CANADIAN JOURNAL OF EXPLORATION GEOPHYSICS
VOL. 33, NOS. 1 & 2 (DECEMBER 1997), P 29-31

AVERAGE VERSUS INTERVAL *Vp/Vs*

ROBERT R. STEWART, HENRY C. BLAND, QI ZHANG* AND FELIX GUTHOFF**

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, from isochron ratios, should be able to discern anomalous reservoir values.

AVERAGE *VP/VS* VALUE OF MULTIPLE LAYERS

In seismic analysis, we often extract a lowresolution or macroscopic parameter, such as average velocity, that is dependent on higher resolution values such as interval velocities. Thus, we may be interested in understanding how the microvalues affect the macro parameters. In this case, how do P and Sinterval velocity ratios affect the average velocity ratio? Average versus interval velocities are of interest for several reasons: For example, when picking events and then isochrons on Pwave and convertedwave (PS) sections, we often take several cycles between picked events (Miller, 1996). The ratio of the PP and PS isochrons (t_{pp} and t_{ps}), assumed to be over the same depths, is used to calculate a *Vp/Vs* value:

$$\frac{Vp}{Vs} = \frac{2t_{ps}}{t_{pp}} - 1 \qquad (1)$$

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 *VpNs* calculation

Suppose that we have a layered medium (with layers i=l, 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 oneway S waves (Figure 1). What is the average velocity ratio for the whole section? Let's first define an average *Vp/Vs* value γ as the ratio of average velocities (after Sheriff, 1984):

$$\gamma \equiv \frac{Z / T_p}{Z / T_s} \qquad (2)$$

where Z is the total depth traveled, Tp is the one-way P-wave travel time to depth Z, and Ts is the one way S traveltime from Z to the surface, and then

$$\gamma = \frac{T_s}{T_p} \qquad (3)$$

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

$$\gamma = \frac{\sum_{i=1}^{N} t_i^s}{T_p} = \frac{\sum_{i=1}^{N} \gamma_i t_i^p}{T_p} \qquad (4)$$

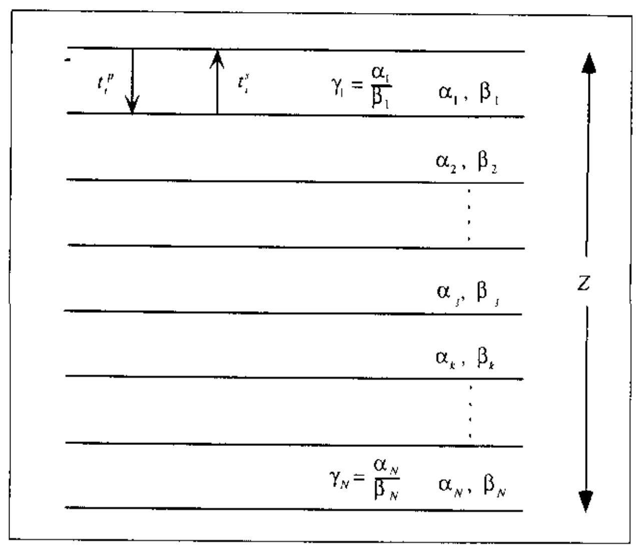

Fig. 1. Plane-layer elastic medium with N layers.

The University of Calgary, Calgary, Alberta T2N IN4; *Matrix Geoservices Ltd., Calgary; **Institute für Geophysik, Münster, Germany

Or

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \tag{5}$$

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

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

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \geq \sum_{i=1}^{N} min(\gamma_i)\, r_i = min(\gamma_i) \sum_{i=1}^{N} r_i = min(\gamma_i) \tag{6}$$

$$\gamma = \sum_{i=1}^{N} \gamma_i r_i \leq \sum_{i=1}^{N} min(\gamma_i)\, r_i = min(\gamma_i) \sum_{i=1}^{N} r_i = min(\gamma_i) \tag{7}$$

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

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

$$d\gamma = \sum_{i=1}^{N} \left(\gamma_i dr_i + r_i d\gamma_i \right) \tag{8}$$

Note that if only γ_j changes, then

$$d\gamma = \frac{t_j^P}{T_p} d\gamma_j \tag{9}$$

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

Examples

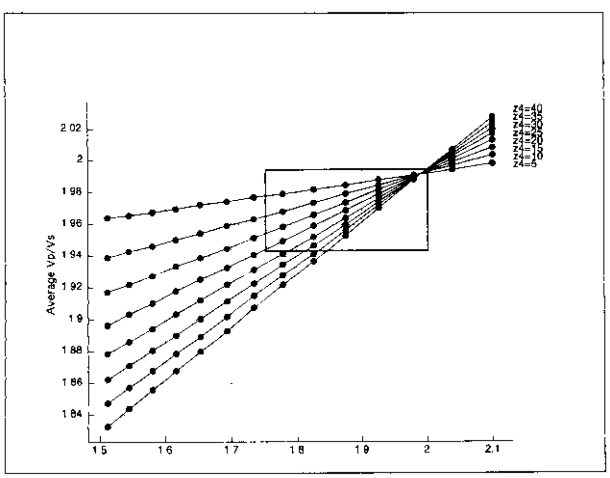

Fig. 3. Variation of the average V_p/V_s value with thickness and interval V_p/V_s from the Lousana Nisku model (Table 2).

