A study of imaging with a synthetic Foothills dataset

Han-xing Lu and Gary F. Margrave

SUMMARY

The commercial processing software, ProMAX, was used to process a numerical data set with both conventional processing flow and pre-stack depth migration from topography. The results show that the image created by pre-stack depth migration from topography using a correct velocity function is the best. Images obtained by conventional processing flow, where velocities are derived from the data, are acceptable too (especially in the time domain); of these, the post-stack time migrations are the best.

INTRODUCTION

The structural geology of the western Canadian foothills is dominated by a series of thrust faults, complex folds and steeply dipping formations. Seismic imaging is an essential tool in the petroleum exploration of such complicated geology. Such thrust-belt geology often causes a violation of common midpoint assumptions. As shown in Figure 1, the common reflection point is not the common midpoint for a dipping event. Theoretically, the seismic data cannot be processed as CDP gathers using conventional procedures; instead, pre-stack depth migration from topography has to be used. This experiment tested for synthetic structural data; the capabilities of conventional (CMP) processing are pre-stack depth migration. Images generated by the conventional method, pre-stack depth migration from topography using model velocity, and using velocities converted from the stacking velocities (which is picked from velocity analysis) are compared.

THE RESULTS

The synthetic shot gathers and the velocity model were donated by Dr. Samuel Gray (Veritas GeoServices). The velocity model in Figure 2 shows a geological section consisting of a number of faults and folded layers (typical of Foothills mountainous thrust regions). The top is air, with a complicated topography (Gray, 1998).

The model is 25000m long, 10000m deep. Velocities range from 3500m/s at the top to 5900m/s near the bottom. This velocity model was used to generate 278 two-dimensional acoustic shot gathers from the earth's surface. The data were recorded by a split spread of 480 receivers with offsets ranging from 15m to 3600m on both sides of the shot point. The 2-D wave equation (finite-difference modeling), used to generate the data set, caused cylindrical spreading loss (roughly proportional to $T^{-1/2}$).

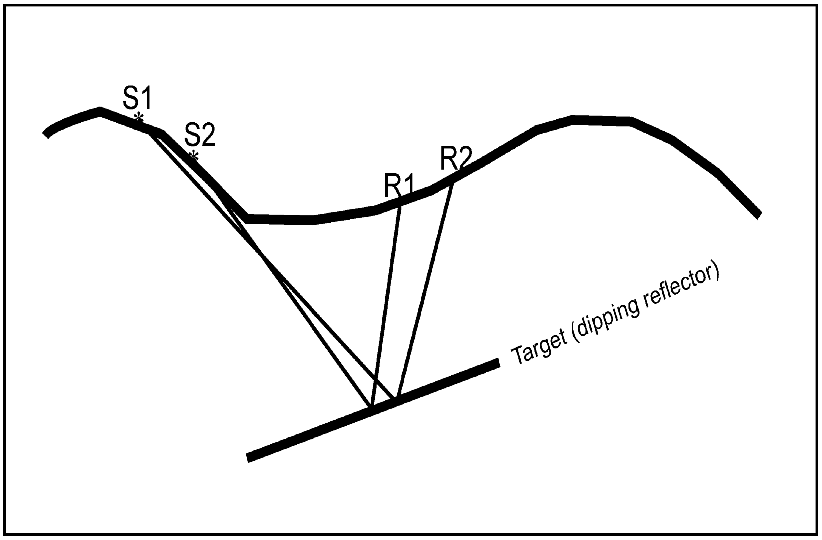

Figure 1. The dipping reflector violates the assumption of common midpoint.

