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Short Note

Research interest: Improving the velocity model

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INTRODUCTION

Travel time is perhaps one of the most important seismic parameter. It can be used to estimate properties of the subsurface. Velocity is one of these properties, and its importance has been increasing because it is the unique element that can convert time into depth. Seismic exploration has been evolving from time studies to depth studies because they map actual geology. Velocities can be also used to estimate petrophysical properties.

My goal is to find interval velocities from seismic data. Seismic velocities were considered important only as a parameter for stacking seismic data (one of the most important computer process in the prospecting industry (Claerbout, 1985)) or for converting structure maps from time to depth.

There are many methods of building an accurate velocity model; one of these uses maximum stacking power. The velocity model built in this way yields it to one kind of seismic velocity: the root mean square velocity (*Vrms*). Interval velocity is sometimes derived from rms velocity. Processes such as prestack depth migration are very sensitive to errors in the velocity model. Because of this, prestack depth migration is also used as a tool to estimate an interval velocity models (Sava, 2000). Methodologies such as Residual Curvature Analysis (Al-Yahya, 1989) and Depth Focusing Analysis (Faye and Jeannot, 1986) are different ways of building a velocity model. Tomography is another technique of estimating velocities from seismic data (Clapp and Biondi, 2000).

We can note that there are many ways of estimating velocities from seismic data, and it is not easy to find a solution to improve such estimation.

In the following pages, I will introduce a method that incorporates well information and seismic data; this method can help us to improve the velocity model. It is not a new approach (Brown, 1998; Clapp et al., 1997), but I review those works and provide a basis on which we can build our ideas about the velocity model building process.

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HOW TO IMPROVE A VELOCITY MODEL

Using inverse theory, the velocity estimation is usually an overdetermined problem. The use of all available sources of velocity information could help us to overcome this overdetermination. Seismic data provide velocity information (residual moveout analysis, dix equation). In addition Vertical seismic profiles give vertical traveltimes and well data provide major geological information (dip, velocities).

Seismic exploration is at a point where the fields are in very complex areas such as salt domes and overthrusts. Classically, the union of seismic information with surface geology has been used to improve the velocity model in an interpretative way, with the work of geophysicists and geologists combined to build a velocity model with an important geological component. This kind of work has been developed in such a way that now, the cooperation of both kinds of geoscientists is of primary importance in the continued development of the velocity model.

I think that a combination of seismic interval velocities along with well information (velocities, dips measurements) could bring in a more refined velocity model.

Problems involved

The introduction of well data in the velocity model demands some extra care because seismic data provide a relatively high horizontal resolution while well data provide a very narrow vertical resolution but a poor horizontal resolution. Well velocities are direct rock properties, estimated directly from the earth, while seismic velocities are indirect rock properties estimated from traveltimes. If the combination of seismic velocities and well velocities were possible, migration results would be favorably improved.

The problem is how to manage both velocities to get better seismic images. Well velocities may be interpolated to obtain a horizontal velocity model. This velocity model can be correlated with the velocity model from seismic data, resulting in a new velocity model from both kinds of information. The interpolation problem, may be solved using geostatistics. As a conclusive example, Lee and Xu (2000) show how geostatistics helped to improve the imaging of a geopressure zone in the Gulf of Mexico. Other interpolation techniques (Fomel, 1997) can be implemented in order to obtain a satisfactory *well velocity model*. Steering filters prove effective in interpolating velocities obtaining a horizontal velocity model from well data (Clapp et al., 1997, 1998; Clapp and Biondi, 1998), but it will be necessary to regularize well velocities in order to allow a satisfying the correlation between the velocity model from seismic and from well to produce good results. In the next section, I am going to discuss a method to obtain interval velocities from RMS velocities.

INTERVAL VELOCITY ESTIMATION

A basic daily problems in seismic processing, such as the estimation of interval velocities from RMS velocities, will be solved in this part.

The method used here was first introduced by Clapp et al. (1998). The method builds a velocity model from surface seismology while retaining the null-space. They start from fundamental concepts in Geophysical Estimation by Example (Claerbout, 1997) and define the simplest interval velocity estimation including the notion of null-space. Generally, Clapp et al. (1998) minimize interval velocities "wiggliness" where there are not good quality reflections.

