Improved interpretation from seismic images using prestack time migration: examples from south Alberta. Dave Klepacki, Janet Porter-Chaudhry and Colum Keith, Imperial Oil Resources Division, 237 Fourth Ave. SW, Calgary, Alberta T2P 0H6

Accurate interpretation depends on the clarity and continuity of the significant geological reflections. This requires that 1) the signal-to-noise ratio is high enough and 2) the reflections are in the right position and orientation. In "bad data" areas the greatest challenges are to suppress noise and estimate effective statics and velocity fields. Migration on data with residual statics and velocity problems cannot image the data properly. In other areas the signal-to-noise ratio is good enough that correct migration strategies greatly enhance the seismic image. The Castle River area is one such area where prestack time migration is an effective imaging tool.

Data from the Castle River area was taken through a normal post-stack migration processing stream and interpreted. The resulting velocity model, which varys both laterally and vertically, is then used to migrate the data prestack, correctly positioning the reflections for stacking. Successive iterations of guided velocity analysis and migrations further enhance the image. In the examples presented here, the clarity of the Cretaceous section was greatly improved. Improvement in the deeper Paleozoic section is less than that present in shallower section and will require further processing.

Close attention to velocity structure and iterative migration result in an image that can be confidently interpreted. For complexly structured regions, there seems little alternative to these relatively high effort methods.

Biographies:

Dave Klepacki

Education: B.Sc. Geology, Univ. of Massachusetts '78; Ph.D. Massachusetts Institute of Technology '85, Geology
Expertise: Structural geology, Seismic interpretation
Years in Petroleum Industry: 6 (Exxon Research/Esso)
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Janet Porter-Chaudhry

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Colum Keith

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Other Experience: '75-'77 Post-doc EPD/EMR, '77-'80 Research Assoc., Lamont-Doherty Geological Observatory

anisotropy and as an aid in noise attenuation problems.

Calvert: You have an interesting point. When we derive a refraction velocity, we should ask: velocity of what? Refracted waves are boundary waves that have nothing at all to do with P-wave transmission velocity.

Vasudevan: What time window was used for the residual statics?

Calvert: I can't recall exactly, but typically we choose a window where there is signal and where geology has parallel events.

Vasudevan: Unfortunately we have the problem that with a different choice of windows, we can end up with different solutions. I have another question that goes back to Ken Larner's presentation. What impact does poor signal-to-noise in the data have on what migration method is to be used?

Larner: Migration really isn't a signal-to-noise enhancing process and shouldn't be used as such.

Peter Cary (Pulsonic Geophysical): What about aperture? Should a low-dip migration algorithm ever be used in preference to a high-dip algorithm?

Larner: In cases where you know that steep dips are not present, a smaller aperture can help you.

Pat Butler: I would like to point out that if you are going to take into account changes due to the near-surface, then it is better to do it in a time sense, not a depth or velocity sense.

Calvert: Yes, times are measured facts, depths and velocities are interpretations.

Shlomo Levy (Landmark-ITA): The choice of statics window is very important. If we take a deep window, and do depth migration, we can destroy near-surface continuity that we could have gained with depth migration. We need to take a long window so that depth migration is not destroyed. The danger is that the CDP term in the statics solution can capture some of the nonhyperbolic moveout that only depth migration can correct for.

Larner: You probably do not want to restrict the window to a narrow portion of your data, but there is nothing gained by including large portions of noise within the correlation window.

Davis Ratcliffe (Amoco): What kind of lateral velocity variations exist below the weathering layer? Were they significant?

Calvert: Yes, they are significant.

Ratcliffe: We have found that prestack depth migration can help a lot in obtaining a better image in a similar problem area in Pakistan, for example.

Calvert: Yes, but you need to start with some coherent data nonetheless.

Bob Godfrey (speaker), Greg Johnson, Nick Moldeneavu (Geco-Prakla): Imaging Foothills Data

Bob Godfrey, a research geophysicist with GECO-Prakla, presented a case history of the processing of one dataset from the Canadian foothills where several processing techniques were used in an attempt to image the data. A considerable amount of time was spent on the preprocessing of the dataset, which included Green Mountain refraction statics. A comparison was then shown of the stack with residual statics after both trace-by-trace spiking deconvolution, and after surface-consistent deconvolution. The statics solution in both cases was obtained with a Gauss-Seidel, Wiggins-type residual statics approach. The result with surface-consistent deconvolution showed a considerable improvement over the trace-by-trace result. Next, crooked-line DMO was applied, but the improvement in the stack was only incremental. DMO aided the stacking of some criss-crossing events without destroying the signal-to-noise ratio in most areas. Next, the result after poststack time migration with an omega-x algorithm, plus some coherency enhancement showed a "reasonably good" final result obtained by normal processing techniques.

