AAPG Search and Discovery Article #90187 © CSPG/CSEG/CWLS GeoConvention 2013, Integration: Geoscience Engineering Partnership, 6-12 May 2013, Calgary, AB, Canada

2D Depth Velocity Analysis without Tomography

J. Patrick Butler*, WesternGeco, Suite 1200, 815-8th Avenue SW, Calgary, Alberta, Canada
jbutler2@slb.com
and
Randy Kolesar, WesternGeco, Calgary, Alberta, Canada

Summary

A module for measuring the depth velocity field (interval velocity, epsilon, delta) from 2D seismic data is presented. Upward ray tracing from selected reflector segments is used to select traces from the whole prestack volume whose angle of incidence equals angle of reflection on the segment. These traces can then be combined to form common offset gathers. Velocity can be scanned in any zone and the velocity, with the common offsets that are flattest and most coherent, picked. This methodology is fast, robust, and effective; and since it works on the prestack data, it removes the need for iterative depth migrations. It also allows the user to inspect the data as the model is formed. Since only a small set of strong reflector segments are selected it is robust in the presence of noise and broken up signal. It may be run routinely on 2D seismic lines.

Introduction

Tomography has become the generally accepted methodology for measuring and building interval velocity models in depth. These models are then ray traced to create travel times tables for prestack depth migration. However, though it has been very successful on large 3D marine projects, it does have some drawbacks, including multiple and noise sensitivity. Event picking can be a problem and the initial model needs to be good. The process is global and we cannot see the effects of individual changes in the model on our data. Run times are also large. Observing that tomography has not been generally adopted in time processing, it was decided to try to build a module that employs the data stacking procedures that underlie the usual time velocity analysis procedures.

Theory and/or Method

In conventional time processing, flat layers are assumed and the data is binned into CDPs. These are gathers of traces that best image the reflections under the CDP – traces whose CMP (common midpoint) is close to the CDP so that angle of incidence equals angle of reflection at the reflector (Figure 1). It is a small data set that contains much of the energy that builds the image of the reflector at the CDP. Even if CDPs are combined it is still a small data subset that can be repeatedly stacked, or common offset stacked, for velocity analysis. Notice that, for these methods, times are not picked – we actually get to look at the data as it stacks. For prestack time migration all the traces within a fresnel width on the line are stacked into each CDP. By stacking separate offset ranges into different output migration canvasses, gathers can be created at each CDP in which the residual offset dependence of the data can be seen. Again, a number of CDPs can be combined to allow us to analyze the velocity on a small number of traces. Now, even for NMO, the rays for the traces within a CDP form fans which cover a region of the line so they actually average the velocity field in time and space. Thus, the velocities we measure are stable, laterally and vertically, and can be successfully interpolated. It is not necessary to measure every event everywhere on the section to get a good velocity field and this is why they can be handpicked on a sparse grid to get reasonable results. The recorded times are integral times and the velocities are integral stacking velocities. They affect the gather at the event but not elsewhere. The velocity field is a unique stacking velocity at each CDP and each time for the whole line.