In order to understand the method used in this part it is necessary to make some definitions (for further explanation the reader could refer to Clapp et al. (1998):

C as the matrix of causal integration, a lower triangular matrix of ones.

D as the matrix of causal differentiation, namely, $\mathbf{D} = \mathbf{C}^{-1}$.

u as a vector whose components range over the vertical traveltime depth τ, and whose component values contain the interval velocity squared v^2_{interval}.

d as a data vector whose components range over the vertical travel time depth τ, and whose component values contain the scaled RMS velocity squared $\tau v^2_{\text{RMS}}/\Delta\tau$ where $\tau/\Delta\tau$ is the index on the time axis.

The theoretical (squared) RMS velocity is defined by

$$\mathbf{Cu} \quad = \quad \mathbf{d}. \tag{1}$$

With imperfect data, our data fitting goal is to minimize the residual

$$\mathbf{0} \quad \approx \quad \mathbf{W}[\mathbf{Cu} - \mathbf{d}]. \tag{2}$$

To find the interval velocity where there is no data, we have the "model damping" goal to minimize the "wiggliness" **p** of the squared interval velocity **u**

$$\mathbf{0} \quad \approx \quad \mathbf{Du} \quad = \quad \mathbf{p}. \tag{3}$$

These two goals are preconditioned by changing the optimization variable from interval velocity squared **u** to its wiggliness **p**. Substituting **u** = **Cp** gives the two fitting goals expressed as a function of wiggliness **p**

$$\mathbf{0} \quad \approx \quad \mathbf{W}'\left[\mathbf{C}^2\mathbf{p} - \mathbf{d}\right] \tag{4}$$

$$\mathbf{0} \quad \approx \quad \epsilon\mathbf{p}. \tag{5}$$

This method was tested on two synthetic CMP gathers and one real CMP gather from the Gulf of Mexico.

Synthetic 1

A synthetic interval velocity model was built and a CMP gather was modeled using a finite difference code (Figure 1)

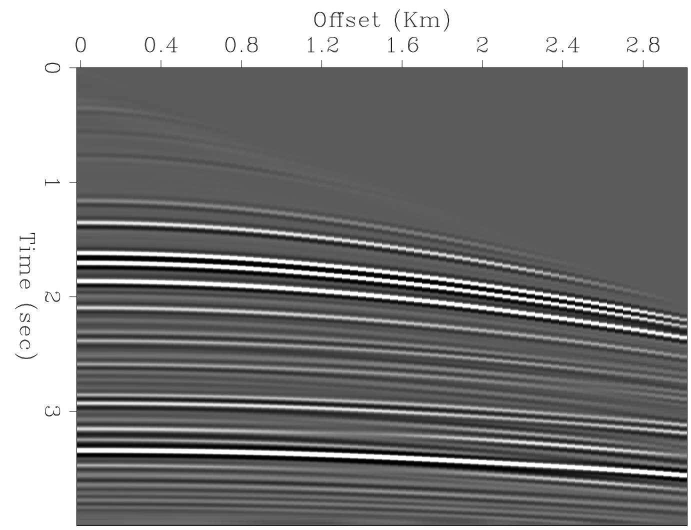

Figure 1: Synthetic Model. daniel1-synt-bob [CR]

For this gather, a velocity analysis is performed to obtain the RMS velocity **d** (equation 1). Figure 2 shows the rms velocity curve picked from the data, and Figure 3 shows a comparison of the interval velocity **u** obtained by the methodology described above, the RMS velocity **d** obtained from the velocity analysis, and the remodeled RMS velocity ($\mathbf{d_{remod}} = \mathbf{Cu}$).

This comparison shows that the remodeled RMS velocity is similar to the picked RMS velocity. This similarity prove that the method used works well.