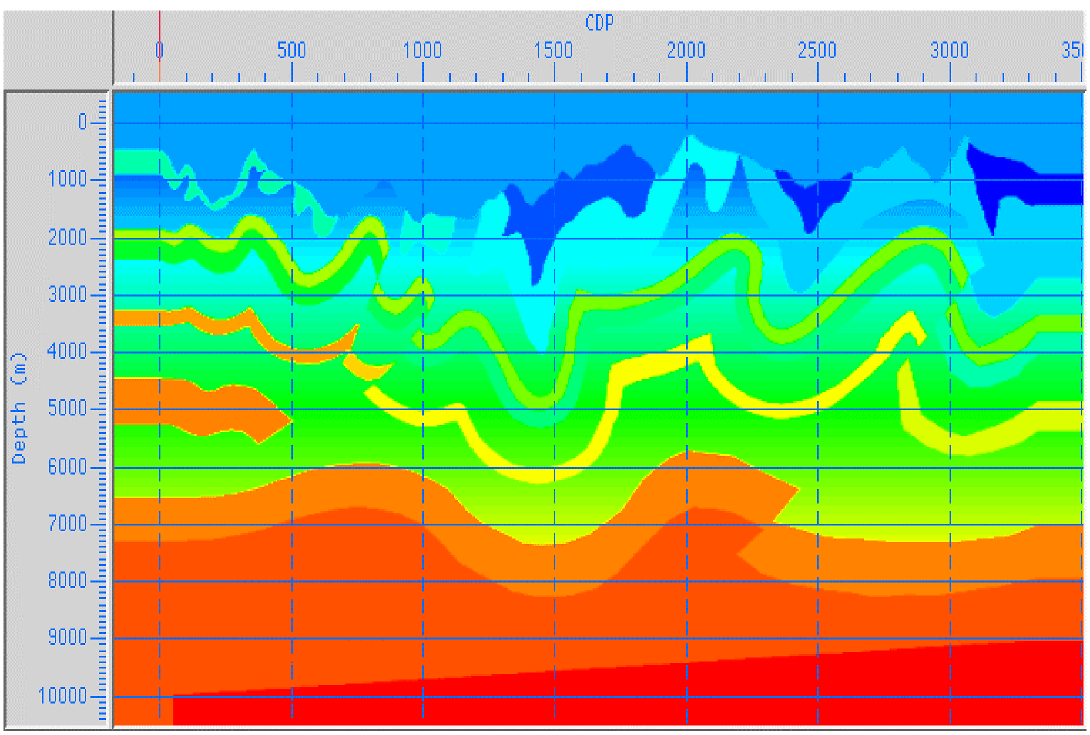

Figure 2. The velocity model is used to create the synthetic shot gathers.

The conventional processing method (Rajasekaran & McMechan 1995) was applied to this data set, (elevation statics, velocity analysis, residual statics, NMO, stack and post-stack migration). The stacked section, using the picked stacking velocities is shown in Figure 3. Many diffractions, or very steep reflections, can be seen in this section.

