Stanford Exploration Project, Report 79, November 16, 1997, pages 109–118

Prestack slant stack migration and its application in AVO analysis

Jen-Yang Lin[1]

keywords: *slant stack, prestack, AVO, velocity, algorithm, amplitudes*

ABSTRACT

One synthetic and one field dataset from the Gulf of Mexico were used to test a program of prestack slant stack migration with phase shift plus interpolation (PSPI). The migrated section showed a correct image with this algorithm, even with lateral velocity variations. I also took advantage of this migration to do amplitude-versus-offset (AVO) analysis on the migrated field dataset. The prestack slant stack migration collapses diffractions, and focuses bright spots, thus increasing confidence in AVO analysis.

INTRODUCTION

The migration of the slant stack of common midpoint gathers is a method that makes no assumptions that deteriorate with wide offset angles, steep dips, or vertical velocity variations. Events of different dips that intersect are equally well-imaged.

Ottolini (1982) proposed the equations for and some applications of common midpoint slant stack migration. The migration can be implemented with either the F-K or the phase-shift algorithm. But his algorithm only allows for velocity variations in depth. Hence, I extended Ottolini's algorithm by using the phase shift plus interpolation (PSPI) method(Gazdag and Sguazzero, 1984), taking lateral velocity variations in slant stack migration into account (Lin, 1993).

Keho et. al (1992) use such migrated $\tau - p$ seismic data to do amplitude-versus-offset (AVO) processing. Their paper shows that prestack migration collapses diffractions, focuses bright spots, and moves them to their proper location.

I migrated one synthetic and one field dataset by prestack slant stack migration with PSPI, and compared the migrated section with the model that generated the synthetic dataset. I then implemented the AVO analysis program to analyze the migrated CMP gathers.

[1]**email:** not available

MIGRATION PROCEDURE

This method of migrating of common midpoint slant stacks is accomplished by performing the following steps.

1) Construct the slant stack section by transforming the CMP gather from the (t, y, x) domain to the (τ, y, p) domain using the $\tau - p$ transformation, where

   $\tau = t - px$

   $p : slant\ parameter$

   $x : offset$

   $y : CMP\ coordinate$

   $t : traveltime$

2) Sort the data into a constant p section.

3) Migrate the constant p section by prestack slant stack migration.

4) Sort the data into CMP gathers.

5) Do AVO analysis or stack all the p sections to get a migration section.

SLANT STACK TRANSFORMATION AND THE MIGRATION EQUATION

The most important two equations used in this method of processing are the slant stack transformation equation and the migration equation for common midpoint slant stacks.

We first have to transform the wavefield in the CMP gather from the (x, t) domain to the (τ, p) domain. Let $d(x, t)$ be the wavefield and $u(\tau, p)$ be the transformed slant stack wavefield(Claerbout, 1985), so that

$$u(\tau, p) = \int d(x, \tau + px) dx \tag{1}$$

A lot of care needs to be taken to construct a high-quality slant stack CMP gather. Kostov (1990) lists several methods of obtaining a high quality gather. Poor quality is probably caused by very coarse offsets and missing offsets beyond the ends of the cable. Those offsets that are missing must be interpolated or extrapolated before slant stack transformation.

The double-square-root equation(Ottolini, 1982) for the downward continuation of common midpoint slant stacks is

$$\frac{\partial u}{\partial z} = \frac{-i\omega}{v} \left[\sqrt{1 - (Y + pv)^2} + \sqrt{1 - (Y - pv)^2} \right] U \tag{2}$$

where

$$Y = \frac{vk_y}{2\omega}$$

The solution of equation (2) is

$$U(\omega, z + \Delta z, k) = U(\omega, z, k)\exp\left\{\frac{-i\omega}{v}\left[\sqrt{1 - (\frac{vk_y}{2\omega} + pv)^2} + \sqrt{1 - (\frac{vk_y}{2\omega} - pv)^2}\right]\Delta z\right\} \tag{3}$$

We can use this equation to obtain the wave extrapolation for constant velocity. Velocity variations in depth are easily accommodated by varying the velocity v with depth z in equation (3). For lateral velocity variations, I use the PSPI (Lin, 1993) algorithm to implement the slant stack migration.