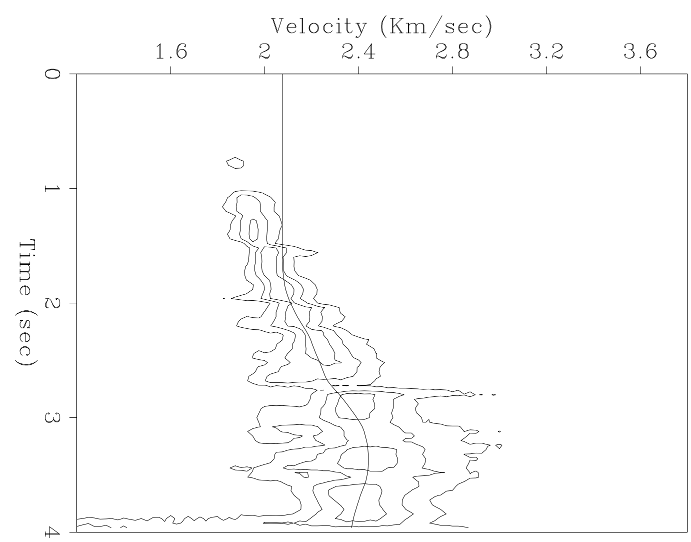

Figure 2: Velocity analysis for the first synthetic example. The curve corresponds to the picked RMS velocity daniel1-scan-bob [CR]

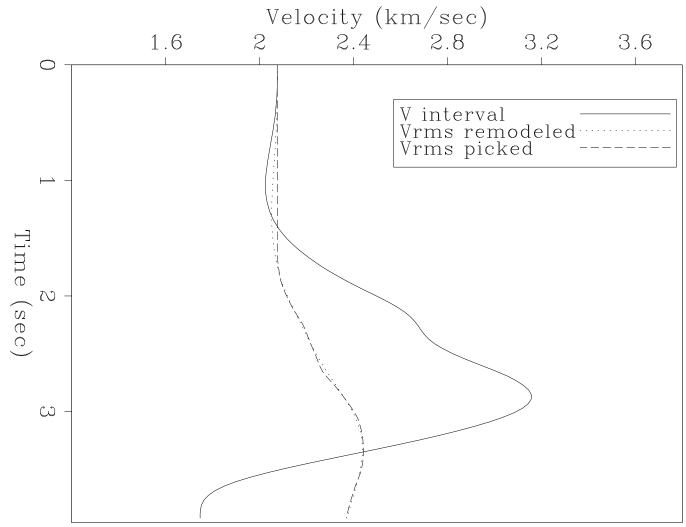

Figure 3: Comparison of interval and RMS velocities. daniel1-compar-bob [CR]

Synthetic 2

Some petrophysical parameters were carefully chosen to generate a synthetic model that simulates a geopressure zone (Dutta, 1987; Mavko et al., 1998). Figure 4 displays the velocity model used. At 3 km, it is possible to see a strong velocity change that identifies the geopressure zone. This velocity anomaly is visible in Figure 5 at 2.3 sec where a polarity inversion occurs.

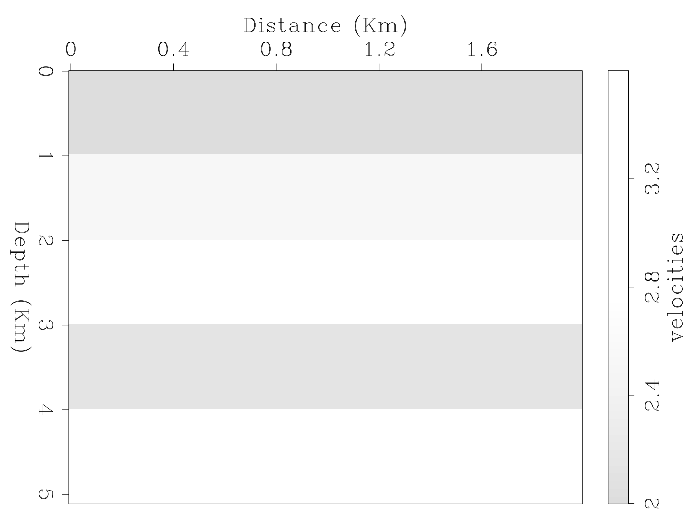

Figure 4: Depth velocity model for a geopressure zone. daniel1-model [CR]

Figure 6 shows the velocity analysis of this synthetic and the picked RMS. Finally, Figure 7 exhibit a comparison of the interval velocity obtained with the inversion method, the picked RMS velocity and the remodeled RMS velocity.

