Subsurface velocity determination by grid tomography of depth migrated gathers

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SUMMARY

Determination of subsurface interval velocity is important for imaging by prestack migration, AVO studies and full waveform inversion. We propose a method which uses depth migrated gathers directly, and does not necessarily need a depth model. The approach is complementary to horizon based tomography. When a subsurface model can be identified, model-based tomography seems appropriate since it produces geologically constrained updates. However, if no depth model can be determined initially, a grid based approach is advisable, where one can update an interval velocity section without building a depth model.

INTRODUCTION

Much research effort has been devoted to devising new strategies for velocity analysis in the depth domain (Al Yahya, 1989, Faye and Jeanot, 1986, Stork, 1992, Kosloff et al., 1996). Among those, tomography of depth migrated gathers seems very promising. The advantage of tomography is threefold: First, tomography works globally on all the data and updates the whole velocity section, as opposed to local velocity analyses. Secondly, by working directly on depth gathers, one is able to use the seismic data without assuming hyperbolic time delays. Thirdly, manual picking of time arrivals is avoided according to a procedure presented in Kosloff et al., 1996. This is very important in 2D and unavoidable in 3D.

THE METHOD

Grid tomography uses as input data migrated gathers and picks on the stacked depth section (Fig 1).

The picked events should be of significant amplitude, however there is no requirement to perform full geological interpretation or build a depth model. For each CRP on a picked depth event, a window is built using the depth gather, centered at the depth of the pick. The nonflatness of the events is used to update the velocity section. The slowness updates are calculated on a coarse grid of a typical size of 30 CMPs horizontally and 200 meters vertically. Inside each cell the velocity is updated by a bilinear interpolation, thus producing a smooth update. If the velocity section is smooth, the traveltime error is connected to slowness by,

$$\delta t = \int_{ray} \delta S_L \, dl + \Delta P_Z \delta z \qquad (1)$$

(Farra and Madariaga, 1988, Kosloff et al., 1996). $\Delta P_Z = (\cos\Theta_r + \cos\Theta_l) S_L$ is the change in vertical slowness between the two rays of the CRP pair, with Θ_r and Θ_l the respective angles between each of the CRP rays and the vertical. S_L is the slowness at the emanating point of the rays (Farra and Madariaga, 1988, Kosloff et al., 1996). By assuming no change in zero offset traveltime, i.e.

$$\delta t_0 = \int_{ray^0} \delta S_L \, dl + \Delta P_z^0 \delta Z = 0 \qquad (2)$$

We can eliminate the depth term in (1) and obtain

$$\delta t = \int_{ray}\delta S_L dl - \frac{\Delta P_z}{\Delta P_z^0}\int_{ray^0}\delta S_L dl \tag{3}$$

This equation gives the change in traveltime of a given offset resulting from a slowness perturbation, when the zero offset time remains constant. Traveltime deviations in (3) are connected to deviation on a time-scaled depth gather via

$$\delta t = \delta\tau(\cos\Theta_l + \cos\Theta)_r/2 \tag{4}$$

(Kosloff et al., 1996). A substitution into (3) yields the final form of the tomographic principle:

$$\delta\tau = 2\left(\int_{ray}\delta S_L dl - \frac{\Delta P_z}{\Delta P_z^0}\int_{ray^0}\delta S_L dl\right)/(\cos\Theta_1 + \cos\Theta_2) \tag{5}$$

The spatial discretization induces the transformation of the integrals to summations, and the system of equations is solved via damped least squares (see e.g. Kosloff et al., 1996).

ANEXAMPLE

We consider a synthetic example consisting of five layers (Fig 2). The seismic line was 5000 meters long, with 500 CMPs. Each CMP had a fold of 30, and maximum and minimum offsets of zero and 2900 meters. The correct layer velocities were of 2000, 2500, 2750, 3000 and 3500 m/s respectively. The layer thickness varied from about 400 meters on the left to 500 - 1000 meters on the right. To test the algorithm, we changed the velocities to 2100,2300, 3000,2700 and 3800 m/s, respectively, and obtained the horizon positions by normal incidence ray migration. The velocity section obtained from this model served as an initial section for the tomography. While the velocities in this section were wrong, the ray migration insures consistent zero offset times which according to (2) is a prerequisite for the velocity determination procedure.

