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Sensitivity of interval Vp/Vs analysis of seismic data

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Summary

The objective of this paper is to set guidelines for an interpreter to accurately pick events and understand the error that can be expected from various isochron intervals to ultimately suggest a minimum interval time that can provide accurate Vp/Vs values. In a study on the Hussar data set, based on the increasing observable error with respect to decrease in the time intervals, as well as taking into consideration the variability of the Vp/Vs values due to uncertainty it is suggested to use isochron intervals greater than 150ms. Interval Vp/Vs analysis for data with intervals greater than this time presented low uncertainty.

Horizon Picking

Once the events of interest were identified and correlated to both seismic sections, horizons were picked using an automatic picker with manual editing. Intervals of Vp/Vs values between horizons were calculated using the following relationship (Garotta, 1987):

$$Vp/Vs = \frac{(2\Delta Tps - \Delta Tpp)}{\Delta Tpp} \qquad (1)$$

In this equation ΔTpp and ΔTps represents the isochrons across the same depth intervals for both PP and PS sections. Horizons were carefully picked and corrected when necessary in order to accurately interpret lateral variations in Vp/Vs. The ratio could be affected due to changes in lithology, porosity, pore fluid, and other formation characteristics (Tatham and McCormack, 1991). A total of six horizons were picked in our analysis; this allowed the study of several isochron intervals for the Vp/Vs error study.

Vp/Vs Error Analysis

To understand the relationship between the sensitivity of Vp/Vs ratios to the time intervals used, we first input the interpreted horizons to create isochrons along the section. A total of eleven isochrons were chosen with intervals ranges from about 22 ms to 500 ms.

Vp/Vs calculations for each interval were compared with one another to find patterns and differences. The results show that the deviations for smaller isochrons were greater than those for larger isochrons. Based on the results, the Vp/Vs ratio calculations are found in part to be dependent on the time interval chosen. Horizon interpretation mis-picks will result in greater error in the calculations for small intervals.

Many factors can influence Vp/Vs ratio values, such as the lithology and pore fluids. A lithology investigation was conducted to understand how this could influence the results. The relationship between Vp and Vs is quasi-linear. The relationship between the gradient and the lithology, especially the shale content, is a subject for further investigation.

Error Analysis Calculation on Vp/Vs

To estimate the error for the Vp/Vs analysis, propagation of error method was used. This method calculates the error in the values of a function based on the effects of the uncertainty of the variables on the function (Louro, 2014). An uncertainty of ±2 ms was used for the horizon picks in order to find the uncertainty in Vp/Vs. In this case, the function used to calculate Vp/Vs (equation 1) has two variables: ΔTpp and ΔTps. According to the propagation of error equation, if a function y depends on the variables $x_1, x_2, \ldots, x_n$, where x_i is measured with uncertainties $u(x_i)$, the uncertainty in the calculated value y is given by

$$u(y) = \sqrt{c_1{}^2 u(x_1)^2 + c_2{}^2 u(x_2)^2 + \cdots c_n{}^2 u(x_n)^2} \tag{2}$$

where c_i are called sensitivity coefficients because they provide information about how sensitive y is to uncertainties in each of the variables. Each sensitivity coefficient is the partial derivatives of y with respect to each x_i:

$$c_i = \frac{\partial y}{\partial x_i}$$

To simplify the expression, the variables ΔTpp and ΔTps were substituted by z and x, respectively and Vp/Vs was substituted by the variable y. The sensitivity coefficients can then be written as

$$c_1 = \frac{\partial y}{\partial x} = \frac{\partial}{\partial x}\left(\frac{2x - z}{z}\right) = \frac{2}{z};$$

$$c_1{}^2 = \frac{4}{z^2} \tag{3}$$

$$c_2 = \frac{\partial y}{\partial z} = \frac{\partial}{\partial z}\frac{(2x - z)}{z} = \frac{2\sqrt{x}}{z^2};$$

$$c_2{}^2 = \frac{4x}{z^4} \tag{4}$$

Then substituting equations 3 and 4 into 2, and with the uncertainties u(x) and u(z) equal to ±2 ms, the final absolute error equation for Vp/Vs will be given by

$$vp/_{vs}\,(error) = \sqrt{\frac{4}{z^2}u(x)^2 + \frac{4x^2}{z^4}u(z)^2;}$$

$$vp/_{vs}\,(error) = 4\sqrt{\frac{1}{\Delta Tpp^2} + \frac{\Delta Tps^2}{\Delta Tpp^4}} \tag{5}$$