A SYNTHETIC DATA EXAMPLE

I used synthetic data to test the program of prestack slant stack migration. Two hundred 24-fold CMP gathers were generated according to the model in Figure 1. There are two horizontal layers, one slant event, and four point diffractors. A velocity function $V(z) = (2000 + 2 * z)$ meters per second was used to generate the synthetic dataset with the prestack Kirchoff modeling program. The record length is 1.6 seconds and the sampling rate is 8 milliseconds. The CMP interval is 25 meters and the far offset is 460 meters. The near offset section is shown in Figure 2.

To migrate the synthetic dataset, I followed the processing steps described in the preceding section. Figure 3 shows one of CMP gathers after slant stack transformation, with a slant parameter p from 0 to 0.48 seconds per kilometer. After the prestack slant stack migration, I obtained the gather shown in Figure 4, at the same CMP location as in Figure 3. After migration almost all the events were lined up.

Finally, I stacked all the different p sections to get the migration section shown in Figure 5. Comparing Figures 5 and 1 shows that the migration algorithm works well for the synthetic dataset.

A FIELD DATA EXAMPLE

To test the prestack slant stack migration algorithm, a marine dataset from the Gulf of Mexico was migrated by the same processing procedures. The record length is 4 seconds and the sampling rate is 8 milliseconds. The offset interval is 50 meters and the far offset is 2591 meters. I used 100 48-fold CMP gathers with a 25-meter CMP interval. The strong events between 2.1 and 2.5 seconds which was the target of the AVO analysis the next section describes.

Velocity analyses were done at CMP 1 and CMP 100. To migrate this dataset, I needed to consider the velocity variations in depth and in lateral variation. I used

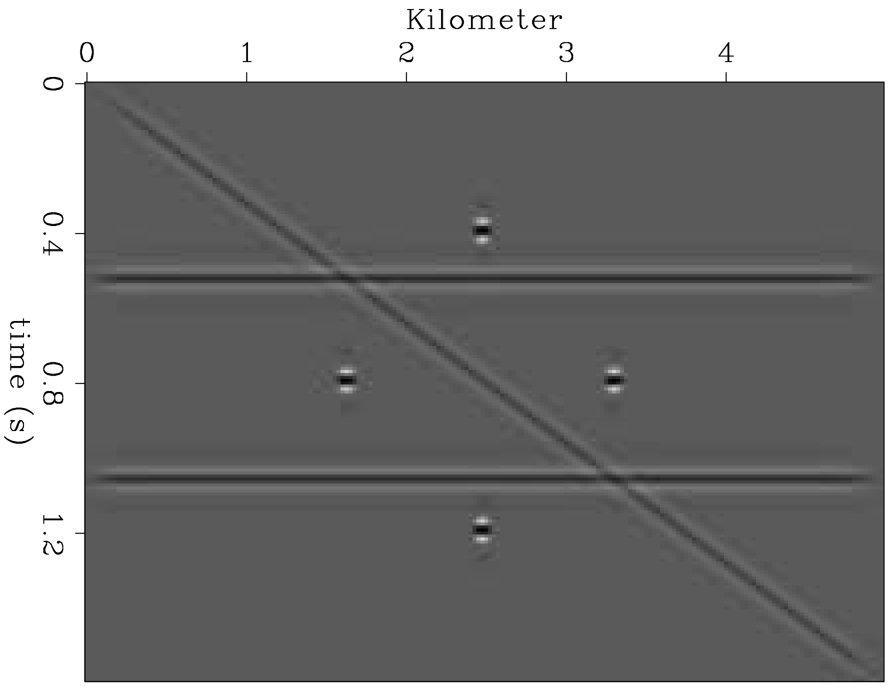

Figure 1: A model for generating synthetic data jenyang1-model [ER]

