Petrophysical relationships derived from well logs in the White Rose oilfield, offshore Newfoundland

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ABSTRACT
This work analyses logs from six wells (A-90, E-09, H-20, J-49, L-08, and N-22) from the White Rose oil field, offshore Newfoundland. From the analysis of sonic, density, and gamma-ray logs, we have developed relationships for: Vp and Vs versus depth, Vp/Vs versus depth, Vp/Vs versus gamma-ray, Vp versus Vp predicted by the Faust relation, actual Vs values versus Vs predicted by Faust relation, real Vs versus Vs predicted by the Castagna relation, and finally the real density versus density predicted by the Gardner relation. In general, Vp and Vs increase with depth and we observe a decrease of Vp/Vs with depth. The Faust relation predicts Vp reasonably well. We applied the Faust equation to predict Vs and the results show some promise for specific units. Gardner's relation, had difficulty predicting the density value in wells J-49, L-08, and N-22; however, it worked relatively well in wells E-09 and H-20. The Castagna relation predicted Vs from Vp quite well. Better fits to empirical relationships can often be achieved by dividing the lithologies into regions.

Introduction

This paper provides petrophysical properties, as measured by well logs, in the White Rose oilfield, offshore Newfoundland, and explores empirical relationships between properties and various parameters. We are particularly interested in the shear-wave velocity Vs and how it performs with some of the classical empirical equations of petroleum exploration.

White Rose oilfield

The White Rose field is situated on the northeastern margin of the Jeanne d'Arc Basin, approximately 350 km east of St. John's, Newfoundland; the White Rose field is 50 km from the Hibernia and Terra Nova oilfields. Water depths in the area are about 120 m. The target reservoir for the White Rose field is the Avalon sandstone.

In the mid-80's, White Rose N-22, J-49, and L-61 wells were drilled in the White Rose domal region, with important quantities of gas discovered. In 1988, White Rose E-09 was drilled (this well discovered high-quality oil, in the Avalon sandstone, trapped in a fault block). The A-90 well drilled in 1989 (into an elevated fault block), missed the Cretaceous reservoirs and bottomed in Jurassic beds. A three-well delineation program was successfully completed during 1999. The location of the wells was based on the E-09 results. White Rose L-08, A-17, and N-30 found hydrocarbons. White Rose H-20 was drilled in summer 2000 (Husky Energy, 2002).

Structurally, the White Rose oilfield is situated in a complex faulted area positioned over the deep-seated Amethyst salt ridge, White Rose diapir, on the hanging wall of the Voyager Fault (Husky Energy, 2002). The units present in the area of interest are from younger to older as follows: South Mara, Wyandot, Dawson Canyon, Petrel Member, Nautilus, Ben Nevis, Avalon, Eastern Shoals, White Rose, Hibernia, Lower Hibernia, Fortune Bay, Jeanne d'Arc, and Rankin.

The Avalon Formation (125m) of Barremian to late Aptian age is a complex and variable siliciclastic series, subdivisible into 3 subunits, displaying a coarsening upward pattern: Basal subunit (42m): "red mudstone" sequence characterized by varicoloured shales containing a few thin interbeds of sandstone. Middle subunit (37m): thick sandstone beds, and interbedded grey shales. Upper subunit (46m): slightly coarsening upward, sandstone-dominated unit, with siltstone at the top.

The lower contact with the Eastern Shoals Formation is always sharp. The upper contact with the Ben Nevis Formation is sharp and unconformable at the basin margins and over major structures, becoming disconformable to conformable toward the basin axis. The Avalon Formation, grades laterally into the Nautilus Shale. The environment of deposition is thought to bea flat, low-lying coastal plain containing brackish lagoons and swamps bordering a large, tide-dominated shallow estuary (McAlpine, 1990).

Well-Log Analysis

We conduct the following analysis for various wells: Vp versus depth (all wells), Vs versus depth (wells H-20 and L-08), Vp/Vs versus depth (wells H-20 and L-08), Vp/Vs versus GR (H-20 and L-08 wells), real Vp versus Faust Vp (all wells), real Vs versus Faust Vs (H-20 and L-08), real Vs versus Castagna Vs (wells H-20 and L-08), real Density versus Gardner's density from Vp (wells E-09, H-20, J-49, and N-22), real Density versus Gardner's density from Vs (wells H-20 and L-08).