Relationships between the time interval, ΔT, and both the standard deviations and error in Vp/Vs were studied. The standard deviation was calculated from the computed ratio analysis for each interval. It was noted that the deviation tends to decrease as the interval length ΔT becomes larger (Figure 1). The best fit line in red shows that the deviation is nearly constant at large time intervals, but exponentially increases as the interval approaches 150 ms. The line increases asymptotically as it approaches zero milliseconds.

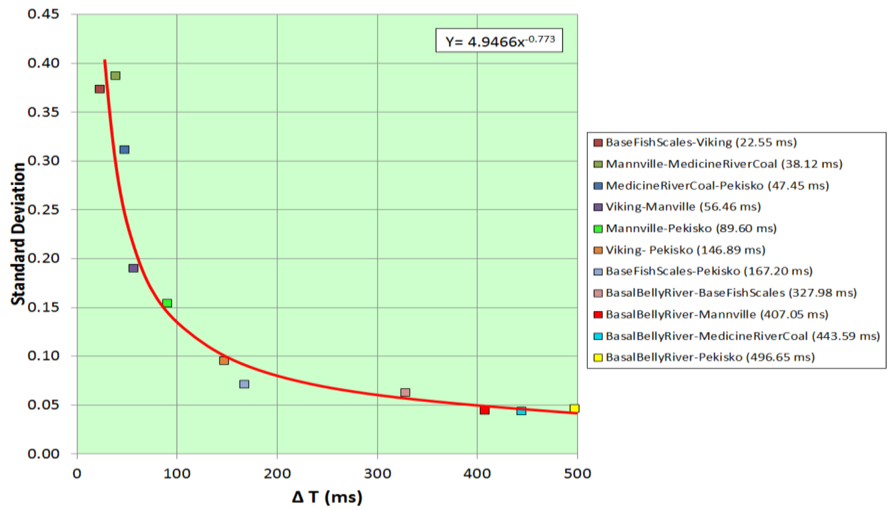

FIG. 1: Crossplot of standard deviation in Vp/Vs analysis against the time interval; the best fit line in red exponentially increases at intervals less than 150 ms.

The uncertainty in the Vp/Vs ratio was used to understand how ΔT can affect the percent relative error in the ratio analysis (Figure 2). Time intervals above 150ms corresponded to percent error values that were consistently low, ranging from 0.74 to 2.20 percent. For intervals below this threshold, the percent error increased exponentially; the smallest time intervals in our study were approximately 22 and 38 milliseconds and their corresponding percent error were 16.52 and 9.76 percent respectively. The calculation for the error assumes an uncertainty of ±2 ms in the interpretation from the horizons picks.

A crossplot using average Vp/Vs values with error bars versus ΔT (Figure 3) show how the uncertainty affects the analysis. Error bars represent the variability of data, in this case Vp/Vs, and it is used here to indicate the error. The line in red is the average of all the Vp/Vs values, and the dashed line indicates values one standard deviation away from this mean. All the points with a ΔT larger than 150 ms fall within one standard deviation of the average of the Vp/Vs ratio and are associated with an uncertainty that does not significantly affect Vp/Vs. The majority of the points with ΔT less than 150 ms fall outside of the one standard deviation, which could be due to either uncertainty or the lithology of the geological area. The uncertainty in the values with a small time interval is large enough to significantly affect the Vp/Vs analysis.