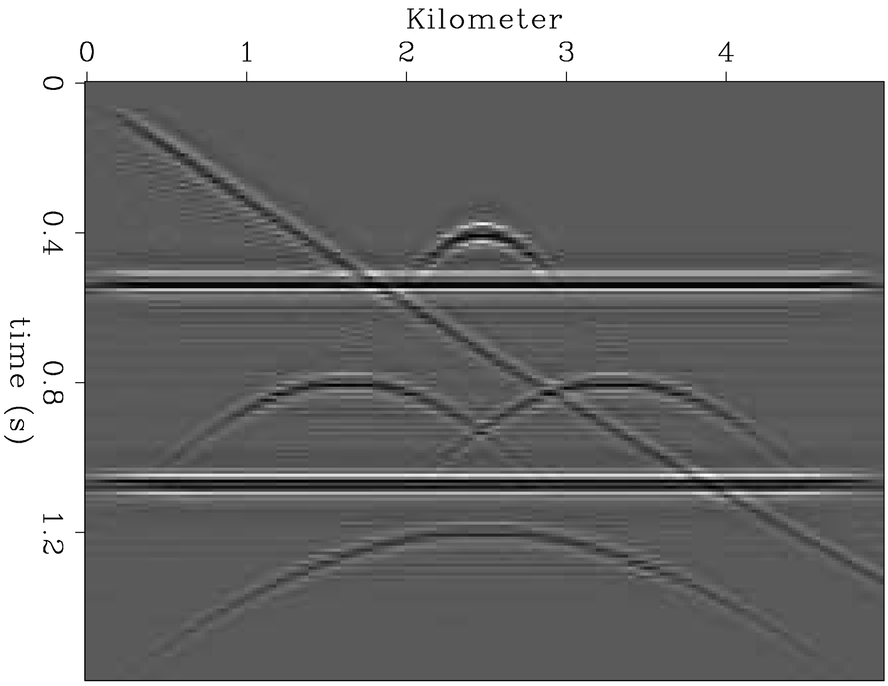

Figure 2: A near-offset section of synthetic data jenyang1-nearoffset [ER]

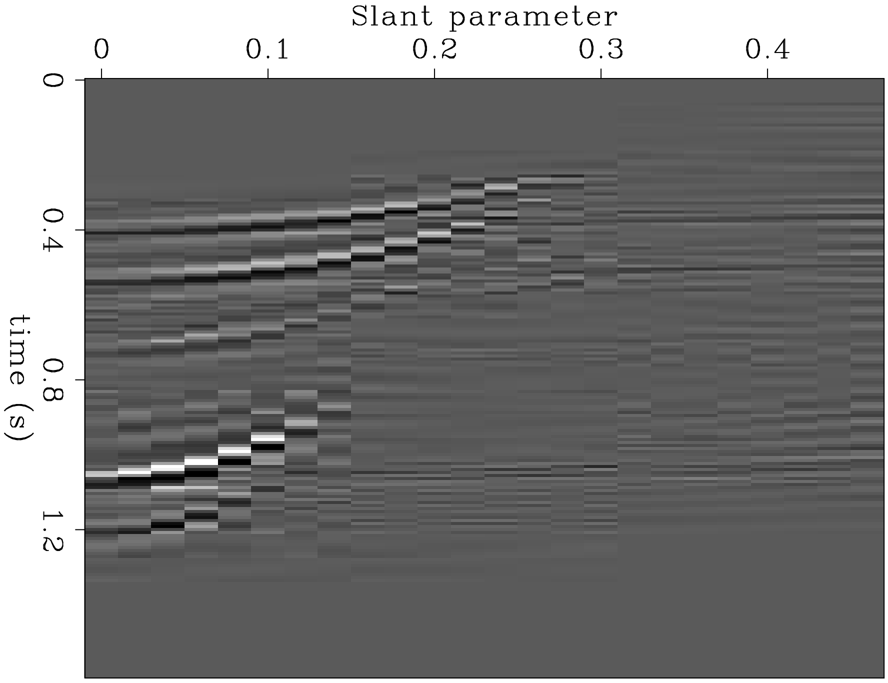

Figure 3: A CMP gather after slant stack transformation jenyang1-vslancdp1 [CR]