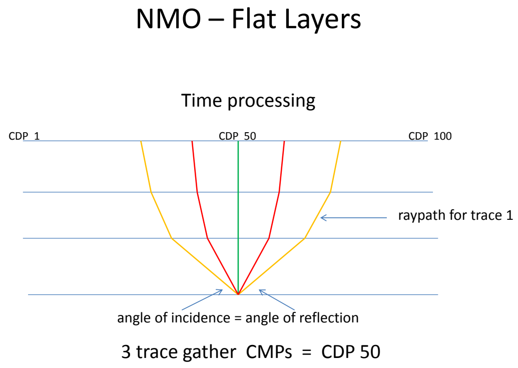


Figure 1: time processing

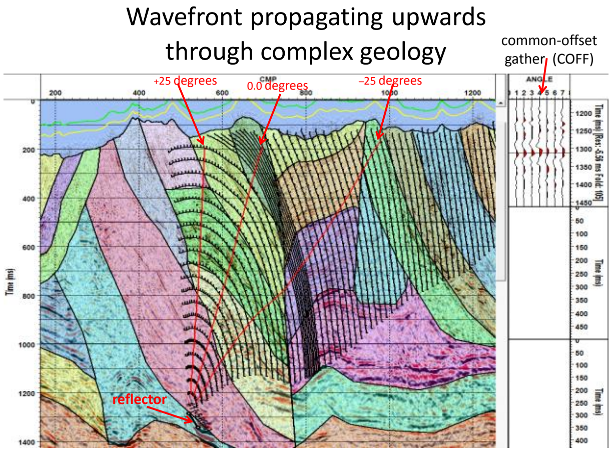


Figure 2: depth processing

In prestack depth migration, a ray is started from the shot followed down to the reflection point and traced back up to the receiver (Figure 2 raypath +25 to reflector to –25 degrees). There is no single stacking velocity at the reflection point as there is in time; instead, there are interval velocities, epsilon, and delta defined at each CDP, and each time, for the whole line. Now this is a much more difficult problem. In principle, this can predict the travel times much more accurately in complex geology but moveout at an event may be attributed to many interval velocities along the rays. Furthermore, if we change any velocities the rays change direction and the event moves.

To reduce this problem, the section (typically a prestack migration) is interpreted to divide it into regions of common geology and hence, interval velocity (Figure 2). This, generally, works well with a single velocity, epsilon, and delta for each zone; though we do have options to include velocity gradients. This reduces the number of velocities that need to be picked to something manageable. Next, some strong events are selected defining their dip extent and position. All the data could be migrated into these events but that is too slow. So as is done in time, the program selects just those traces that contain the most energy from the reflectors – those traces whose angle of incidence equals angle of reflection at the reflector. Since the angle is known the data can be binned into angle (and hence offset) ranges and stacked to create COFFs – common offset gathers (Figure 2). The velocity in a zone which is traversed by the rays can now be scanned and set to the velocity that gives the flattest and most coherent gathers. The other zones that are traversed also contribute so it is best, generally, to try to work from the top down (Figure 3). However, it has been observed that the velocity picked in a deeper zone is somewhat insensitive to errors in upper zones; especially if several reflectors, with rays that cross the zone in different directions, are picked simultaneously. If the zones above are incorrect the gather will not be flat but it will tend to be best near the true velocity.