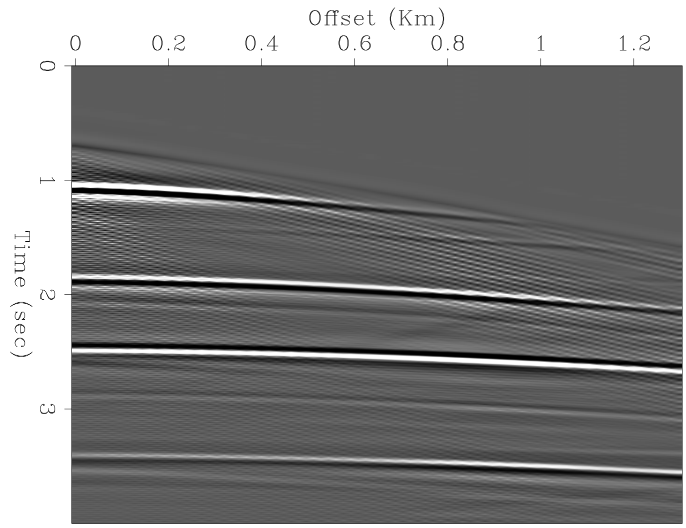

Figure 5: Synthetic gather simulating a geopressure zone. daniel1-synt-inv [CR]

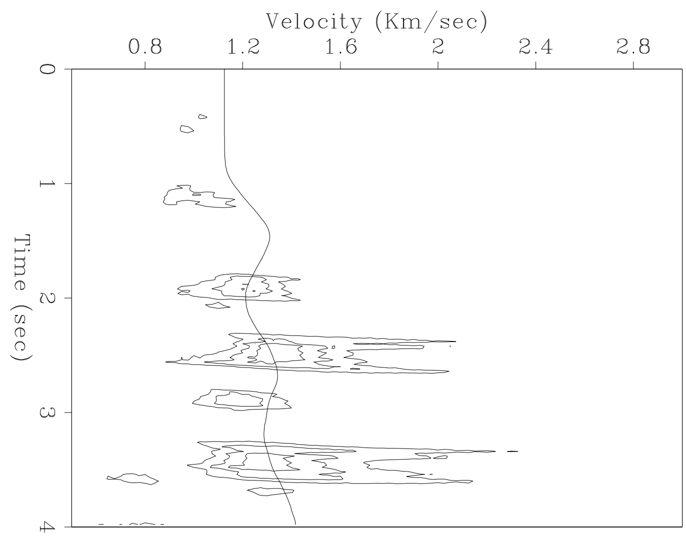

Figure 6: Velocity analysis for the second synthetic example. The curve is the picked RMS velocity. daniel1-scan-inv [CR]

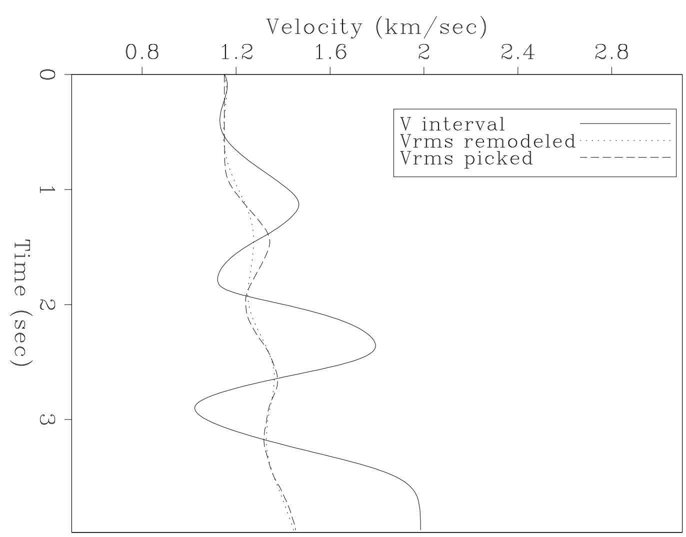

Figure 7: Comparison of interval velocity and RMS velocities. daniel1-compar-inv [CR]

Real Data

A CMP gather from the Gulf of Mexico (Figure 8) is used. The velocity analysis is displayed in Figure 9, with its corresponding *Vrms* picked in a velocity fairway. The comparison of the interval velocity obtained with the inversion method, the picked RMS velocity and the remodeled *Vrms* is illustrated in Figure 10.