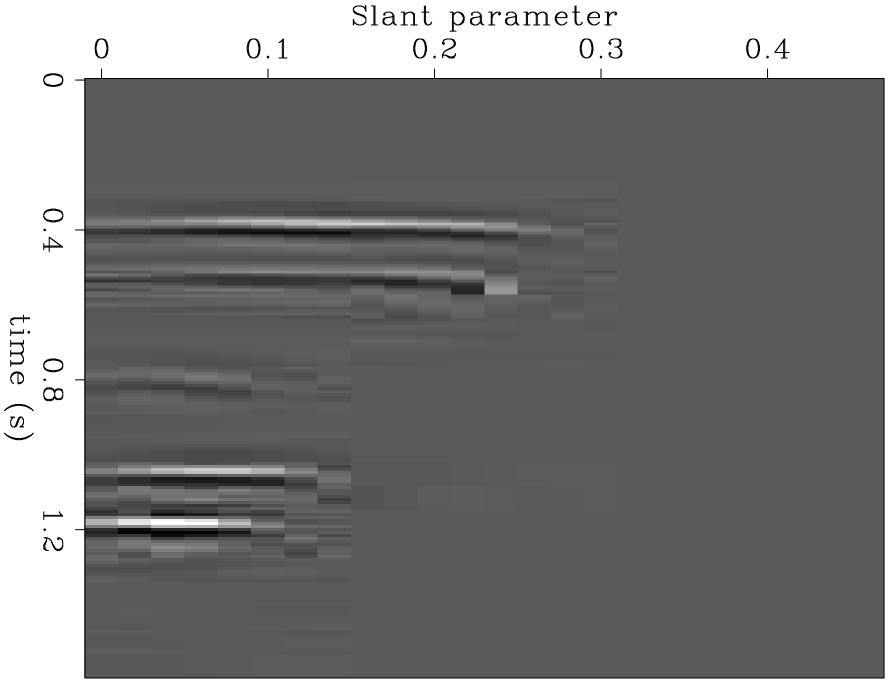

Figure 4: The CMP gather in Figure 3 after prestack slant stack migration jenyang1-migcdp1 [CR]

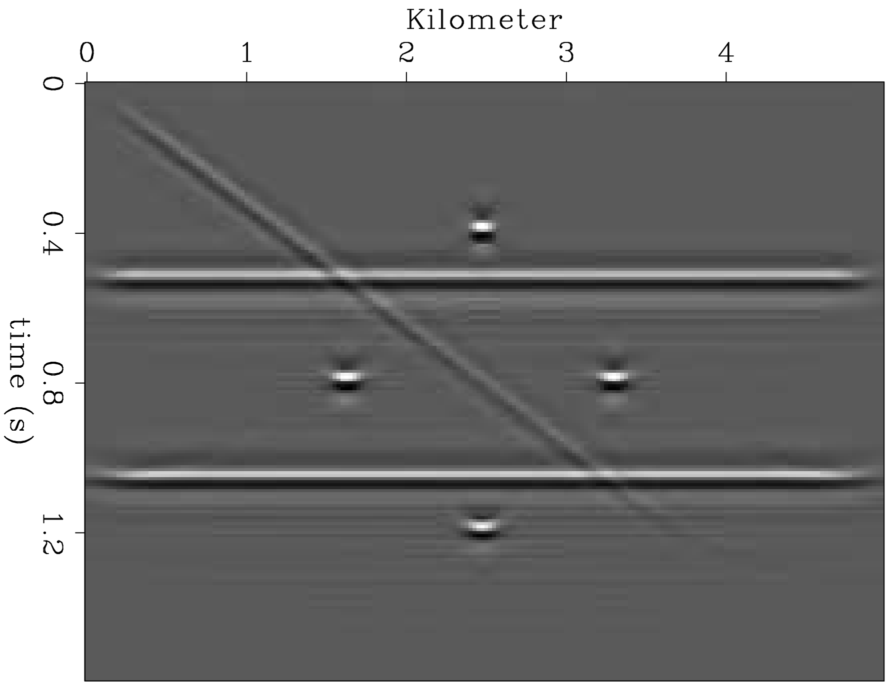

Figure 5: Migrated synthetic data jenyang1-stack [CR]

prestack slant stack migration with PSPI to migrate these field data. In the slant stack transformation, I chose the p range from 0 to -0.36 Kilometer per second to fulfill the requirements of the AVO analysis that are explained in the next section.

The CMP stack section and the migrated section are shown separately in Figures 6 and 7. Some collapsed diffractions and faults (at 1 second from 0.2 to 2.0 Kilometers) are apparent after migration.

AVO ANALYSIS AFTER MIGRATION

By sorting each constant p section into CMP gathers after prestack slant stack migration, we can obtain unstacked migrated CMP gathers. Consequently, we can perform AVO analysis on those gathers.

For AVO analysis, the most widely used approximation of the reflection coefficient was derived by Shuey (1985) in the following equation:

$$R(\theta) = R_0 + G * sin^2(\theta) \tag{4}$$

where θ is the incidence angle, R_0 the reflectivity for zero incidence, and G a quantity related to elastic parameters. This linearization defines a framework within which seismic amplitudes must fit. Conventionally this formula can be directly applied to an NMO-corrected CMP gather. For every sample point, amplitudes are used to compute

