Estimation of long-wavelength near-surface velocity and low-relief structural anomalies Part 2: A new near surface reconstruction method

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Summary

In certain situations, velocity or structure anomalies in the near surface can cause a distortion in the structural interpretation of the deeper horizons. We present a tomographic approach, which tackles this problem by creating a detailed near surface depth-velocity model. The procedure uses three types of data; namely prestack depth migrated gathers, refraction delay times and refractor velocities, and zero offset travel times. The method is evaluated through tests on a synthetic data set where different combinations of input data are used. Results indicate that when all types of data are available, it is possible to resolve both the velocity and structure of the near surface horizons.

Introduction

In the past, the traditional isochron/isopach depthing procedure assumed that the shallow datum is free of structure. However, as discussed in part 1, recent field work has shown that shallow structural deformation may be caused by basement regeneration. In such a situation, the depthing procedure can yield an inaccurate estimation of the size of the subsurface structure. It appears therefore, that the only solution is to have a method which resolves both structure and velocity of the near surface.

In this work we present a new tomographic approach for determining both the shallow and the deep structure. The tomography is able to use different types of input data simultaneously. The data includes prestack depth migrated gathers, refraction delay times and velocities, and zero offset times from reflecting horizons. By means of a synthetic example we examine different options of using the data and modeling the near surface. The results indicate that when all types of input data are used, it is possible to resolve both the velocity and the structure of the near surface and the deeper layers. However, when not all types of data are present, there is a velocity-depth ambiguity, and in such situations the best alternative appears to be to fix depths of the near surface layers, and absorb all the near surface anomalies into the velocity.

In the following sections we describe the tomographic approach and evaluate its performance through a synthetic example.

Theory

The tomography updates interface depths and layer slowness of a subsurface model. Refracting horizons are considered as part of the model. The thickness and slowness updates in each layer are calculated by linear interpolation at equally spaced nodes. A typical distance between nodes is 20-30 cmps. With this type of spacing, the tomography is mainly designed to resolve long wavelength statics. The algorithm used in this study is the algorithm described in Kosloff et al., 1996 for macro model construction, - except that here it is mainly used for resolving near surface problems.

The tomography uses three different types of input. The first consists of correlated panels created from data in windows centered around reflection events in prestack migration gathers. The tomography detects non-flatness in the panels by operating on them directly with an automatic procedure which avoids event picking (Kosloff et al., 1996). The second type of input consists of refraction delays and refractor velocities (Hagedoorm, 1959). The difference between the delays and the travel time along the corresponding ray path in the initial model is calculated and passed on to the program as a time error (Fig 1).

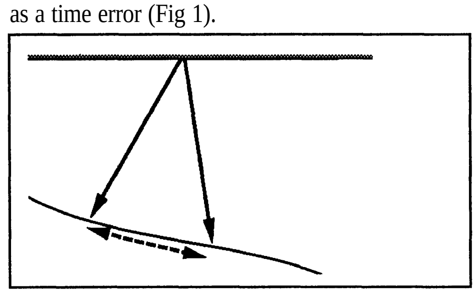

Figure 1.

The third type of input which can be used is zero offset travel times from the horizons. It is assumed that the zero offset times from the horizons in a prestack migrated section are preserved. Although this assumption is not always exact, in many cases it helps stabilize the inversion. Moreover, in Saudi Arabia very often portions of the refracting horizons are quite deep and can also be identified as reflections on a CMP stacked section. Although in such cases there is not a sufficient number of offsets for velocity analysis, the zero offset times however are valuable data.

In the following section, we explore by means of a synthetic example, a number of options for using tomography for the resolution of near surface problems.

Example

The tomography is tested against a model containing six layers (Fig 2). All the horizons except for the first horizon were planar and had uniform velocity above them. The first layer had a thickness of 250m and a velocity of 2000m/sec in the unperturbed regions, and contained three anomalies. The first anomaly was only in depth. The second anomaly was both in depth and time while maintaining the zero offset travel time of 500 msec of the unperturbed region (Fig 2). The third anomaly was only in the velocity.
The horizontal extent of each anomaly was 1800m which is also approximately the cable length of the synthetic seismic survey. The anomalies were separated by a distance of 3150m.

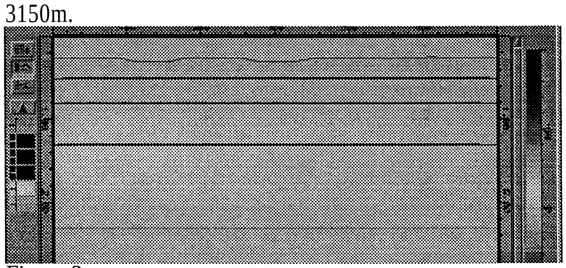

Figure 2.

A synthetic survey containing 600 cmps with a spacing of 30m was carried out over the structure. Each CMP contained 20 offsets with minimum and maximum offsets of 100 and 2000 meters, respectively.

The first series of tests started from an initial model where the first layer had a thickness and velocity of 250m and 2000m/sec respectively. The deeper horizons were placed by ray migration of picks from the zero offset time section obtained from the correct model, using the correct velocities for those layers. Because of incorrect parameters in the anomaly regions of the first layer, the deeper horizons for this model are not flat, as if the anomalies propagated downward (Fig 3).

Four tests were performed namely:

(a) Using only data from prestack migration gathers for horizons 2-6, and updating the velocity of the first layer while keeping its thickness as well as the velocities of horizons 2-6 constant.

(b) Like (a) but also using refraction delays for the first layer.

(c) Input like in (b) but both the depth and velocity of the first layer were updated.

(d) Input like in (b) but all velocities and depth were allowed to change.

