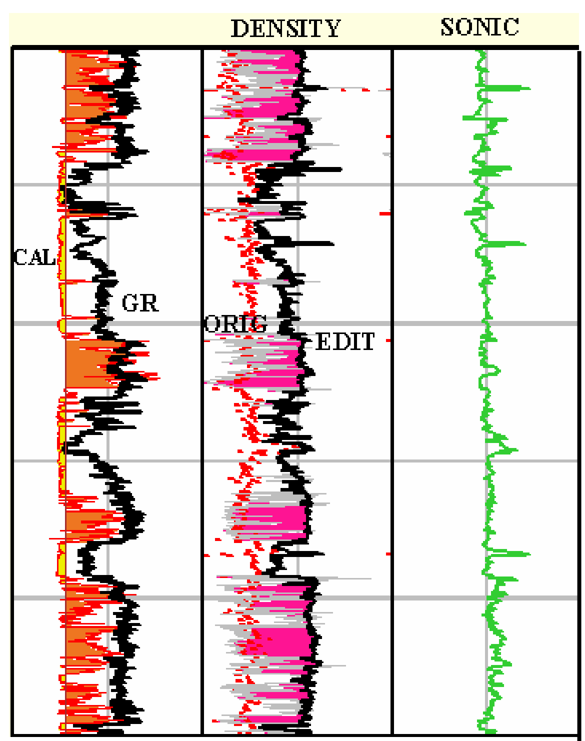

Figure 4. Example of curve reconstruction for density in washed out shales. In track 2, original Rhob is gray, edited Rhob is black.

Shear Estimation

With fewer than a dozen wells in the BMB having dipole shear data, it is necessary to estimate shear velocity in order to perform any log-based attribute analysis. This is commonly done by deriving a local shear estimator from well data or by applying one of the many published empirical estimators (e.g. Castagna et al., 1993). Shear velocities for the

BMB wells were estimated from a locally-developed Vp-Vs trend, which was based upon data from 5 wells with measured dipole (figure 5). These data points were from brine-filled clastic rocks only and excluded pay sands, gas hydrates, and carbonates. The local "mudrock" trend (eq. 1) is very similar to Castagna et al's (1993) trends for sand and shale.

$$Vs = 0.765*Vp - 0.808 \quad \text{(km/s)} \qquad (1)$$

Shear estimations using equation (1) are for brine-filled clastic rocks only, and application to hydrocarbon-bearing zones results in shear velocities which are too low. In hydrocarbon zones, we used the P-wave modulus formulation of Gassmann's equation (see Mavko et al., 1995 and 1999) to correct the P-wave velocities back to a "pseudo-brine" response before applying our shear estimator.

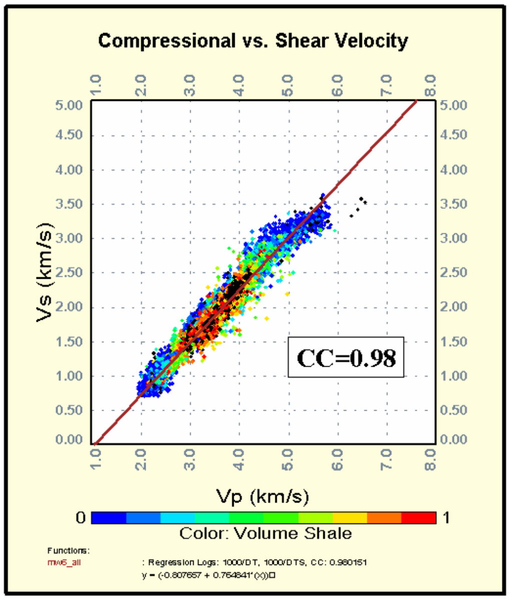

Figure 5. VpVs relationship for BMB based on 5 wells with measured shear data.

Formation Evaluation

Another important contribution of the log analyst is using the log data to provide an understanding of the subsurface geology at the well location. Clearly we must know something about insitu lithology, porosity, and fluids before we can evaluate the seismic response to these reservoir qualities. Standard formation evaluation techniques were used to derive lithology (Vsh), porosity (phie), and water saturation (Sw). Formation pressures were estimated from drilling mud weights and from compaction trend offsets using the techniques of Hottmann and Johnson (1965). Where possible, formation evaluation results were calibrated to core, mudlog, and DST information.

Gassmann fluid substitutions to brine, oil, and gas were performed for an average of three to four sands per well to enable us to model the effects of changes in pore space fluids. Fluid properties were calculated using formation pressure, temperature, and salinity and the equations of Batzle and Wang (1992).

Geophysical Modeling and Results

From the high-graded geophysical curve dataset, we generate AVO attributes and rock properties for use in generating trend curves, calibrating seismically-derived AVO attributes, and for input into rock property inversions. The computation of AVO attributes and elastic rock properties from log data is fairly trivial – their interpretation is not. Interpretation must be accompanied with an understanding of the assumptions, limitations, and uncertainty inherent in the log measurements and the formation evaluation results.

Ultimately, the goal of this study was to characterize the seismic response of reservoir rocks for the BMB on a regional scale – particularly with respect to AVO and rock properties. Initial results illustrating the AVO and rock property behavior for various regions of the BMB will be presented. Our investigation into the factors controlling the seismic response poses additional interesting questions. For example, "How do fluids/porosity impact the offset seismic response?", "What can we expect for impedance contrasts in over-pressured zones?", "What lithologic variations (e.g. carbonate streaks, bentonite layers, coaly shales) are present in the well which might give anomalous AVO signatures?", and "Is anisotropy present and how will it impact AVO?". These and similar issues can be addressed through the careful application of log-based rock physics and modeling.

References

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