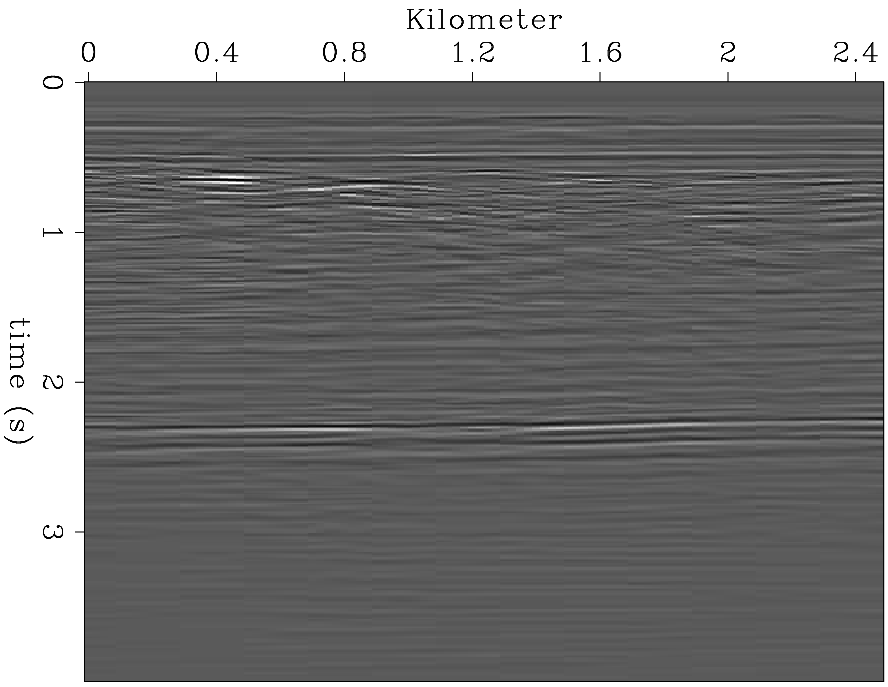

Figure 6: CMP-stacked field data jenyang1-stacknmo [CR]

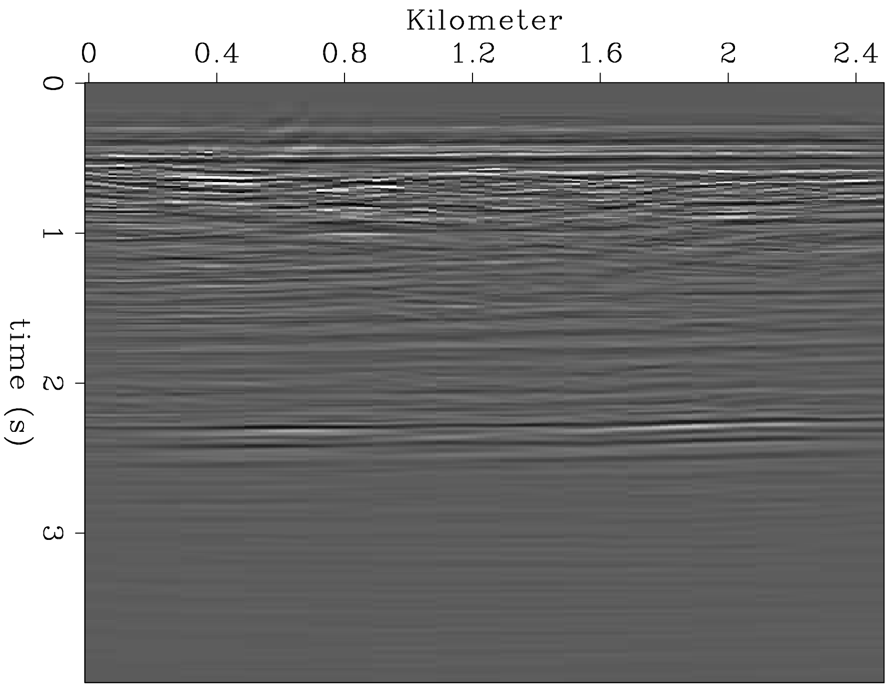

Figure 7: Migrated field data jenyang1-stackfield [CR]

R_0 and G through a linear regression. The series $R_0(t) * G(t)$ provides a useful section for AVO analysis. In this section, positive amplitude indicates amplitude increasing with offset, and negative amplitude indicates amplitude decreasing with offset.

With data from the (τ, p) domain in each CMP gather, we can do the AVO analysis directly according to equation (4), after some preprocessing for amplitude correction. Because we already know the value of p for each trace and the interval velocity in depth, we can calculate the $sin^2(\theta)$ in equation (4) directly from

$$pv = sin(\theta) \tag{5}$$

This provides a more accurate measurement of $sin(\theta)$. We also have to be very careful about the noise shown in the CMP gather (Figure 4). Those low-frequency waves propagating nearly horizontally should be avoided in the AVO analysis.