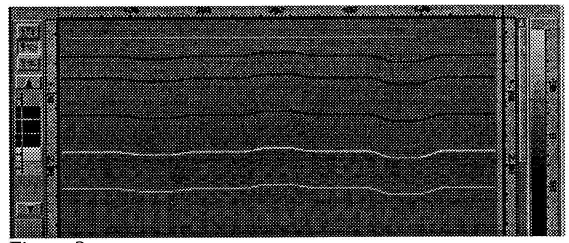

Figure 3.

Fig 4 shows the position of the horizons before (thin lines) and after tomographic updating according to (a) (thick lines), while Fig 5 is the corresponding figure for case (b). A comparison between the two figures shows that the inclusion of the refraction delays improved the results, and that the tomography is able to flatten the deeper horizons and move them close to their correct positions. As for the first layer, since its thickness was kept fixed, all the anomalies were absorbed in the velocity. The results for tests (c) and (d) were less successful, indicating that depth gathers and refraction delays are insufficient to resolve both the depth and velocity of the surface layer, and that it is advisable to resolve most of the surface anomalies before attempting to do a detailed velocity determination for the deeper horizons.

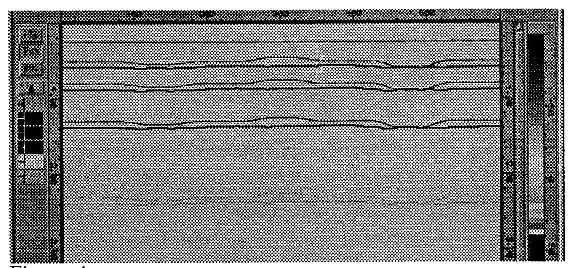

Figure 4.

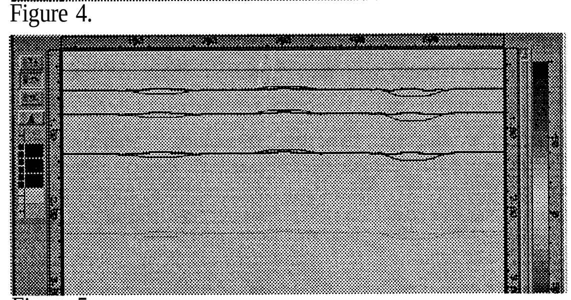

Figure 5.

In the second set of experiments, the treatment of the near surface was quite different, and rather than having a constant thickness first layer, the initial model was created by zero offset migration of all horizons including the first (Fig 6). Such a procedure is possible whenever the refracting horizon also appears as a reflection on the cmp stacked section. In this figure the anomalies in the first layer again caused non flatness in the deeper horizons. The series of tests described in (a)-(d) above were performed again.

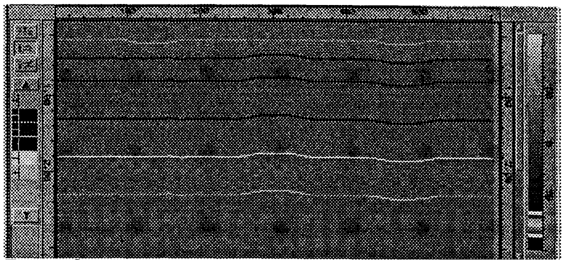
Figure 6.

For tests (a) and (b) in which the thickness of the first layer was kept fixed, the results were comparable to those of the previous experiment. In test (c), where both the velocity and thickness were allowed to change, we added the constraint of constant zero offset time for the first layer and obtained good results (Fig 7). In this figure the deeper horizons are quite flat and close to their correct locations, while the topography and the velocity (Fig 8) of the first layer are quite well resolved. The success of this synthetic experiment demonstrates the feasibility of resolving both velocity and structure of the near surface when all types of data are available.

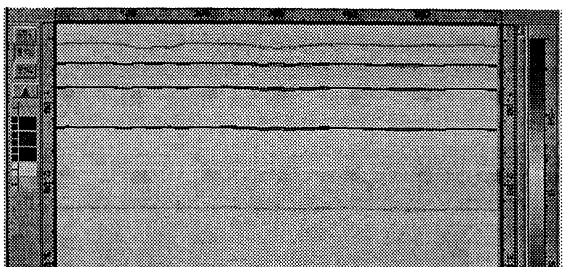
Figure 7.

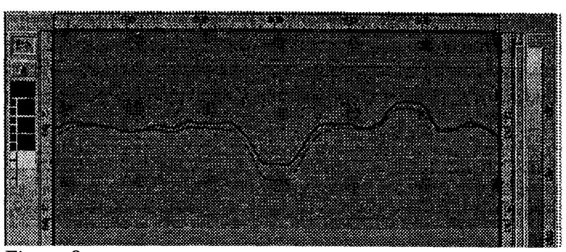
Figure 8.

Conclusions

We have presented a methodology for resolving near surface velocity and structure based on tomography. Three types of input data are used in the procedure, namely, prestack depth migrated gathers, refraction delays and zero offset time picks on CMP stacked time sections.

The series of tests on the synthetic example using different combinations of input data indicated that when all three types of input data are used, the tomography is able to determine both the velocity and horizon depths of the shallow part of the structure. The velocity-depth ambiguity is thus highly reduced. However, when the zero offset times are not used or not present, there is a velocity-depth ambiguity and the shallow structure and the deeper horizons cannot be determined simultaneously. In such a situation it appears that a more promising approach would be to fix the thickness of the shallow horizons and absorb all the anomalies into the velocity of those layers.

References

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Kosloff, D., Sherwood, J., Koren Zvi, Machet, E., and Falkovitz, Y., 1996. Velocity and interface depth determination by tomography of depth migrated gathers. Geophysics, vol 61,1511-1523.