Average versus interval *Vp/Vs*

Robert R. Stewart, Henry C. Bland, Qi Zhang*, and Felix Guthoff**

*Matrix Geoservices Ltd., Calgary; **Institute für Geophysik, Münster, Germany

ABSTRACT

The average *Vp/Vs* value of a set of layers is a weighted sum of the interval *Vp/Vs* values. The weighting is the fractional transit time in the interval relative to the total traveltime across the set of layers. The average value is also bounded by the maximum and minimum interval values. The thicker a specific layer is or the more anomalous its *Vp/Vs* value, the greater is its influence on the average value. Two modeling results (for a porous dolomite case and a sand channel) indicate that average *Vp/Vs* analysis should be able to discern anomalous reservoir values.

AVERAGE *Vp/Vs* VALUE OF MULTIPLE LAYERS

In seismic analysis, we often extract a low-resolution or macroscopic parameter, such as average velocity, which is dependent on higher resolution values such as interval velocities. Thus, we may be interested in understanding how the micro-values effect the macro-parameters. In this case, how do P- and S-interval velocity ratios effect the average velocity ratio? Average versus interval velocities are of interest for several reasons: For example, when picking events and isochrons on P and S sections, we often take several cycles between picked events (Miller et al., 1996). This means that a series of layers are entering into the isochrons, isochron ratios and thus overall *Vp/Vs* calculation. The question is how does the overall or average *Vp/Vs* value relate to the interval *Vp/Vs* values? Furthermore, what size of interval value anomalies could be expected to make a significant contribution to the average value?

Average *Vp/Vs* calculation

Suppose that we have a layered medium (with layers i=1, N) having P-wave and S-wave interval velocities (α_i, β_i). Each layer has thickness z_i and a set of transit times: t_i^p for one-way P waves and t_i^s for one-way S waves (Figure 1).

What is the average velocity ratio for the whole section? Let's first define an average *Vp/Vs* value as the ratio of average velocities (after Sheriff, 1984):

$$\gamma \equiv \frac{Z/T_p}{Z/T_s} , \tag{1}$$

where Z is the total depth traveled, T_p is the one-way P-wave traveltime to depth Z, and T_s is the one-way S traveltime from Z to the surface, and then

$$\gamma = T_s/T_p . \tag{2}$$

But $t_i^s = \gamma_i t_i^p$, and

$$\gamma = \frac{\sum_{i=1}^{N} t_i^s}{T_p} = \frac{\sum_{i=1}^{N} \gamma_i t_i^p}{T_p} \tag{3}$$

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \tag{4}$$

where $r_i = t_i^p / T_p$ or the fractional transit time.

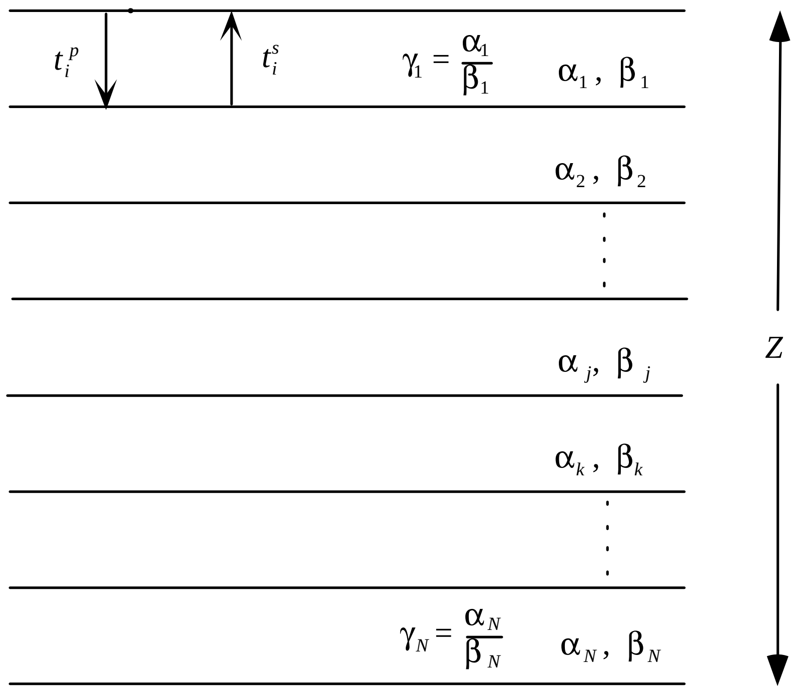

Figure. 1. Plane-layer elastic medium with N layers.