After two iterations of prestack depth migration followed by tomography the velocity section improved considerably (Fig 3). In the inversion we used every fifth CRP, the grid spacing was of 50 CRPs horizontally and 100 meters vertically. To help analyze the results we extracted the mean velocity for each CRP at each horizon (Fig 4). The first layer returned to its correct value of 2000 m/s, and also the second layer returned to 2500. The third layer deviates by up to 50 m/sec from the correct value of 2750. The fourth layer has an error of about 100 m/s in the center, and shows coverage problems on the sides, more so on the right side since the rays propagate beyond the model limits. The fifth layer was updated to a value of about 3650 m/sec in the middle.

This example shows the capability of grid tomography to resolve velocity errors that are not of the same sign. The quality of the update was better at the shallower locations which obtained more data. In real surveys, there are events also inside layers, which can help to further improve the results.

CONCLUSIONS

We have described a tomographic approach which improves a subsurface velocity section by using migrated reflection gathers. By avoiding the building of a depth model one can perform velocity analysis even in difficult cases when initially a depth model cannot be built.

The use of panels, in the procedure described in Kosloff et al., 1996, enables to incorporate nonhyperbolic traveltime errors in an automatic manner. We have illustrated the potential of the method by a synthetic example. Grid based tomography can be used after horizon based tomography as a final improvement of the result, and will be demonstrated elsewhere.

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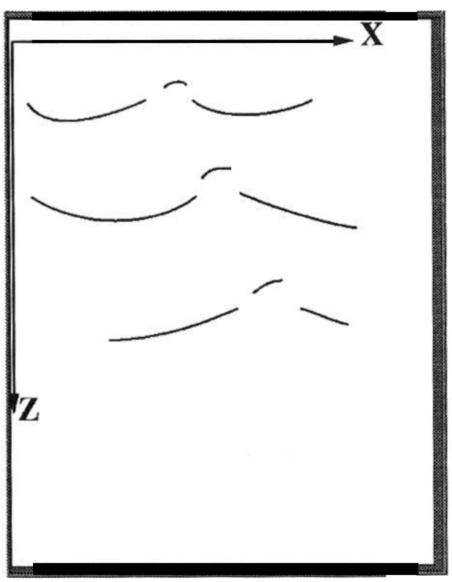