Vp, Vs versus depth

The six wells show a general increase of Vp with depth. The wells with shear sonic logs (H-20 and L-08), show increasing Vs with depth (*Fig. 1*). There are some parts of the section where the velocities decrease - the decrease of velocities seems to be associated with local changes in lithology. The higher values are related to the Avalon and Eastern Shoals Formations, and the low values in velocities are in the Nautilus and Ben Nevis Formations. Regression lines fit reasonably well for the Tertiary sediments, Vp = 0.4479z + 1804m/s (R^2 = 0.7849) and Vs = 0.3116z + 559.6m/s (R^2 = 0.6829).

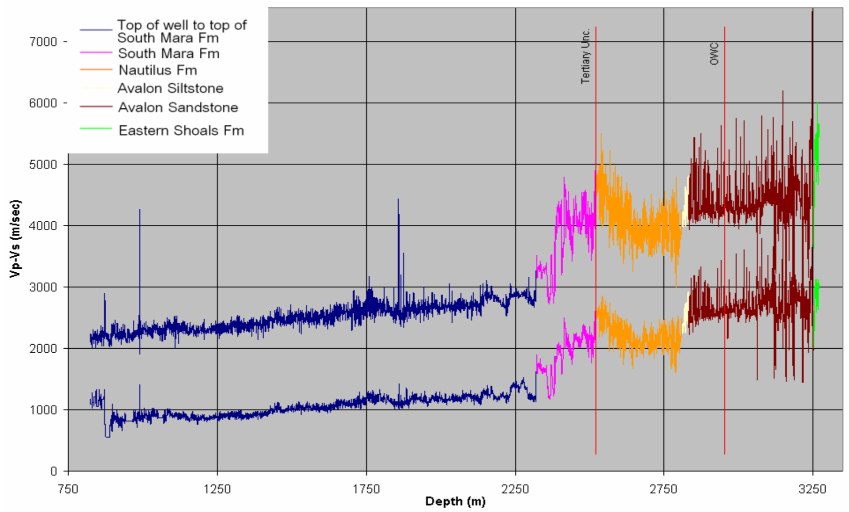

Fig. 1. Vp and Vs versus depth for well H-20 (measured) showing the increase of velocities with depth.

Vp/Vs versus depth

A general decrease of Vp/Vs with depth is observed in the H-20 (*Fig. 2*) and L-08 wells. However, within units, we sometimes observe an increase of the Vp/Vs values. Examples of regression lines for the wells are given in Table 1 (in these cases, the lines are fit above the top of South Mara and below it).

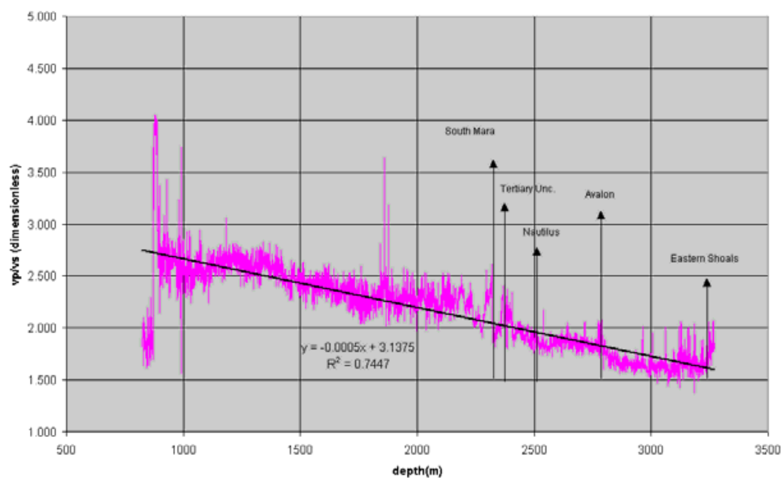

Fig. 2. Vp/Vs versus depth for well H-20. The regression line, fit over the whole well, is shown (Vp/Vs= -0.0005z + 3.1375, z is in metres).