Thus, the average *Vp/Vs* value is the transit-time weighted sum of the interval velocity ratios. Furthermore, γ will be bounded by the minimum and maximum interval ratios (γ_i) as shown below:

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \geq \sum_{i=1}^{N} min(\gamma_i)\, r_i = min(\gamma_i) \sum_{i=1}^{N} r_i = min(\gamma_i) \qquad (5)$$

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \leq \sum_{i=1}^{N} max(\gamma_i)\, r_i = max(\gamma_i) \sum_{i=1}^{N} r_i = max(\gamma_i) \qquad (6)$$

Thus, $\min(\gamma_i) \bullet \gamma \bullet \max(\gamma_i)$.

In addition, if there are small changes in r_i and γ_i then

$$d\gamma = \sum_{i=1}^{n} (\gamma_i dr_i + r_i\, d\gamma_i) \qquad (7)$$

Note that if only γ_j changes (not the r_i 's), then

$$d\gamma = \frac{t_j^p}{T_p} d\gamma_j \qquad (8)$$

So if $d\gamma_j$ is, say, 0.2 and $d\gamma$ is 0.05 then r_j needs to be about 0.25 (one-quarter of the total traveltime in the isochron).

Examples

Let's take several examples to show the effect of a variable velocity layer on the average *Vp/Vs* value. In the first case, the medium's velocities are given in Table 1. Figure 2 shows the results graphically. If the observable change in an average *Vp/Vs* value is say 0.05 and we have an interval ratio change of 1.9 to 1.7, then we need a layer of about 50 m thickness to be discernible. So, for an isochron ratio or average *Vp/Vs* determination across a thick stack of layers, 130 m in this case, a 10 m layer gives little impact. On the other hand, and as expected, a 50 m target layer has a sizable influence on the final *Vp/Vs* value.

Table 1. Five-layer elastic model with variation in the third layer.

Layer	Thickness (m)	*Vp* (m/s)	*Vs* (m/s)	*Vp/Vs*
1	30	2300	1100	1.77
2	30	3000	1800	1.67
3	10 - 100	3500	1400 - 3000	1.2 - 2.5
4	30	4500	2500	1.80
5	30	3750	2200	1.70

