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Prediction of Shear Wave velocity for carbonate rocks

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Abstract
In many oil fields only the BHC logs (borehole compensated sonic tool) are available to provide interval transit time (Δtp), the reciprocal of compressional wave velocity VP.

To calculate the rock elastic or inelastic properties, to detect gas-bearing formations, the shear wave velocity VS is needed. Also VS is useful in fluid identification and matrix mineral identification.

Because of the lack of wells with shear wave velocity data, so many empirical models have been developed to predict the shear wave velocity from compressional wave velocity. Some are mathematical models others used the multiple regression method and neural network technique.

In this study a number of empirical models were considered to predict VS from VP. The models had been correlated and a general equation, based on statistical method, was established for carbonate rocks.

The proposed equation, then, was examined using log data and good results observed.

Key Words: shear wave velocity, elastic properties of rocks, sonic logs.

Introduction
In the characterization of a hydrocarbon reservoir the estimation of the shear wave velocity, VS , is important in the determination of the mechanical properties of rocks, identification of gas bearing zones, and estimation of gas saturation.

The standard practice is to derive VS, VP from testing rock samples in the laboratory. When shear wave velocity, VS, cannot be measured, it may be replaced with synthetic shear wave velocity computed from empirical models using compressional wave velocity.

Researchers have employed a variety of approaches, based on laboratory core analysis, well log interpretation, and numerical modeling to predict VS from VP. Most of these studies have discussed sandstone formations.

In order to predict a more comprehensive empirical model, for carbonate rocks, a number of models have been combined to determine one equation across them all.

The predicted equation, then, examined using Vs and Vp data obtained from full-wave sonic logs and a useful qualitatively results have been achieved.

Vp – Vs Relationships

A good Vs values can be predicted form the empirical relationships in similar formations, if all measurement are error free.

In carbonate rocks, prediction of Vs using Vp is most reliable according to the compression of prediction with laboratory and logging measurements.

Pickett 1963, [1] demonstrated the potential of Vp/Vs as lithology indicator. His laboratory and field data for many different formations showed that measurements corresponding to limestone and dolomite were found along lines of constant but different ratios:

$$Vp/Vs = 1.9 \text{ or } Vs = Vp/1.9 \quad \ldots (1)$$

$$Vp/Vs = 1.8 \text{ or } Vs = Vp/1.8 \quad \ldots (2)$$

where equation (1) for limestone and (2) for dolomite.

He, also, demonstrated that Vs is 2-5 times more sensitive to variation in porosity than Vp in limestone. Vp in limestone was found to be the least sensitive porosity indicator.

Castsgna et. al; [2] (1993) gave representative polynomial relations for estimating sS from Vp depending on data derived from sonic log. Empirical equations by Castanga for limestone and dolomite respectively are:

$$Vs = 0.05509\ Vp2 + 1.0168\ Vp - 1.0305 \quad \ldots (3)$$

$$Vs = O.583\ Vp - 0.0776 \quad \ldots (4)$$

Where Vp and Vs are in km/sec.

He observed that Vp/Vs is sensitive to gas in most clastics and will often show a marked decrease in its presence. The response of carbonate rocks to gas is variable, a discrepancy which may be attributed to pore geometry. The gas effect may not be observed on well log if the depth of penetration does not exceed the invaded zone.

Eskandari et.al 2004, [3] proposed a method to predict Vs from wireline data using multiple regression and neural network technique. At first they obtained equation for limestone and dolomite depending on Castagna relationships:

$$Vs = -0.I236\ Vp2 + 1.6126\ Vp - 2.3057 \quad \ldots (5)$$

They complete their study to show the effect of petrophysical parameter on the predicted Vs in carbonate rocks and concluded that Vs decreases with increasing porosity and deep resistivity and increases with increasing bulk density.

W.M Al-Kattan 2008, [4] depending on the fact that porosity measured by compressional wave velocity or by shear wave velocity, in carbonate rocks, should be equal for the same sample. She predicts Vs from Vp depending on Wyille equation and used a statistical method to propose the given equation:

$$Vs = 0.5734\ Vp - 90.337 \quad \ldots (6)$$

Where Vp, Vs in m/sec.

Results and Discussion

In order to predict a general equation for carbonate rocks, data taken from laboratory measurement and sonic log were used to draw the predicted empirical equations of Pickett, Castanga, Eskandari, and Wafa correlated as shown in Fig (1).