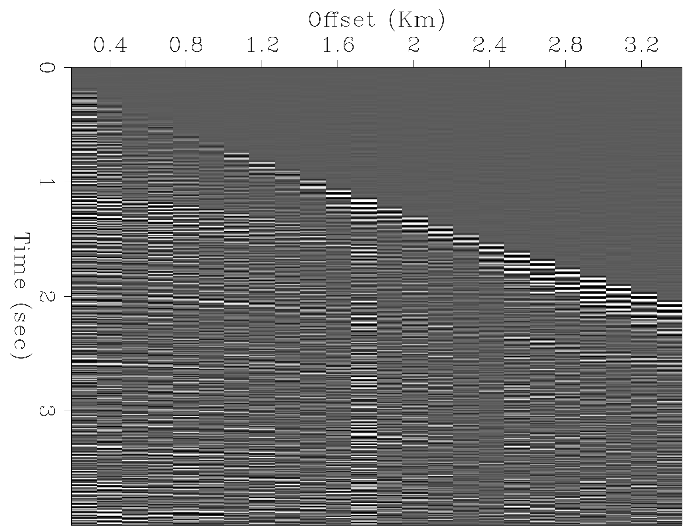

Figure 8: CMP gather from the Gulf of Mexico. daniel1-data [CR]

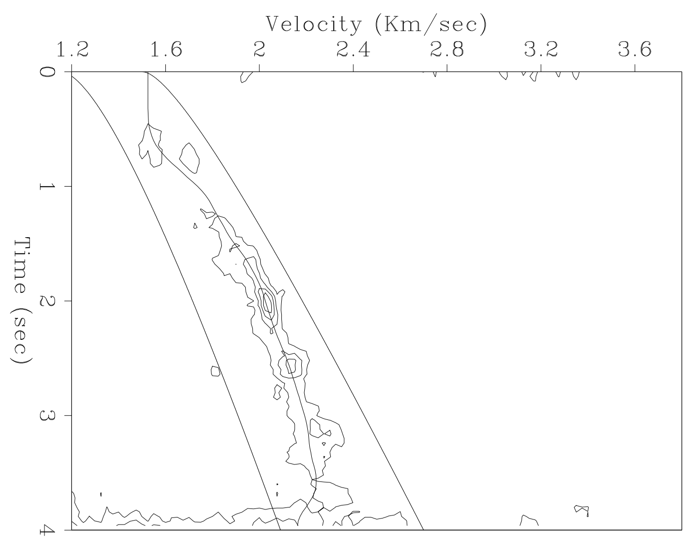

Figure 9: Velocity analysis for the real data. The picking for *Vrms* is done in a velocity fairway. daniel1-scan-data [CR]

FUTURE WORK

One of the next step will be to incorporate and interpolate dip data obtained from dip meters. This data converted into time could be utilized as a new parameter in the velocity estimation problem. Finally, interpolation of well velocities will give us a velocity model. That can be correlated with the seismic velocity model. This way, we hope to have a more accurate velocity model for future analysis.

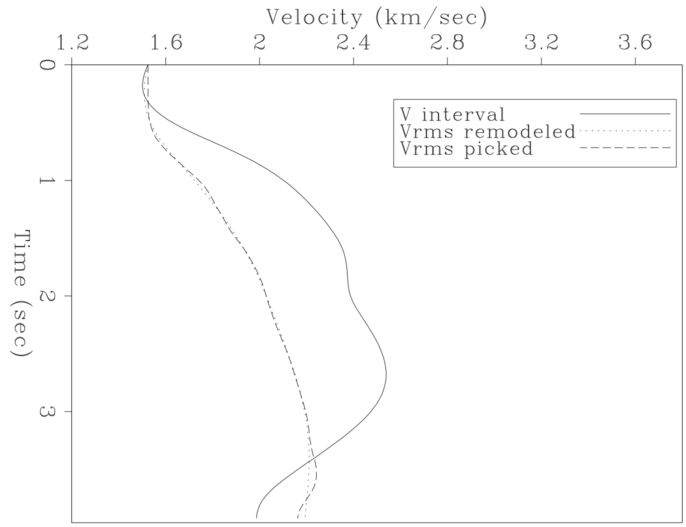

Figure 10: Comparison of interval velocity and RMS velocities. daniel1-compar-data [CR]

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