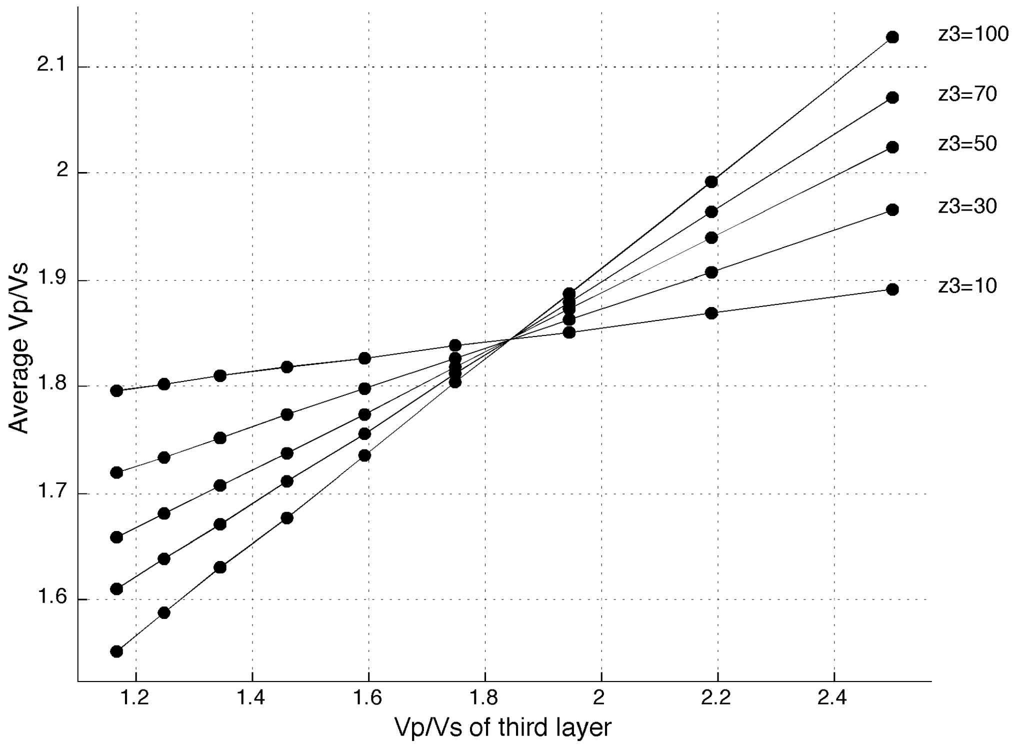

Figure. 2. Variation of the average V_p/V_S value over the 5 layer model (Table 1) with changes in thickness (z3) and V_p/V_S value of the third layer.

Two more examples, directly related to field cases are shown. We observe the effects of altering the reservoir thicknesses and *Vp/Vs* values for a Lousana Nisku case (Miller et al., 1996) and a Blackfoot sand channel example (Stewart et al., 1996) - both from Alberta.

The reservoir of interest in the Lousana example is a 23 m porous dolomite unit. Analysis of well logs and seismic data in the area indicate that the V_p/V value drops from about 2.0 to 1.75 from the basinal anhydrite to the reservoir dolomite. In Table 2 and Figure 3, we see that a 10 m reservoir in an 80 m isopach will likely be difficult to resolve using isochron analysis, but a 20 m reservoir should be discernible.

Logs in the Blackfoot, Alberta area indicate that P-wave velocities are about 4000 m/s in both reservoir sands and regional shales. The sand channels can be up to about 45 m thick. The S-wave velocity changes from about 2200 m/s to 2400 m/s from regional values to reservoir sandstone (Ferguson and Stewart, 1997). This provides a V_p/V_s change of about 1.9 to 1.7 from regional to reservoir units. Results from the Blackfoot model of Table 3 are shown in Figure 4. Again, if we assume that we can pick real variations in *Vp/Vs* down to about 0.05, then a Glauconitic sand with thickness greater than about 10 m in the 40 m isopach should produce an anomalous and measurable V_p/V_s value.

Table 2. Elastic values for intervals in the Lousana Nisku case.

Layer	Thickness (m)	V_P (m/s)	V_S (m/s)	V_P/V_S
Wabamun salt	25	4600	2300	2.00
Calmar shale	10	4300	2050	2.10
Nisku anhydrite	15	6100	3050	2.00
Nisku porous dolomite	5 - 40	7000	3333 - 4666	1.5 - 2.1
Nisku tight dolomite	10	7000	3950	1.77