The next approach that was used was to apply prestack time migration using a Kirchhoff algorithm. The approach was to output migrated gathers, which are used for postmigration velocity analysis. The velocities can then be used either for stacking the migrated gathers, or as improved migration velocities for another iteration of prestack time migration. In this case the migration was not repeated. The stack of the migrated gathers showed the wormy appearance that is characteristic of Kirchhoff migration. A maximum migration aperture of 9 km was used. For this dataset the stack after prestack time migration showed only marginal improvement over the poststack time migration result.

At this point, the dataset was processed with prestack depth migration. A Kirchhoff algorithm was used, with the traveltimes calculated with the finite-difference, eikonal equation technique of van Trier. In order to obtain the starting depth model, an image-ray migration of the time model was performed, and this model was then smoothed. The starting model for this dataset showed large lateral velocity variations from 3000 m/s to 6000 m/s. The first prestack depth migration was done with a model derived from the prestack time migration result. The structure in the model was then modified with four iterations with these velocities. At this point the result was given to the interpreter, who modified the velocities, and the migration was performed again. At this point the process was stopped, and poststack depth migration was applied to the final stack obtained by the "normal processing stream" with the model derived from prestack depth migration. The result was degraded by a large number of migration artifacts.

In conclusion, the prestack depth migrations were observed to be very sensitive to residual statics. Surface-consistent deconvolution was an important step in obtaining a good statics solution. In addition, modeling software for determining whether the time-depth models are consistent is important. When unbalanced sections are derived, this can lead to changes in the models.

Questions:

Davis Ratcliffe: I am concerned with the methodology you used for changing the velocity model. We use well control and any conventional velocity information to derive the starting model. We then iterate 30 to 40 times with prestack depth migration and let prestack depth migration dictate how the velocities should be modified.

Godfrey: What we have done is fix the velocities provided by the interpreter, and then iterate on the structure prestack. In this example, we have iterated on the structure four times. At each iteration we can do some focussing analysis to update the model. This is a method used in a paper by Whitmore with poststack depth migration.

Ratcliffe: To get the structure to stabilize, you may need to iterate 30 or 40 times.

Larner: Have you tried looking at individual offsets to see residual moveout and using that to update model?

Godfrey: Yes, we have done that on marine data, but, not yet on foothills data.

David Klepacki (speaker), Janet Porter-Chaudhry, Colum Keith (Imperial Oil Resources Div.): Improved Interpretation from Seismic Images using Prestack Time Migration: Examples from South Alberta

David Klepacki, a foothills interpretation geophysicist with Imperial Oil, began his talk by pointing out that the interpreter's job is a lot easier when there are long continuous reflectors to interpret. His talk showed examples where prestack time migration succeeded in giving a better, more continuous, image. Klepacki also reiterated a couple of points from the previous presentations. First, you need good signal-to-noise going into the migration. This often requires a lot of front-end work on statics and velocities. Second, it should be obvious to everyone now that we need to move away from common midpoint stacking in processing complex data.

For illustration Klepacki used some data from the Waterton area of southern Alberta that has good signal-to-noise. The data were processed with prestack time migration because of time and expense constraints. They have found that the ability to perform residual velocity analysis after migration has helped to solve many of the imaging problems due to smear and steep dips. This is not to say that prestack depth migration would not be preferable. Prestack time migration works well with a vertically varying velocity field, but not so well for laterally varying velocity. Depth migration would be preferable, but time constraints at present inhibit the use of prestack depth migration all the time.

A shot record from the Waterton area data showed the good quality of the data. Klepacki noted that this area was a fairly good one for data quality. On the other hand, other areas, such as the northeastern British Columbia foothills are well known for producing data with extremely bad signal-to-noise. A stack of the line after "normal" processing showed large gaps of "no data" zones, where no good reflectors were visible. Using the velocities from this initial result, prestack time migration was then performed on the data. Residual velocity analysis was then performed on the prestack, postmigrated data with the use of common-velocity-function panels. At this point it is important for the interpreter to be involved. A processor might pick the highest energy events, whereas the interpreter might pick events that reinforce a preconceived notion of what the section should show. Probably neither is perfectly right, but hopefully there will be a happy medium. The interpreter probably has a better idea of what the correct interval velocity is at a particular time or depth. The improvement in the Waterton dataset after prestack time migration was dramatic. The improved stack was then interpreted, and a depth model was derived from the time section. To conclude, Klepacki reiterated that prestack depth migration was desirable, but that time constraints inhibited its use right now.