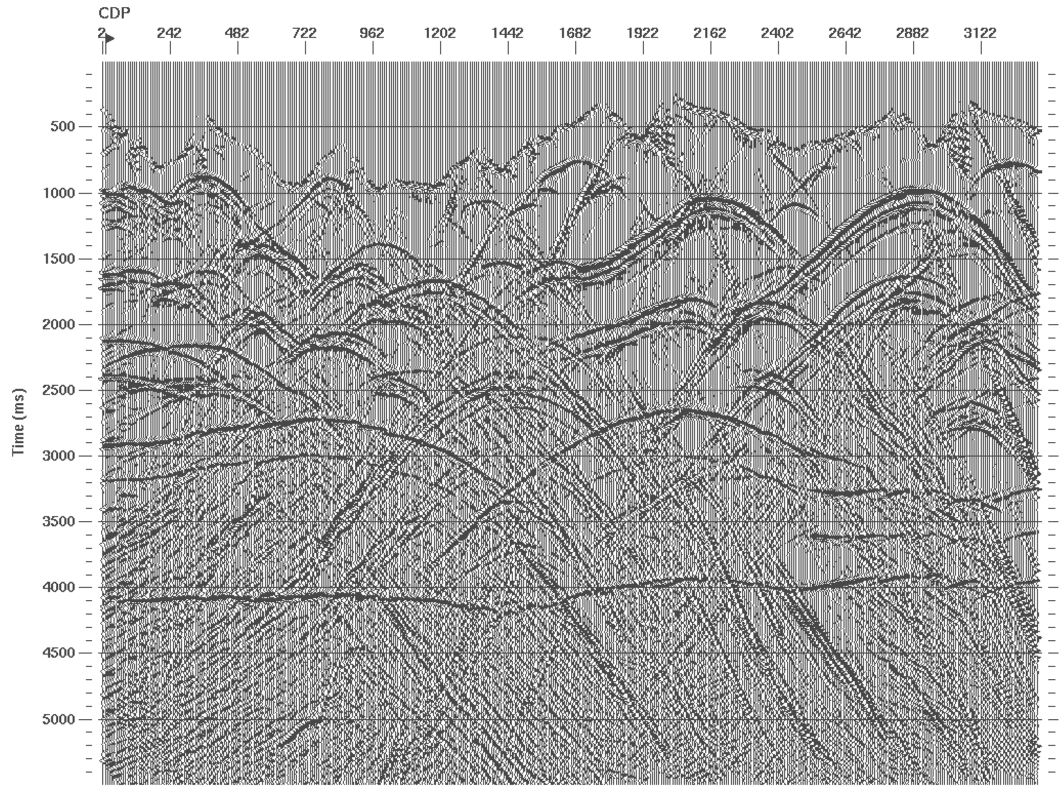

Figure 3. The unmigrated stacked section in the time domain from conventional processing.

In the following, various depth images, created with various velocity models are always shown plotted on top of the correct velocity model in color. This allows an easy comparison between the images, and each can be compared to the correct structure.

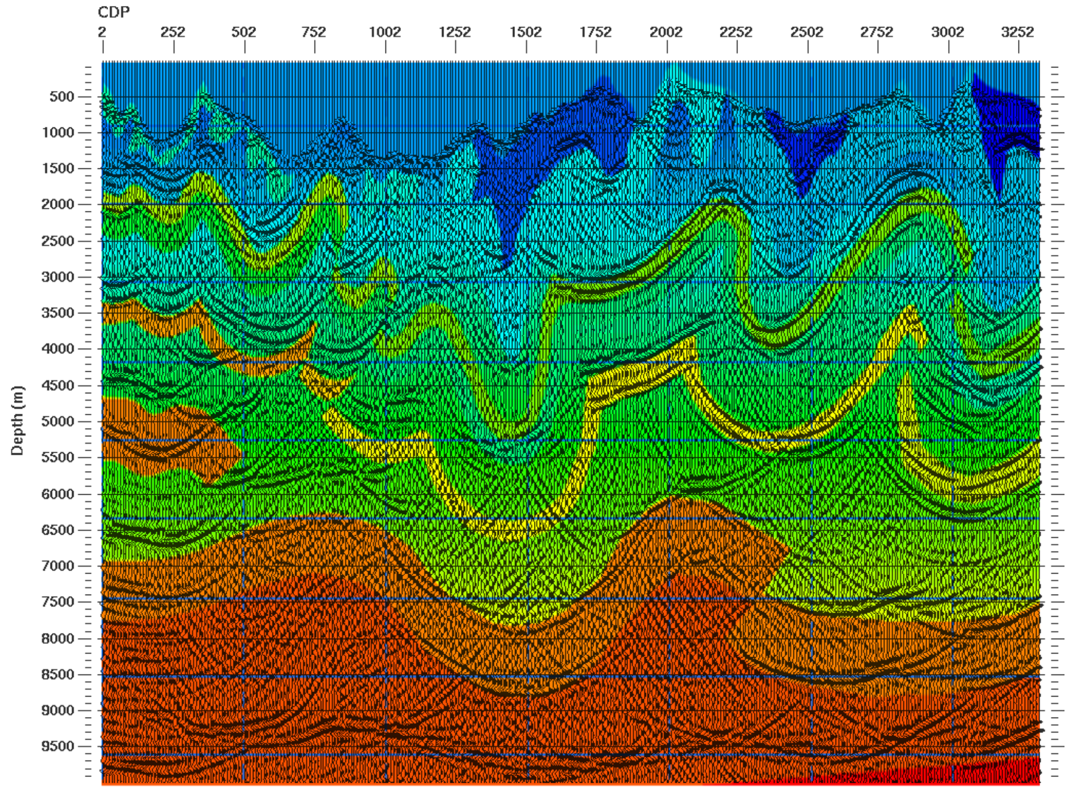

Figure 4. The post-stack depth migration image is super-imposed over the correct velocity model. This migration was performed with internal velocities calculated from picked stacking velocities.