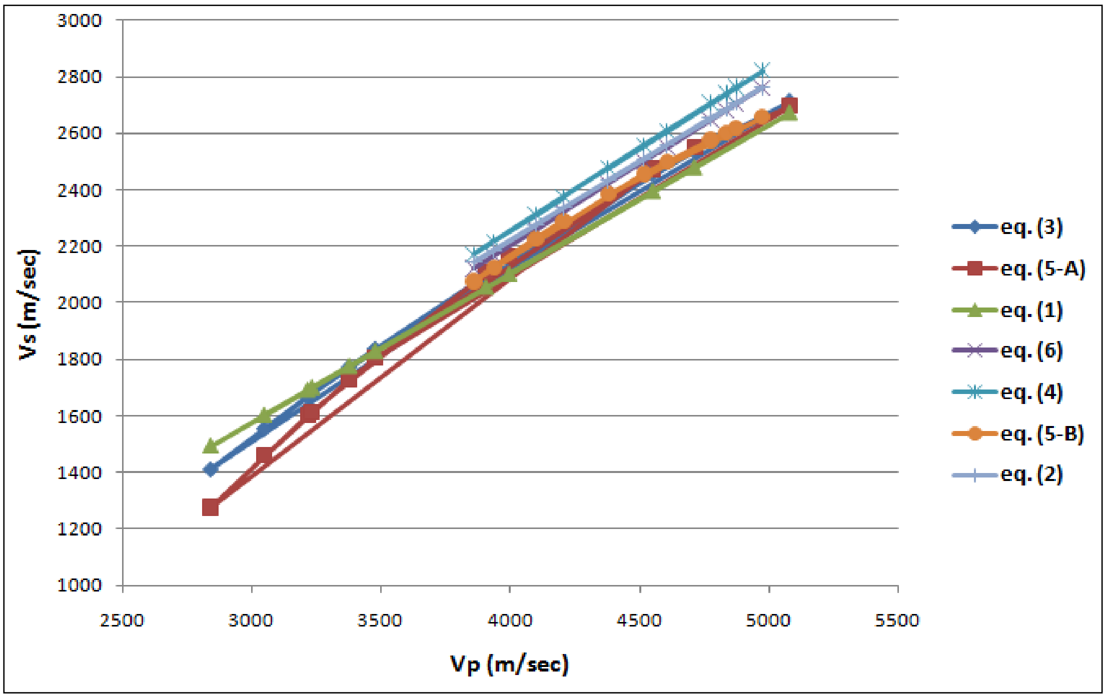

Fig 1, VP-VS predicted relations

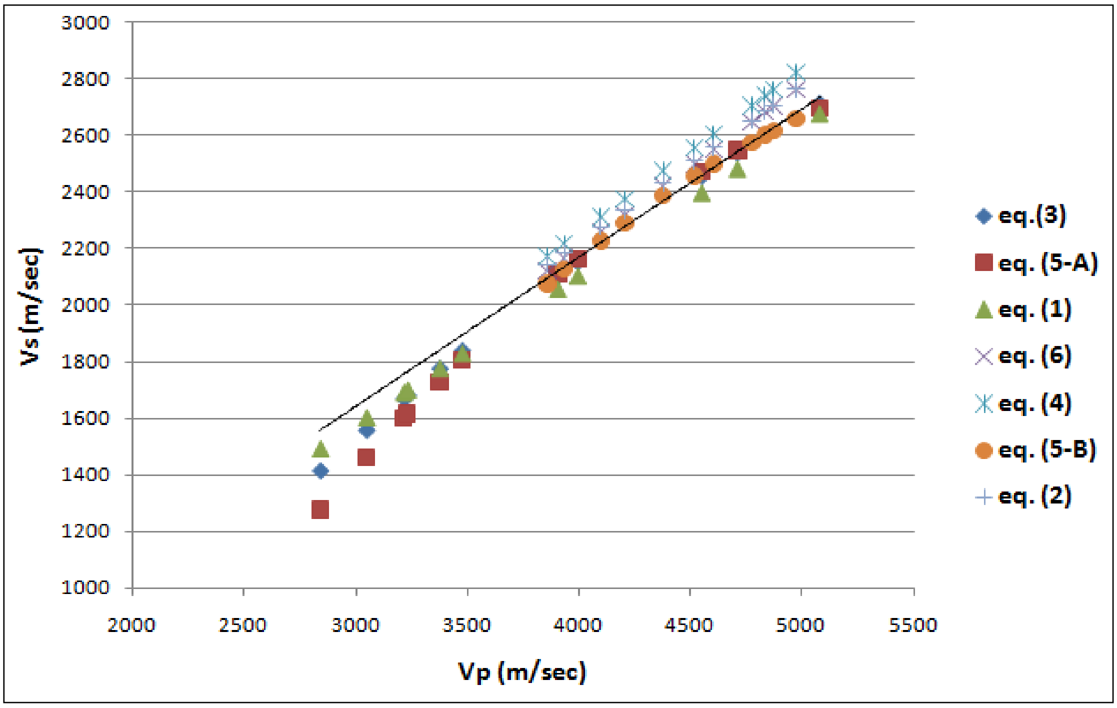

Fig 2, the general relation between Vp, Vs for Carbonate rocks.