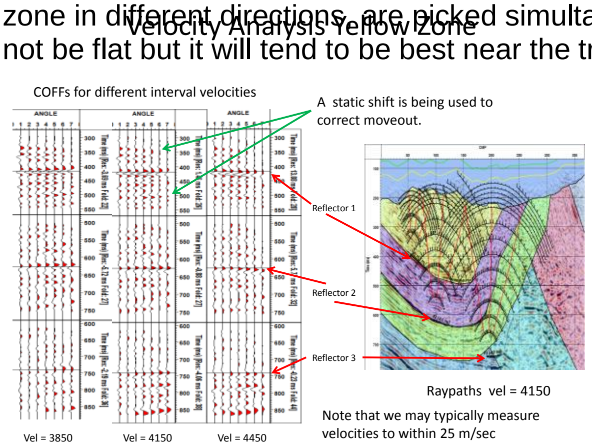


Figure 3: isotropic model

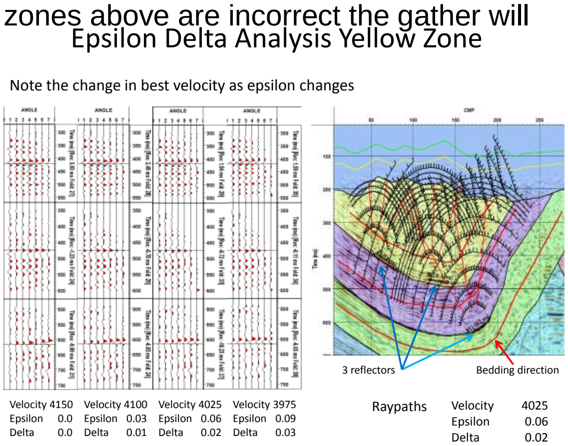


Figure 4: anisotropic model

To make this process work, the traces needed to construct our gather must be selected. This is nontrivial but still possible. An initially circular wave front is propagated upwards from each end of our reflector segment to surface. The dip is known so the angle of incidence can be carried along with the wave front samples. We are using a Huygons principle wavefront propagator; but a ray cluster would also work. As it crosses the surface the angle, time, and CDP are recorded. The positive angles can be combined with the negative (angle of incidence equal to angle of reflection) to yield a table of angle, two-way time, offset, and common midpoint (CMP). A trace header is brought in and the offset gives us two CMPs; one for each end of the reflector. If the trace's CMP falls between the two values then the trace belongs to the gather. The angle is known so the trace can be placed into an angle, which is equivalent to offset bin. The travel time and the CDP shift from the reflector midpoint is known; so the moveout can be removed and the common offset gather created. Now, this is a static shift valid for the reflector and is not time variant NMO, so the data will dip above and below the reflection time (Figure 3). However, it is easy to see this; and some data above and below the event is visible. The moveout is stretch free so longer offsets are more easily evaluated. Notice that the reflector that has been picked in time does not necessarily exist on the depth section exactly as picked. If the reflector is above or below the picked event the picks can be moved. Similarly, if the COFF is unexpectedly dim the dip may be wrong and that can be adjusted too. Note that because the display is in time, changes in velocity make minimal changes to reflector positioning. Note also that the picked segment should be short – the moveout is being interpolated linearly between the end points.

Examples

Performance:

Each time the velocity is changed in a zone, the velocity field must be resampled and the wavefronts repropogated. If we are examining, say, three events then that is six propagations to surface. We must also reselect the data, create the COFFs, and refresh the display. However, all this is completed single thread on a desktop in less than three seconds – that is 1200 different models per hour. Thus the picking time is dominated by user evaluation time. The processing time for a line in depth becomes very similar to the processing time for the line in time.

To measure epsilon and delta first the bedding direction is defined. Velocity and epsilon are interdependent so epsilon and delta are scanned with the velocity being repicked for each value. Only now can the best gathers be compared to choose epsilon (Figure 4). Hopefully, three reflectors that illuminate the zone from different directions are being used. We tried to automate this procedure but on this example the data was not good enough to produce a reliable result. Since the manual method is fast enough the code was abandoned.

Selecting only those traces whose angle of incidence equals angle of reflection on the reflector is an NMO, as opposed to, a migration technique. If we could pick all the dips on the section, say from the final prestack depth migration, then we could generate a full stack in depth. The diffractions would not be collapsed but the data would be positioned properly. This process works but does not have much application at this time. The beam steer migrations are a hybrid of this idea. (Gray et al., 2009) Note that the NMO process does not suffer the loss of frequency content seen with the Gaussian Beam method.

Quality Control:

Now, since this process uses the unmigrated prestack data, a final velocity model may be constructed without iterating migrations. Generally, the migration is run once and the position of the layer boundaries is adjusted slightly to create the final velocity model and migration. However, it is nice to check the velocity field. Some velocity may have been miss-picked or some small anomaly missed.

Three methods are available to check the migration. Firstly, look at the prestack time migration. If the depth model is accurate then the prestack depth migration in time should be as good overall as the prestack time migration. (Figures 5 and 6).

Secondly, all the velocities may be stepped out by a percentage. Any event that improves indicates something that has not been NMOed properly and points to an error in the zones above it.