The image from the post-stack depth migration of the stacked time section (Figure 2) is shown in Figure 4. Before stacking, the traces were multiplied by $T^{-1/2}$ to accommodate the spreading loss. For this depth migration, the interval velocity function was converted from stacking velocities picked from super-CDP gathers (in order to increase the signal/noise ratio), and the interval velocities were smoothed over 170 CDPs. Although the image from 0m to 6000m is mostly acceptable, the image below 7000m is not very good. Even above 6000m, there are places where the image is poor, such as in very tight folds like that at CDP 3000 and depth 3000m.

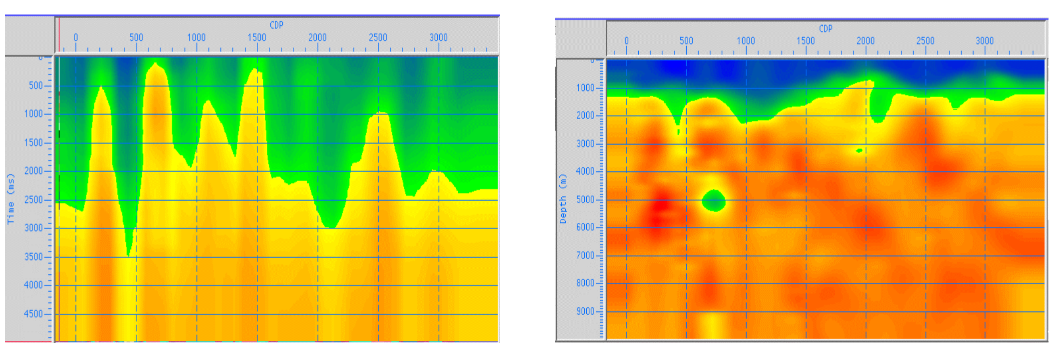

Figure 5 (a) and (b) The stacking velocity is on the left, the smoothed (170 CDP smooth length) interval velocity converted from stacking velocity is on the right.

The stacking velocities and the converted interval velocities are shown in Figure 5. The details of the velocity function are difficult to observe. The use of super-CDP gathers (which already violates the CMP assumption in this case), has caused the velocity function to be very smooth.