The data have been replotted, as shown in Fig. (2), using a statistical method a general exponential relationship was established for carbonate rocks with R2= 0.995 the equation is given by:

$$V_S = 0.699\, V_P^{0.969}$$

To examine the validity of this equation Vp and Vs data from a full, waveform sonic logs taken in different type of formations (Limestone, limestone with some dolomite and shale, and dolomite with some sands) were correlated with the predicted Vs as shown in Fig (3).

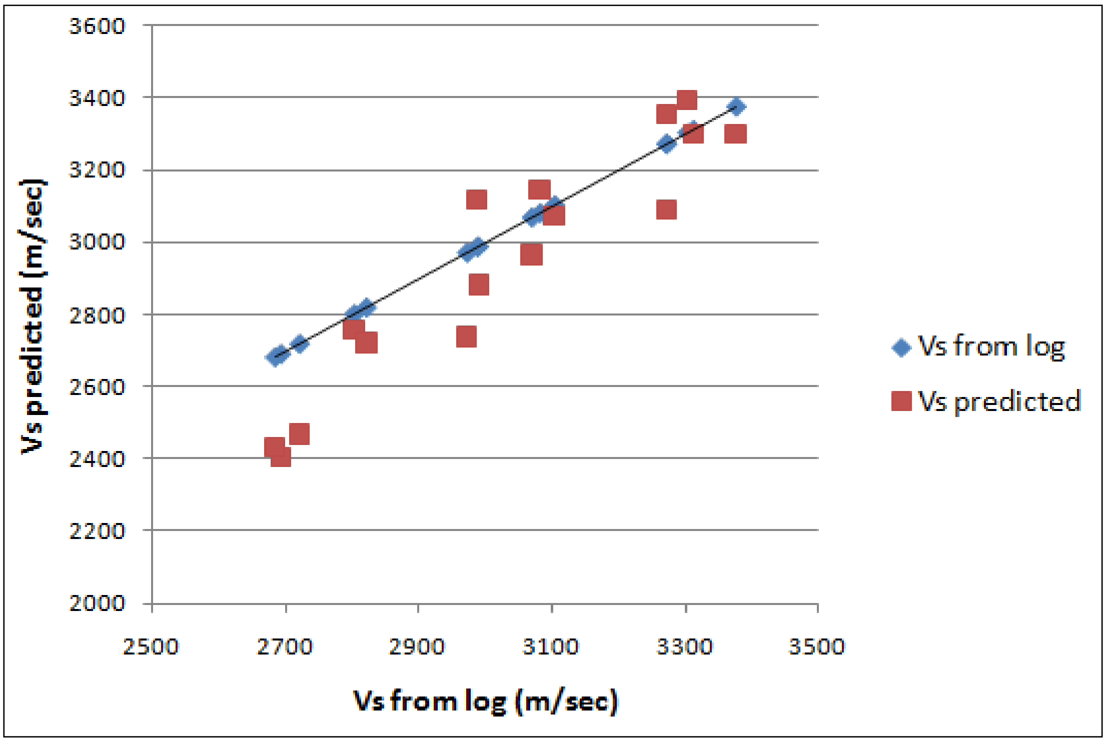

Fig. 3, Cross plot between measured Vs and predicted Vs

The point's lies on a straight line represent the Vs data from logs while the other points are the Vs predicted from the proposed equation using Vp data from the same logs.

Remembering that all the models assume clean water saturated formation the scattering can be easily explained.

The data were taken from complex formations with a range of porosity vary from 3-25%, the shale content vary from 0-30%. This leads to the deviation of the predicted Vs from the measured Vs.

Because Vs decreases with increasing porosity while Vp is less sensitive to porosity, also Vs decreases more than Vp with increasing Shale content.

The deviated points are those with high porosity and shale content.

The matrix shear wave velocities for limestone and dolomite measured at laboratory are equal to 3384 m/sec and 3872 m/sec respectively. Using the predicted equation the velocities are 3409 m/sec and 3725 m/sec respectively which is very close to the measured values.

For porosity ranging from 5-20%, the shear wave velocities measured in laboratory for limestone are 2896 m/sec – 2134 m/sec. The predicted velocities are 3409 m/sec – 3725 m/sec.

In dolomite the laboratory measured velocities, for the same porosity ranging, are 3353 m/sec – 2286 m/sec while the predicted velocities are 3253 m/sec – 2462 m/sec.

It can be noted that the measured and the predicted velocities are very close which confirm the validity of the predicted equation.

Conclusion

The proposed equation gives very accepted shear wave velocities predicted from compressional wave velocities in carbonate rock.

In future work, the influence of porosity and shaliness on velocities should not be ignored, when the porosity and shaliness values are high, in the prediction of Vs from Vp, also the effect of density should be considered to get a more comprehensive relationship.

Nomenclature

Vp: Compressional wave velocity, m/s

Vs: Shear wave velocity, m/s

Δt: Interval compressional transit time, µsec/f

Δts: Interval shear transit time, µsec/f

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