Well	Representative line fit equation (Top of well to top of South Mara)	Representative line fit equation (Top of South Mara to bottom of well)
H-20	Vp/Vs = -0.0003z+2.9293 R^2 = 0.2806	Vp/Vs = -0.0004z+2.9979 R^2 = 0.5846
L-08	Vp/Vs = -0.0009z+3.9917 R^2 = 0.8326	Vp/Vs = -0.0004z+2.7256 R^2 = 0.6301

Table 1. Representative line fit equations for Vp/Vs in H-20 and L-08 wells.

Vp/Vs versus GR

In A-90, H-20, J-49 and L-08, the GR values decrease with depth while the velocities increase with depth as described before. In E-09, GR values stay constant for most of the well, at values between 26-140 API. n N-22, the GR values increase from 100-134 API with depth.

The Avalon sandstone shows some variability in the properties (GR, Vp, Vs) throughout the White Rose field. The variability of the GR, Vp, and Vs in the Avalon sandstone could be indicative of porosity and/or shale content. Vp/Vs increases somewhat with the GR value, with Vp/Vs values from 1.5-2.0 (*Fig. 3*). Shales and interbedded sands in the Tertiary section have values from 1.8-4.0. The Avalon siltstones range in Vp/Vs from 1.6-1.7.

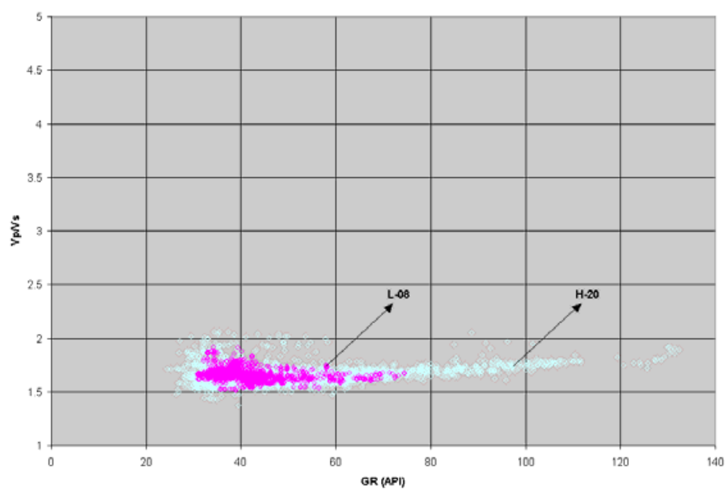

Fig. 3. Vp/Vs versus GR for H-20 and L-08 wells for the Avalon sandstone in the wells. There are indications of an increase in Vp/Vs with gamma ray value.

Vs predicted by Castagna

We used Castagna's (1985) relationship (see *Equation 1*) to predict Vs from Vp. This equation predicted Vs for the entire well section reasonably well (*Fig. 4*). We note that this could be applied only for wells H-20 and L-08 where the actual Vs values were acquired.

$$V_s = \frac{(V_p - 1360)}{1.16}, \text{ in m/s} \quad (1)$$

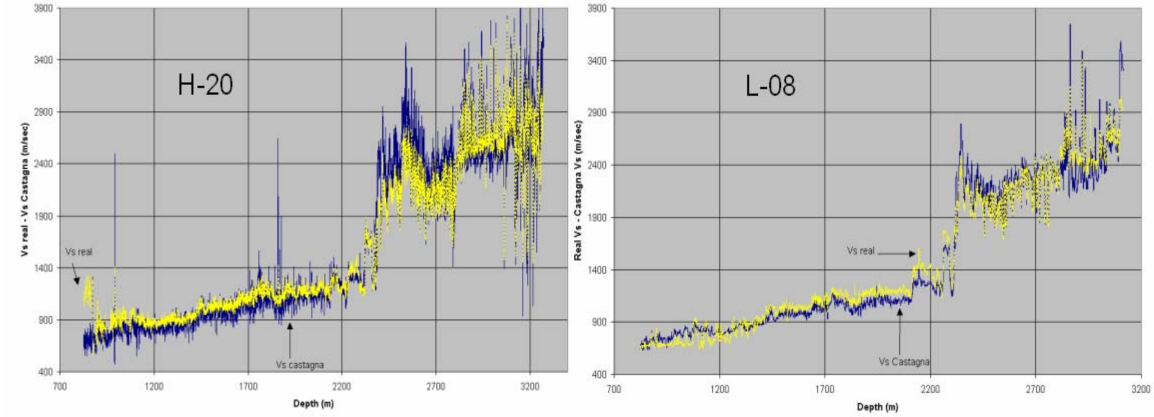

Fig. 4. Measured Vs and Castagna's Vs from Vp versus depth for wells H-20 and L-08.