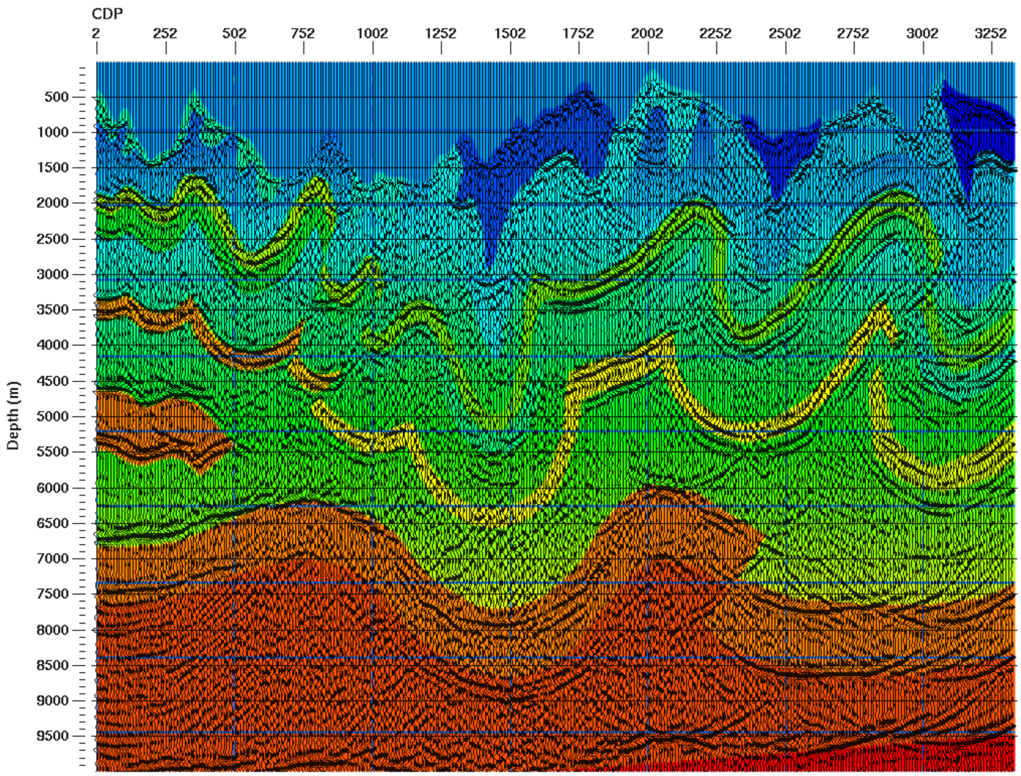

Figure 6. The post-stack time migration section, converted from time to depth. This section was migrated using internal velocities calculated from stacking velocities.

A post-stack time migration was also performed, and the depth section in Figure 6 was converted from that time migration. This result is a little better than the post-stack depth migration because depth migration is more sensitive to velocity errors, and our velocity function is not accurate.

For a complex geological situation with rapidly variable elevation, post-stack time migration or post-stack depth migration may provide a good image, so pre-stack depth migration was tested (Gray & Marfurt, 1995). The depth section from pre-stack depth migration with topography, using an interval velocity function converted from picked stacking RMS velocities is shown in Figure 7, and the image shown in Figure 8 used the same method, but with the correct velocities (the velocity function used in this migration is shown in Figure 2). We can see that the seismic image perfectly corresponds with the velocity model.

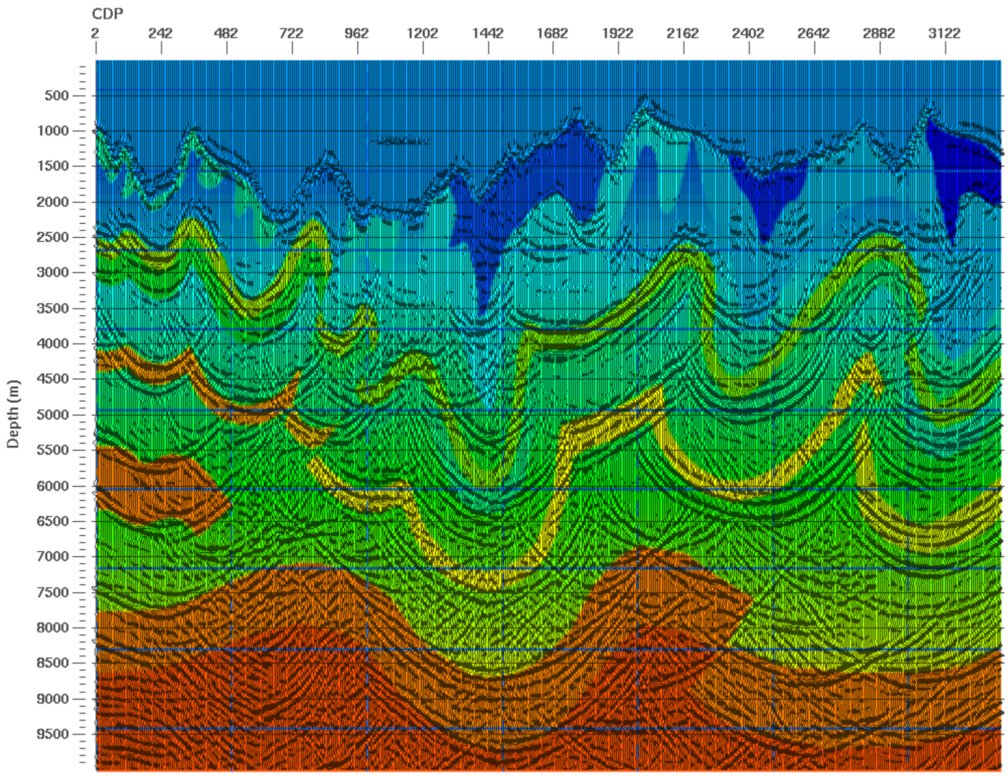

Figure 7. The depth image from pre-stack depth migration from topography is superimposed the correct velocity model. The migration velocity model was derived from stacking velocities (Figure 5b).