Questions:

Ken Larner: How frequently spaced were the velocity analysis positions? Were they close?

Klepacki: Yes, I don't remember exactly, but we try to do velocity analysis at very close intervals after prestack time migration.

Cary: Is it possible to force the image to have long continuous reflectors, even if the subsurface is really not that way?

Klepacki: It is a possibility. Sometimes there is a choice as to which events to pick, in which case you just hope that you can see your way. It is somewhat of a seat-of-the-pants approach, but hopefully it is obvious when you are abusing the system, and when you are getting closer to reality.

Cary: You stated that prestack time migration gives improved images, but that prestack depth migration would be preferable. Do you think that time migration is eventually going to become extinct?

Colum Keith: I think that we are probably going to want to do poststack time migration on everything. Then, for the interesting areas we would acquire more data in that area. With the new data we would do the processing with prestack time migration, to get a better understanding of the velocity model. With a line that will be drilled, we would then do prestack depth migration, since drilling is a significant investment. I don't think that prestack depth migration will be done on every line that comes in house in the foreseeable future. That's just my opinion.

Calvert: Your results showed that events which were not dipping very much were imaged better with prestack time migration, so the stacking must have been better. Was this just because of closer velocity analysis positions, as Ken Larner said?

Colum Keith: I suspect not. We always do our velocity analysis at close intervals. The prestack time migration does allow a better velocity analysis. Probably prestack time-migration velocities applied even to "normal" processing would produce a large improvement.

Karl Schleicher (Halliburton Geophysical Services): What method of prestack time migration did you use and why?

Klepacki: We used common-offset Kirchhoff migration. Janet may have more to say about why.

Janet Porter-Chaudhry: We have tried other prestack time-migration methods and have ruled them out for various reasons. Kirchhoff is the method we tend to use.

Larry Mewhort (Husky): With the final prestack time-migration image, did you do horizon-based migration with image rays to get the final depth model?

Klepacki: No, we use a Sierra-type depth conversion. We then stick this model into a GEOSEC balanced-section construction tool, and use that to smooth the lines and check the model for balance and thicknesses.

Moshe Reshef (Landmark-ITA): Structural Imaging in Complex Structural Areas

In contrast to the previous talks, Moshe Reshef presented results from working entirely with prestack depth migration. All the final sections were displayed in depth rather than time. Reshef began by emphasizing a few important points that must be taken into account with foothills data. First, the migration algorithm must be capable of handling the irregular acquisition geometry that is used for land data. This can have a big influence on the choice of migration algorithm to use. Next, the algorithm must handle the combination of topography variations and high velocities at the surface. Also, 3-D effects are obviously important, so issues such as crooked lines and energy arriving from out-of-the-plane must be considered.

The sparse, and often irregular, sampling of shot points with land data compared to marine data can have a big impact on the performance of the migration algorithm. With marine data it is possible to use a migration algorithm that works in both the shot and receiver domains, but with land data the common-receiver domain can be severely aliased. It is not unusual to have a jump in the shot interval within the line of, say, a quarter of a cable length. For this reason, migration on common-shot gathers is preferable. In this domain the migration can be localized to specific areas of a line. All the migrations are done from surface. In addition, results are often improved just by treating the topography correctly. Just applying a static shift and starting the migration from a flat datum isn't good enough.

Prestack depth migration does not have to be an expensive process. To reduce the processing time, downward continuation and velocity analysis can be performed in layers. It is possible to keep the result from the last layer and use it as the input for the migration of the next layer. In practice several different migration methods are needed: Kirchhoff, phase-shift, and space-frequency finite-difference.

Reshef then showed some data examples. Looking at a single migrated shot profile, you could see the topography variation within a cable length, which shows how important it is to handle topography correctly. The poor quality of a "normal" stack from the area indicated that the data were acquired in a complex, problem area. As described earlier, the interval velocity analysis required for prestack depth migration was performed in an iterative manner, from the surface down. This analysis requires interactive geological interpretation. A method that has been found to be fairly robust, a true CDP panel analysis, is used for picking correct interval velocities. The migrated panels are analyzed locally, not in one pass of the entire dataset.