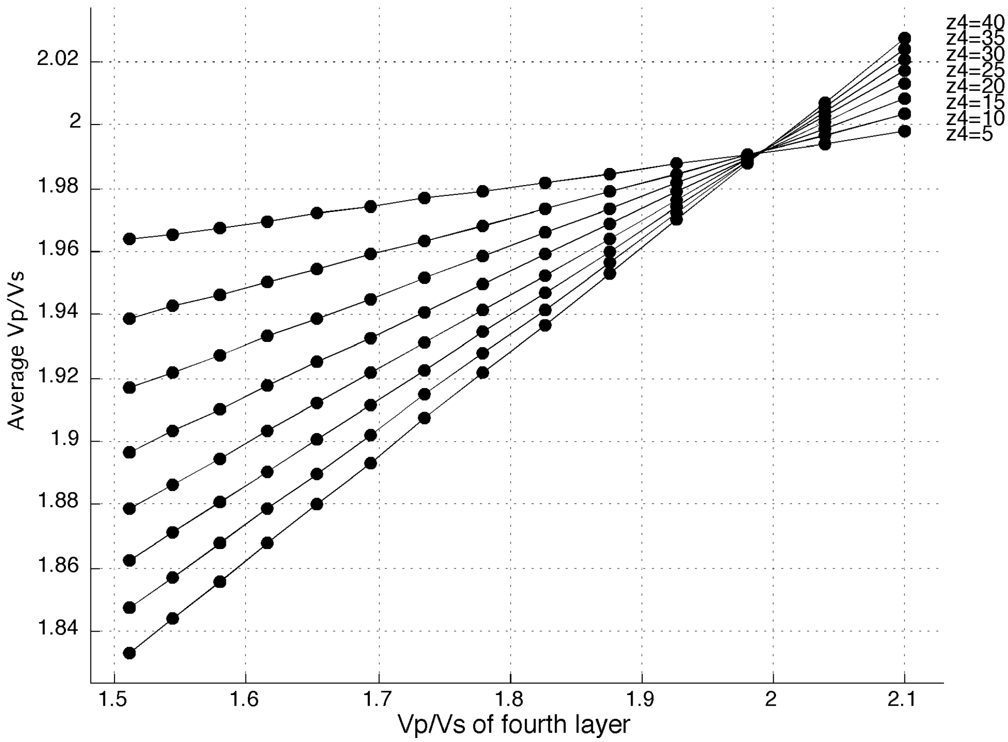

Figure 3. Variation of the average V_p/V_S value with thickness and interval V_p/V_S from the Lousana Nisku model (Table 2).

Table 3. Elastic values for the Blackfoot sand channel model.

Layer	Thickness (m)	V_p (m/s)	V_s (m/s)	V_p/V_s
Mannville	20	4200	2330	1.80
Glauconitic channel	5 - 45	4000	1900 - 2500	1.60 - 2.10
Basal quartz	10	4500	2500	1.80

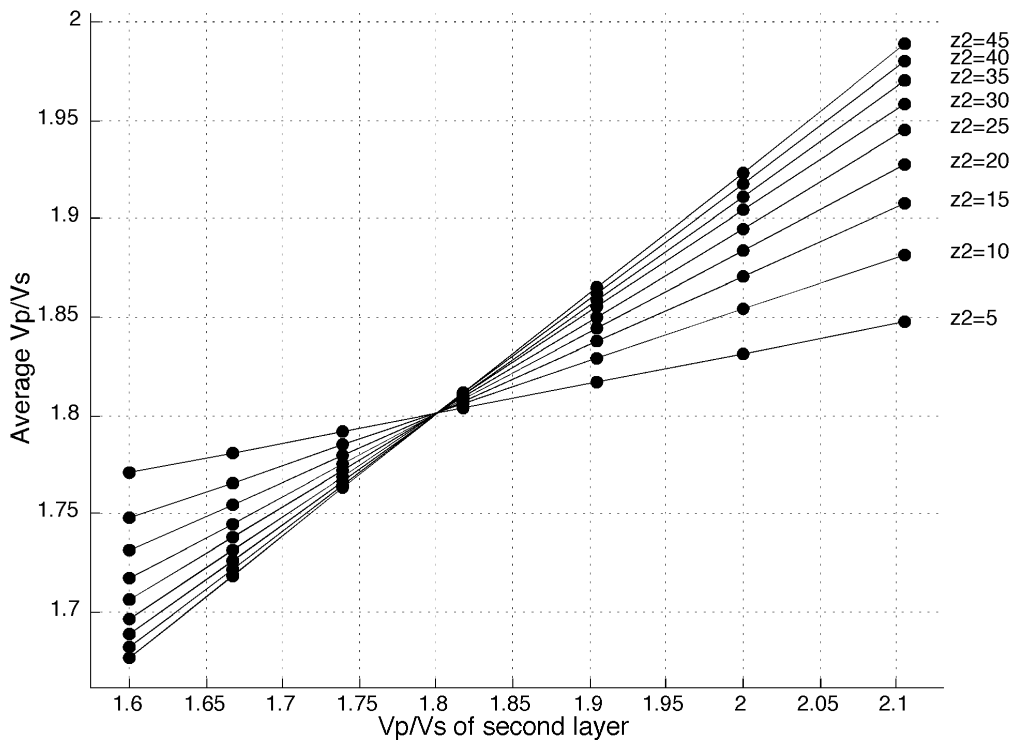

Figure. 4 Variation of the average V_p/V_s value with thickness and interval values from the Blackfoot sand channel model (Table 3).

CONCLUSIONS

The average V_p/V_s value of a set of layers is a weighted sum of the interval velocity ratios. The average value is also bounded by the maximum and minimum interval values. It will change according to changes in the target layer. The thicker the layer or more anomalous its V_p/V_s value, the greater its influence on the average value. Modeling for a porous dolomite reservoir and sand channel indicate that the reservoirs should be resolvable using average V_p/V_s values.

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