Vp predicted by Faust

The Faust equation (see *Equation* 2), where T is the formation age, z is its depth, and c=125.3, predicts compressional velocities with geological time and depth of burial of the rock, (Faust, 1951). This section compares the predicted Vp from the Faust relation with the actual Vp value measured. The Faust curve does give an overall description of the velocity trend (*Fig. 5*). The actual velocities can be matched better by fitting the Faust curve to various units using different constants.

$$V_p = c(Tz)^{1/6}, \text{ in m/s} \quad (2)$$

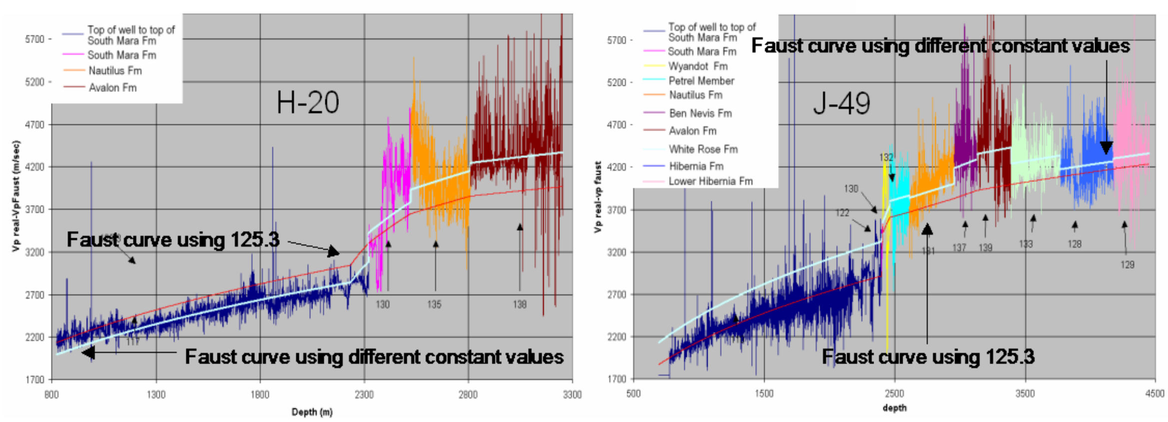

Fig. 5. Vp measured and Vp predicted by Faust versus depth for wells H-20 and J-49. Showing the different Vp curves derived from Faust equation using different constants for various units.

Vs predicted by Faust

We explore the prediction of Vs using a Faust-type relationship. In this case, the "Vs Faust equation" attempts to predict shear velocities with geological time and depth of burial of the rock. We expect the constant to be quite likely different than 125.3. We evaluate the relation in wells H-20 and L-08 (*Fig. 6*).

The overall Faust curve does not predict Vs very closely. Another Faust-type relationship may do a better job. However, over specific units Faust provides a closer match.