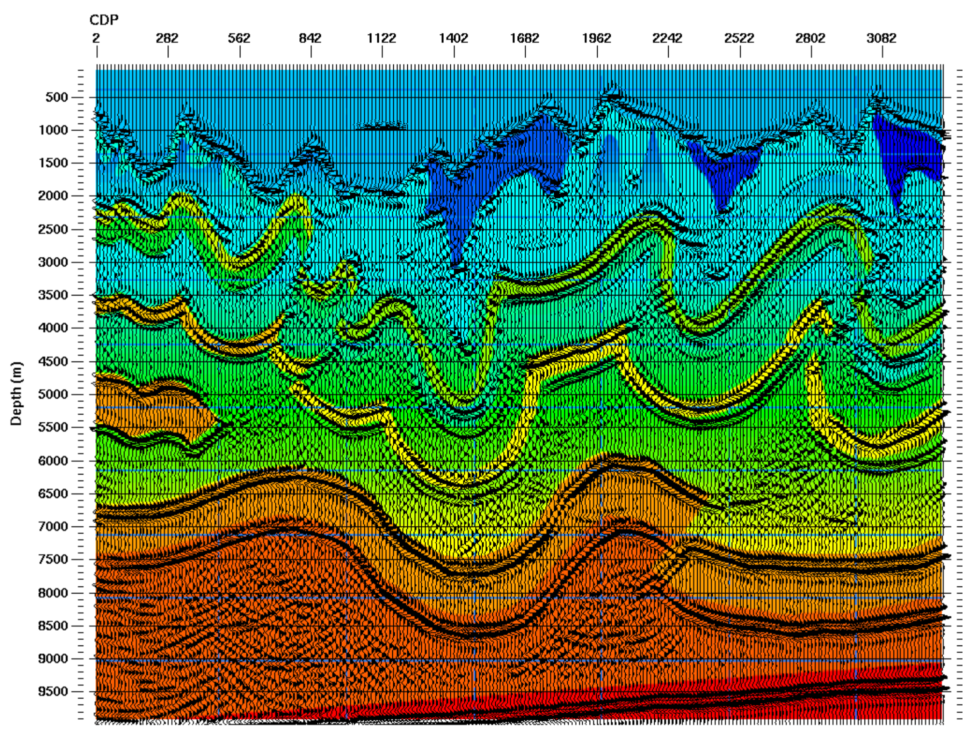

Figure 8. The image from pre-stack depth migration from topography is superimposed on the correct velocity model. The migration velocity was the correct model.

From Figures 3, 4, 6, 7, and 8, it is apparent that the best image was generated by pre-stack depth migration from topography using the correct velocity model. In a practical setting, where the velocity model is unknown, this result is not attainable. Of the practical results, post-stack time migration was the best.