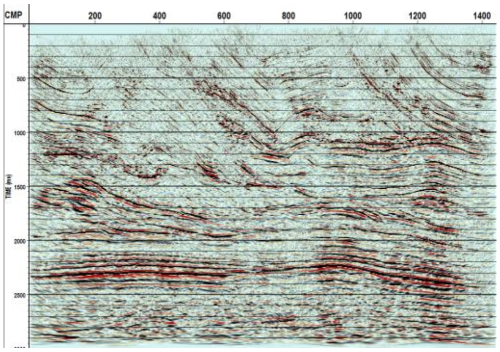
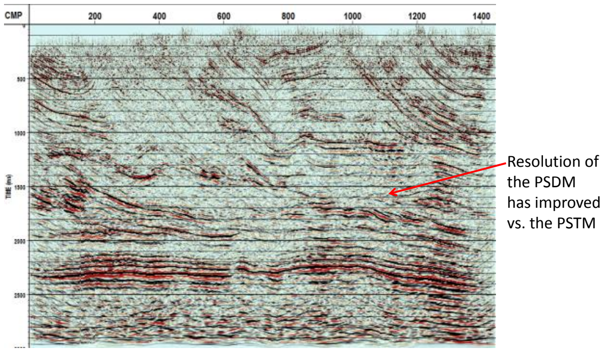


Figure 5: prestack time migration



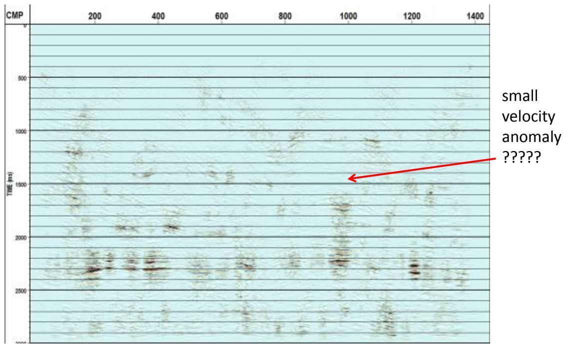
Resolution of the PSDM has improved vs. the PSTM

Overall the depth migration is as good as, or better, than the time migration

Figure 6: anisotropic prestack depth migration

For more sensitivity the input may be split into offset bins and each data set migrated separately. This output is sorted into CDP gathers and stacked. The stack and the gathers are combined to create a static, as a function of offset, in small overlapping windows in time and space. These statics are applied time variantly to the gathers and the data is stacked. These two stacks are subtracted and only those places where changing the moveout as a function of offset makes a difference will remain (Figures 7 and 8). This shows all those places where changes might be profitably made to the velocity model.

Effect of Residual Moveout

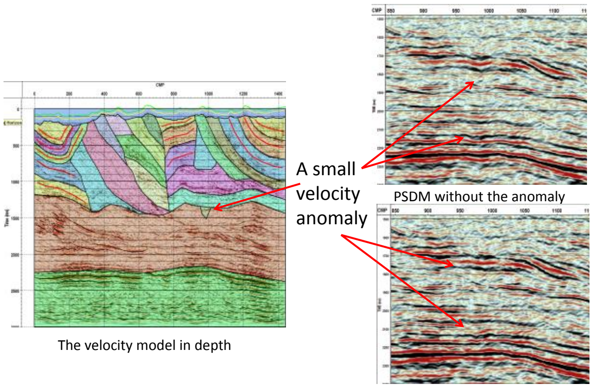


small velocity anomaly ?????

The dark events are places where changes in the moveout as a function of offset make a difference to the stack. A velocity anomaly may exist above them.

Figure 7: the velocity field diagnostic

Adding a Small Velocity Anomaly to the Model



A small velocity anomaly

PSDM without the anomaly

The velocity model in depth

PSDM with the anomaly

Figure 8: correct a small velocity anomaly

Conclusions

It has been shown that, by selecting data based on the angle of incidence equal to the angle of reflection in depth, a velocity analysis package can be created to easily, reliably and quickly create a 2D velocity model (velocity, epsilon, and delta) suitable for depth migration in highly structured areas. Tools are available to easily verify the fidelity of the result. The resulting velocity field may be used as a starting point for tomography; or as a final product.

Acknowledgements

Thank you to WesternGeco for allowing me to present the details of our 2D depth velocity analysis package from VISTA® 2D/3D Seismic Data Processing Software.

References

Gray, S., Bleistein, N., 2009, True-amplitude Gaussian-beam migration. Geophysics, **74**(2), pp. S11-S23