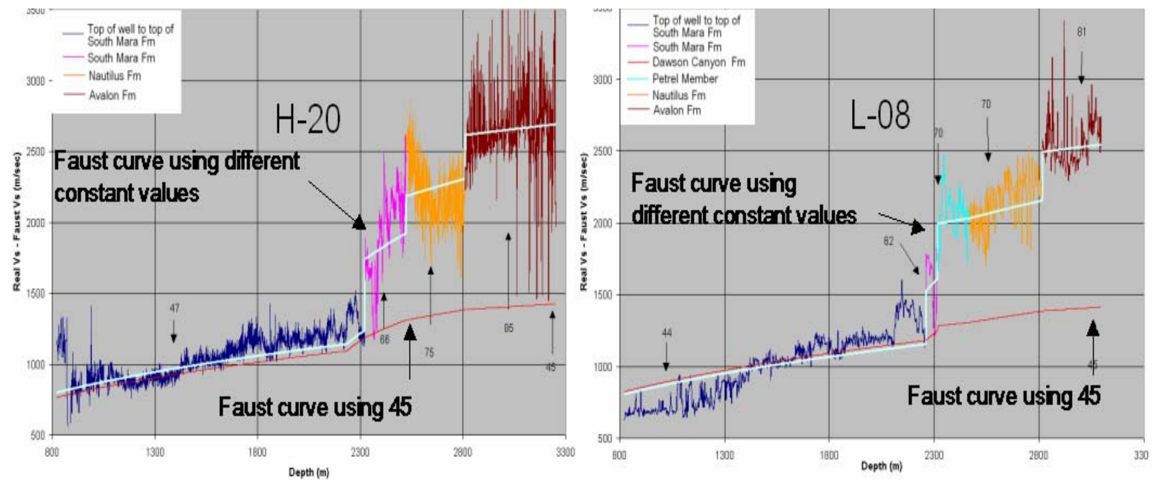

Fig. 6. Vs measured and Vs Faust versus depth for wells H-20 and L-08. Showing the different Vs curves derived from Faust equation using different constants per unit.

Density from Vp

The Gardner's equation (see *Equation 3*), predicts density using compressional velocities (α), constant a=310, and exponent m=0.25 (Gardner et al., 1974). This section compares the predicted density from Gardner with actual density value. We apply this relation to all wells where there was a density log acquired, A-90 did not have density log. The results were reasonably good, using the constant of 310 for the entire wells, in the case when the wells were broken down into their main units, the constants were changed to have more accurate results (*Fig. 7*).

$$\rho = a\alpha^{m} \text{, in kg/cm}^3 \quad (3)$$

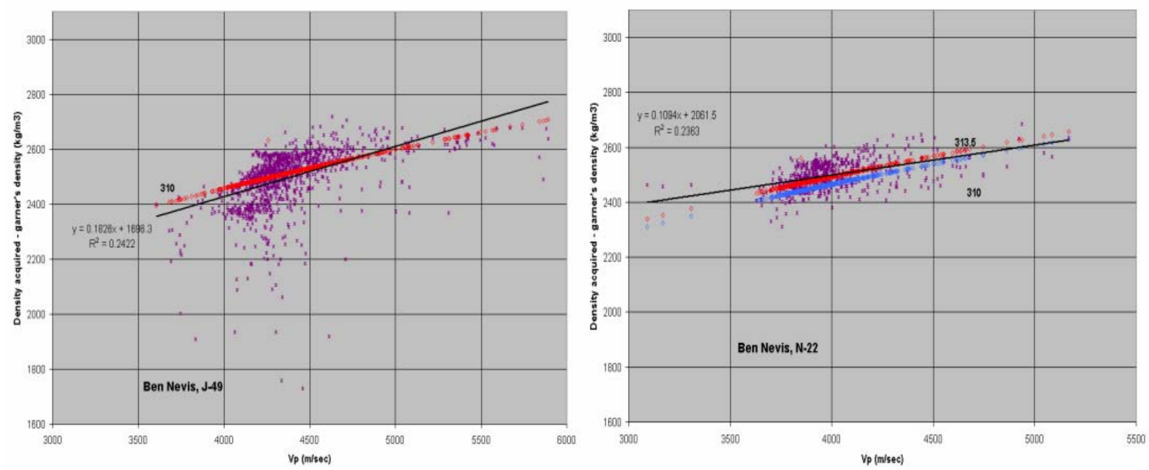

Fig. 7. Use of different Gardner "constants" in the case when the wells were broken down into their main units, in this case the Ben Nevis Formation for wells J-49 and N-22.

Density from Vs

We analysed the prediction based on Gardner equation (1974), (see *Equation 3*), using Vs instead of Vp with a constant of a=65 and exponent m=0.25. This section compares the predicted density from Gardner using Vs with the actual density value. We did this comparison for well L-08 entirely and for a portion of well H-20 (2272-3271m) is shown in Figure 8. Wells A-90, E-08, J-49 and N-22 did not have a Vs log. Vs predicts density about as well as Vp does over much of the section.