Owing to the prestack migration, the seismic events were moved to the correct position, and more accurate amplitude was recovered. Figure 8 shows the $R_0 * G$ section after linear regression of the migrated CMP gathers. This section displays bright spots (at 2.2 seconds and 1.8 Kilometers), which is similar to those in Figure 13 of Lumley's paper (1993). They indicate a known gas producing reservoir.

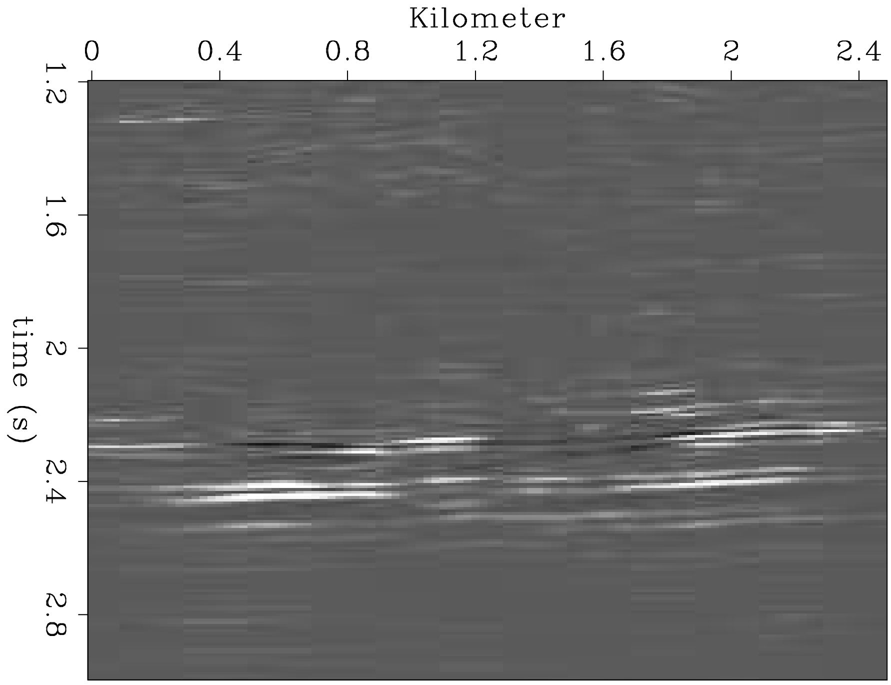

Figure 8: An $R_0 * G$ section jenyang1-avopg [CR]

CONCLUSIONS

Prestack slant stack migration with PSPI produces good migration sections with both synthetic and field datasets. The slant events and diffractors are migrated to their original positions. This algorithm performs migration well even when there are lateral velocity variations present.

When, after the prestack slant stack migration, the seismic events are lined up at the correct position in the CMP gathers, we can do AVO analysis more precisely by using linear regression in the (τ, p) domain, and no NMO correction is necessary. This prestack slant stack migration collapses diffractions, and focuses bright spots, thus increasing confidence in selecting drilling locations.

ACKNOWLEDGMENTS

Thanks to Martin Karrenbach and David Lumley for many valuable discussions. I am also grateful to the Chinese Petroleum Corporation in Taiwan for providing financial support during my stay at Stanford.

REFERENCES

Claerbout, J. F., 1985, Imaging the earth's interior: Blackwell Scientific Publications.

Gazdag, J., and Sguazzero, P., 1984, Migration of seismic data by phase-shift plus interpolation: Geophysics, **49**, no. 2, 124–131.

Keho, T., Smith, S., Abarr, G., and Hargrove, K., 1992, An example of uncollapsed migration followed by avo: Joint SEG/EAEG summer research workshop, Technical program and abstract.

Kostov, C., 1990, Least square inverses for time invariant transforms: SEP–**63**, 73–88.

Lin, J., 1993, The migration of prestack slant stack with PSPI: SEP–**77**, 109–116.

Lumley, D. E., 1993, Kirchhoff prestack impedance inversion: A gas reservoir pilot study: SEP–**77**, 211–230.

Ottolini, R., 1982, Migration of reflection seismic data in angle midpoint coordinates – thesis: SEP–**33**, 00–14.

Shuey, R. T., 1985, A simplification of the zoeppritz-equations: Geophysics, **50**, no. 4, 609–614.