Figure 1

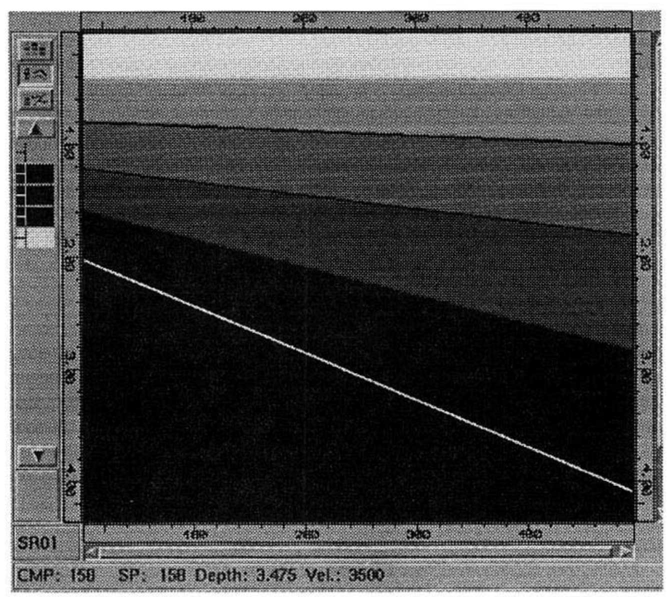

Figure 2

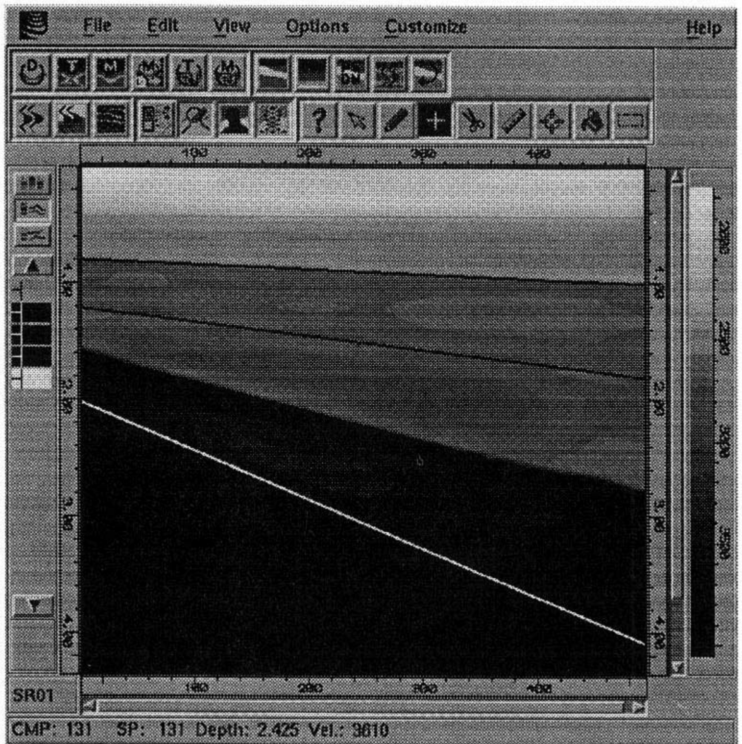

Figure 3

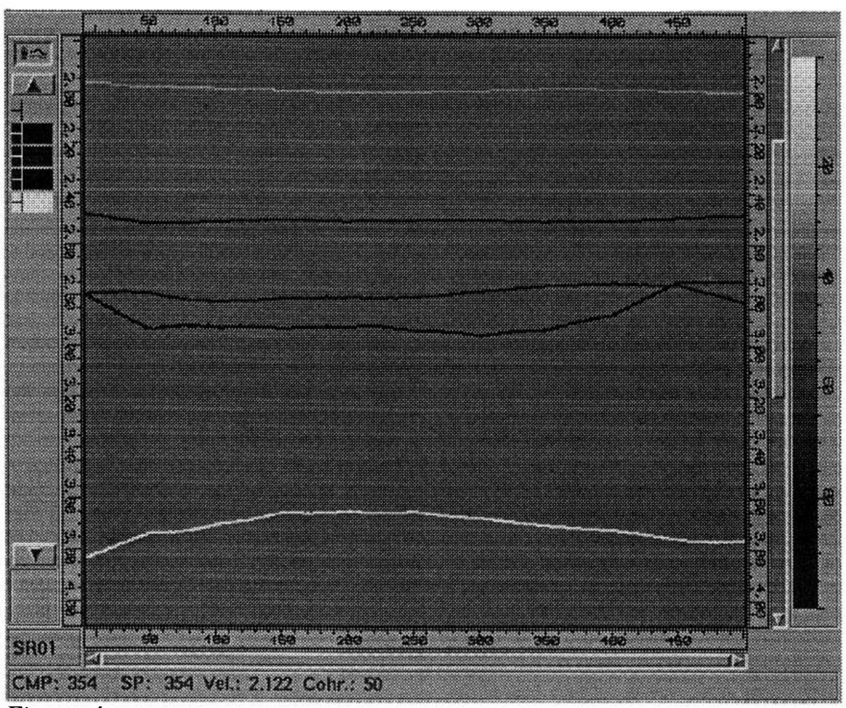

Figure 4