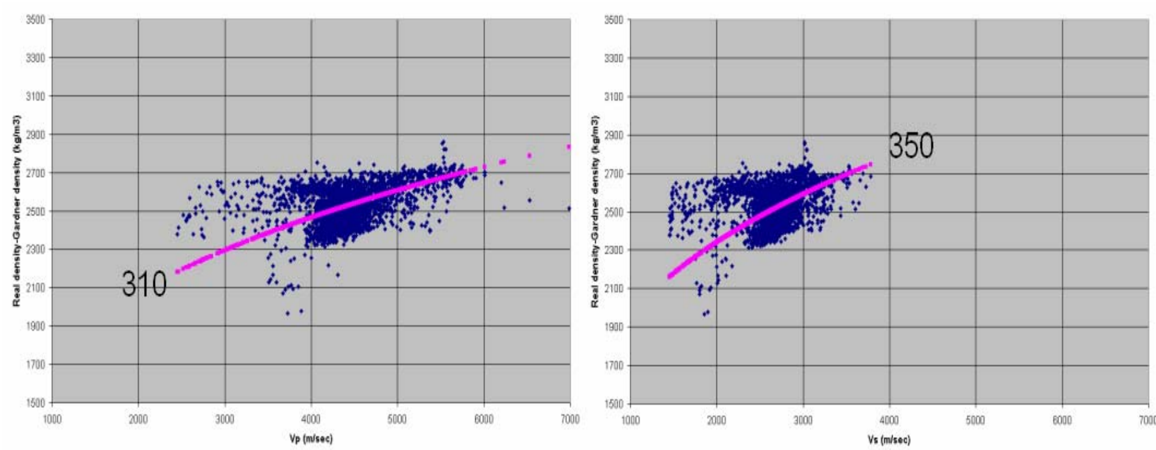

Fig. 8. Real density and Gardner's density versus real Vp, using a constant of 310 and real density and Gardner's density versus real Vs, using a constant of 350. Both crossplots for well H-20, from 2772m to the bottom of well (3271m)

Predicting Vs from density

The possibility of predicting Vs from density values in assessed with wells H-20 (from 2772 to bottom of well, where there is a density value) and L-08 (entire well). We invert the Gardner equation to give Vs from density. The results are shown in *Fig. 9*. The best-fit constants were a=634 and m=0.18. The results are reasonably good in the shallower parts of the well (less than 1800m) but less accurate in the deeper section.

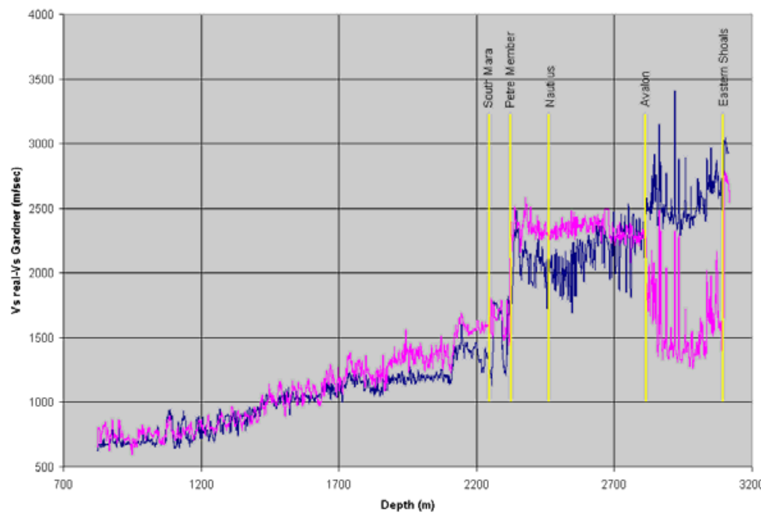

Fig. 9. The measured Vs values versus those predicted from the inverted Gardner equation for well L-08

Conclusions

The values of the logs from the White Rose field generally behave in a manner consistent with some of the classic empirical petrophysical equations. Some of the empirical relationships (Vp from Faust, Vs from Castagna, density from Gardner) are especially predictive in the White Rose case. Gardner's relation, using Vp values, did have difficulty predicting density values in wells J-49, L-08, and N-22. However, it worked relatively well in wells E-09 and H-20. Using Vs to estimate density gives reasonable results in given regions. Predicting Vs based on the Gardner relation, shows promise especially in the shallow parts of the wells (H-20 and L-08). The Vp/Vs values from 1.5-2.3 indicate sandstones, while values from 1.8-4.0 indicate shales.

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Web Pages

Husky Energy, 2002, http://www.huskywhiterose.com/