Table 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

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. Experience with picking real data and synthetic seismograms suggests that we may measure changes in the *Vp/Vs* value of about 0.05 (Miller, 1996). Also, using the differential form of equation (1), for millisecond changes in the P and P-S isochrons over a hundred millisecond P isochron, we arrive at a change in *Vp/Vs* of about 0.05. 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 in this case. 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.

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, 1996) and a Blackfoot sandchannel 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 *Vp/Vs* 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

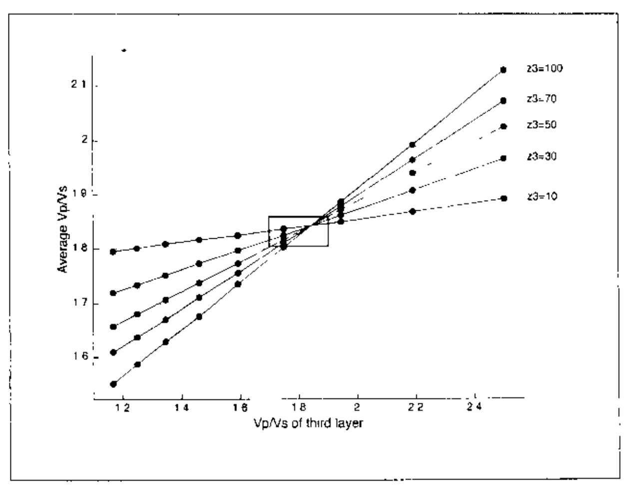

Fig. 2. Variation of the average V_p/V_s value over the 5 layer model (Table 1) with changes in thickness (z3) and V_p/V_s value of the third layer. The box shows a 0.05 variation in average *Vp/Vs* and a range from 1.9 to 1.7 in the third layer, indicating a 50m layer gives an average *Vp/Vs* change of slightly greater than 0.05.

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

Layer	Thickness (m)	*Vp* (m/s)	*Vs* (m/s)	*Vp/Vs*
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

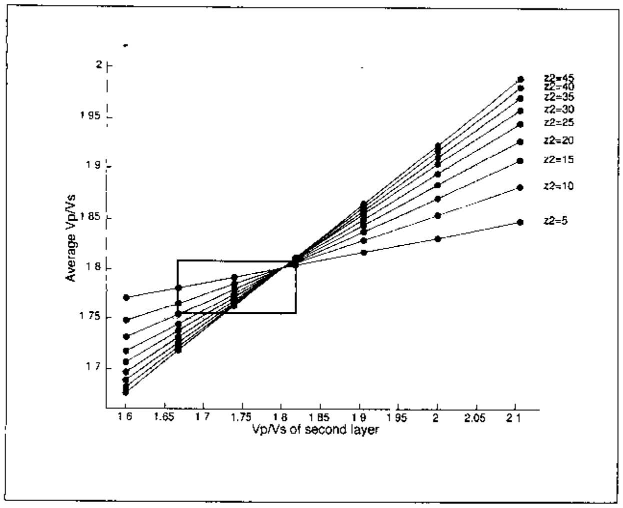

Fig. 4 Variation of the average V_p/V_s value with thickness and interval values from the Blackfoot sand-channel model (Table 3).

80 m isopach will likely be difficult to resolve using isochron analysis, but a 23 m reservoir should be discernible.

Logs in the Blackfoot, Alberta area indicate that P-wave velocities are about 4000 m/s in 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). If we have only changes in *Vs*, then this provides a *Vp/Vs* change of about 1.82 to 1.67 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 15 m in the isopach should produce an anomalous and measurable *Vp/Vs* value.

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

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

Conclusions

The average *Vp/Vs* 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 *Vp/Vs* 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 isochron ratios and average *Vp/Vs* values.

References

Miller, S.L.M., 1996.Multicomponent seismic data interpretation: M.Sc. thesis, Univ. of Calgary.

Sheriff, R.E., 1984, 2nd ed., Encyclopedic dictionary of exploration geophysics: Soc. Expl. Geophys.

Stewart, R.R., Ferguson, R.J., Miller, S.L.M., Gallant, E., Marrave, G., 1996, The Blackfoot seismic experiments: Broadband, 3C3D, and 3D VSP surveys: CSEG Recorder, 6, 710.

Ferguson, R.J. and Stewart, R.R., 1997, Sand/shale differentiation using shearwave velocity from PS seismic data: In press in J. Seis. Explor.