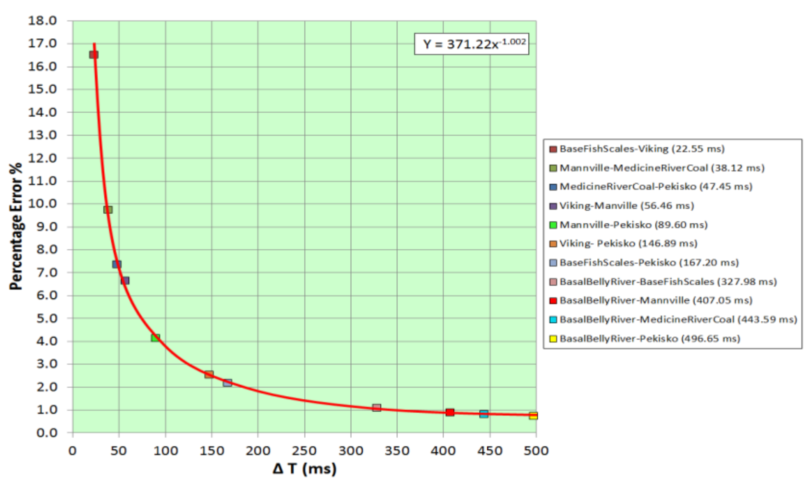

FIG. 2: Crossplot of percent relative error in Vp/Vs versus ΔT; the error tends to increase as the time interval becomes smaller.

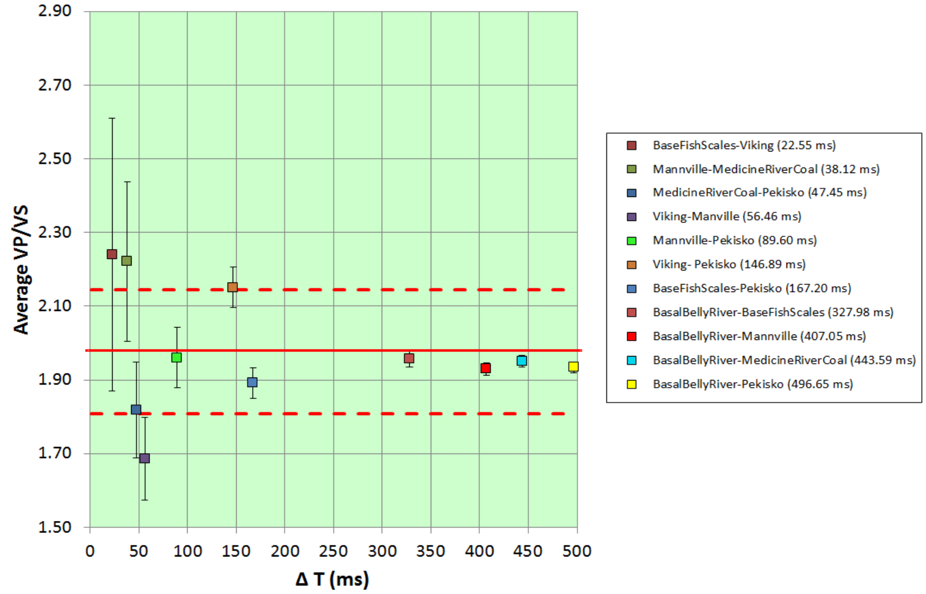

FIG. 3: Crossplot of average Vp/Vs versus ΔT; error bars represent the amount of uncertainty; the solid red line represents the average Vp/Vs value and the dashed red lines represent values one standard deviation away from the mean.

Conclusions

Analysis performed on the Hussar data indicates that the uncertainty in Vp/Vs values will increase as time interval becomes smaller. It is important for interpreters to understand this relationship in order to avoid erroneous results in interval Vp/Vs analysis. Based on the increasing behavior of error with respect to decrease in the time interval, as well as taking into consideration the variability of the Vp/Vs values due to uncertainty it is suggested to use isochron intervals greater than 150 ms. Interval Vp/Vs analysis for data with intervals greater than this time presented low uncertainty

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