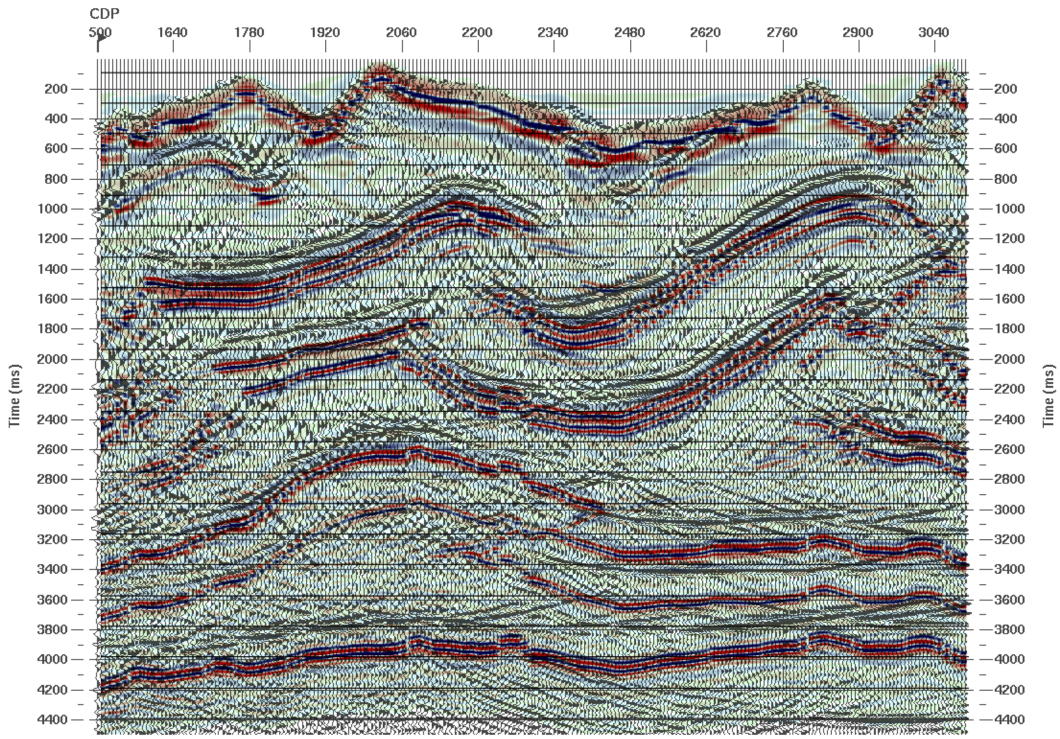

Figure. 9 The results from post-stack time migration (displayed in black wiggle) superimposed on the results from pre-stack depth migration from topography (displayed in color).

Finally, a comparison of the results from pre-stack depth migration from topography with the results from post-stack migration is shown in Figure9. The black wiggle represents the post-stack time migration with the results of pre-stack depth migration from topography converted from depth to time using the correct velocity model in color. We can see that in the time domain both results tie very well. In the time domain, even though the exact velocity is unknown, good results can be obtained using the velocity picked by semblance method.

CONCLUSIONS

Post-stack time migrations can produce a seismic image quickly and easily. This seismic image can serve as an initial image for the interpreter. They can then use their detailed knowledge of the geology and the interval velocities to revise the velocity model. The velocity function is unknown at the beginning. When it is generated by the standard procedure it is usually not accurate, but it can be used for intermediate results.

Depth migration requires a detailed interval velocity function: an actual propagation velocity at each point in the subsurface. So, estimation of the velocities used for depth migration is much more difficult than the problem of migration, because migrating the seismic data is necessary to estimate the velocity itself. Pre-stack depth migration of foothills seismic data depends upon accurate velocity models. This correct velocity model is the key to obtaining a correct image. Interactive velocity analysis should be performed here and used together with geological knowledge of the area. This process will be investigated in the near future.

ACKNOWLEDGEMENTS

We would like to thank the sponsors of the CREWES Project for their financial support and Veritas GeoServices and Dr. Samuel Gray for donating this synthetic model data. Han-xing Lu also thanks Mark Kirtland for assistance in preparing this paper, and our colleagues in CREWES for their contributions to this project.

REFERENCES

Gray, S.H., 1998, Interpretative seismic imaging in structurally complex areas: GeoTriad'98, June 15-18, Calgary, Alberta, Expended Abstracts, 282-283.

Gray, S.H., and Marfurt, K.J., 1995, Migration from topography: improving the near-surface image: Canadian journal of Exploration Geophysicists, 31, Nov. 1 & 2, 18-24.

Rajasekaran, S., and McMechan A.G., 1995, Prestack processing of land data with complex topography: Geophysics, Vol. 60, No. 6, 1875-1886.