J. Ind. Geophys. Union (January 2010)
Vol.14, No.1, pp.15-20

Imaging subsurface geological features with seismic migration – A numerical study

P.R.Mohanty
Department of Applied Geophysics, Indian School of Mines, Dhanbad – 826 004
E.mail: priyamohanty@hotmail.com

ABSTRACT
The seismic data recorded at the surface are processed in a complex sequence of steps among which seismic migration plays an important role. This paper presents an overview of the Phase Shift (PS) and Phase Shift Plus Interpolation (PSPI) wave equation migration methods applied to various geological models. PS time migration and PSPI depth migration schemes are applied to a syncline, anticline, graben and complex salt dome structures. It is observed that the PSPI migration method works well for all the structures in terms imaging and accuracy as compared to PS migration.

INTRODUCTION

Post stack migration techniques are widely used in hydrocarbon exploration and play an important role in imaging complex subsurface structures. The most popular and flexible Phase Shift (PS) migration is generally preferred. It provides moderately good image quality in presence of constant velocity variation. For lateral velocity variation, Phase Shift Plus Interpolation (PSPI) depth migration is normally attempted. In the present study these two migration schemes are tested with data for simple to complex geological structures to judge the imaging capability. The PS method proposed by (Gazdag, 1978) is computationally fast which deals with constant velocity variation and implemented in time domain. Whereas, PSPI method is a phase shift like method for dealing with strong lateral velocity variation (Gazdag & Sguazzero 1984).

METHODOLOGY

There are two steps in the migration extrapolation and imaging. Extrapolation involves numerical reconstruction of the wave field at depth from the wave field recorded at the earth's surface. Imaging is the process that allows one to obtain the reflection strength from the extrapolated data in depth and make an image of the sub-surface reflectors.

Phase Shift (PS) and Phase Shift Plus Interpolation (PSPI) migrations

The Phase Shift migration operates in f-k domain and is based on the downward continuation process propagating the wave field from one depth step to the next by a phase shift operation (Gazdag 1978). Whereas, Phase Shift Plus Interpolation (PSPI) migration is a phase shift migration in which different lateral extent of the seismic sections are migrated with a single velocity representing that extent and after migration each lateral extent is appropriately interpolated to achieve final migrated section (Gazdag & Sguazzero 1984).

Numerical Examples

To test a migration scheme and evaluate its performance, we need a set of seismic data, e.g. a zero-offset section obtained from an idealized model with known reflectivity and velocities. This is usually carried-out by simulating the forward process using the standard forward modeling schemes. Presently, zero offset sections are generated using the resources (Seismic Unix, 1999) for a syncline, anticline and graben models. In addition, data for the SEG/EAGE Salt model (Wu & Jin 1997) was available in form of time section along with velocity depth model. All the four models were tested using the Phase Shift time and Phase Shift Plus Interpolation (PSPI) depth migration methods. Migration analyses were also carried out using Seismic Unix Software.

SYNCLINE MODEL

Figure 1a represents velocity depth model for a synclinal structure. The background velocity was taken 2.0 km/s with dv/dz = 0.5 and dv/dx = 0.5 indicating velocity variation in lateral as well as vertical direction. Figure 1b represents the corresponding zero offset section for the syncline model. The zero offset section over synclinal structure shows complicated signature indicating a bow tie feature. This is due to ray path crossing of multiple reflected events over the structure. The zero offset time section is difficult to interpret in terms of sub-surface structure. Then PS migration as well as PSPI migration methods are applied to the above zero offset section. Figures 1c and 1d represent migrated time section and migrated depth section corresponding to PS and PSPI methods respectively. Figure 1c indicates broad synclinal structure with poor imaging condition associated with strong numerical artifacts. In contrast, the depth PSPI migrated section delineates synclinal structure accurately after positioning the events properly. However, insignificant noise due to numerical artifacts is observed at the bottom of the Syncline.

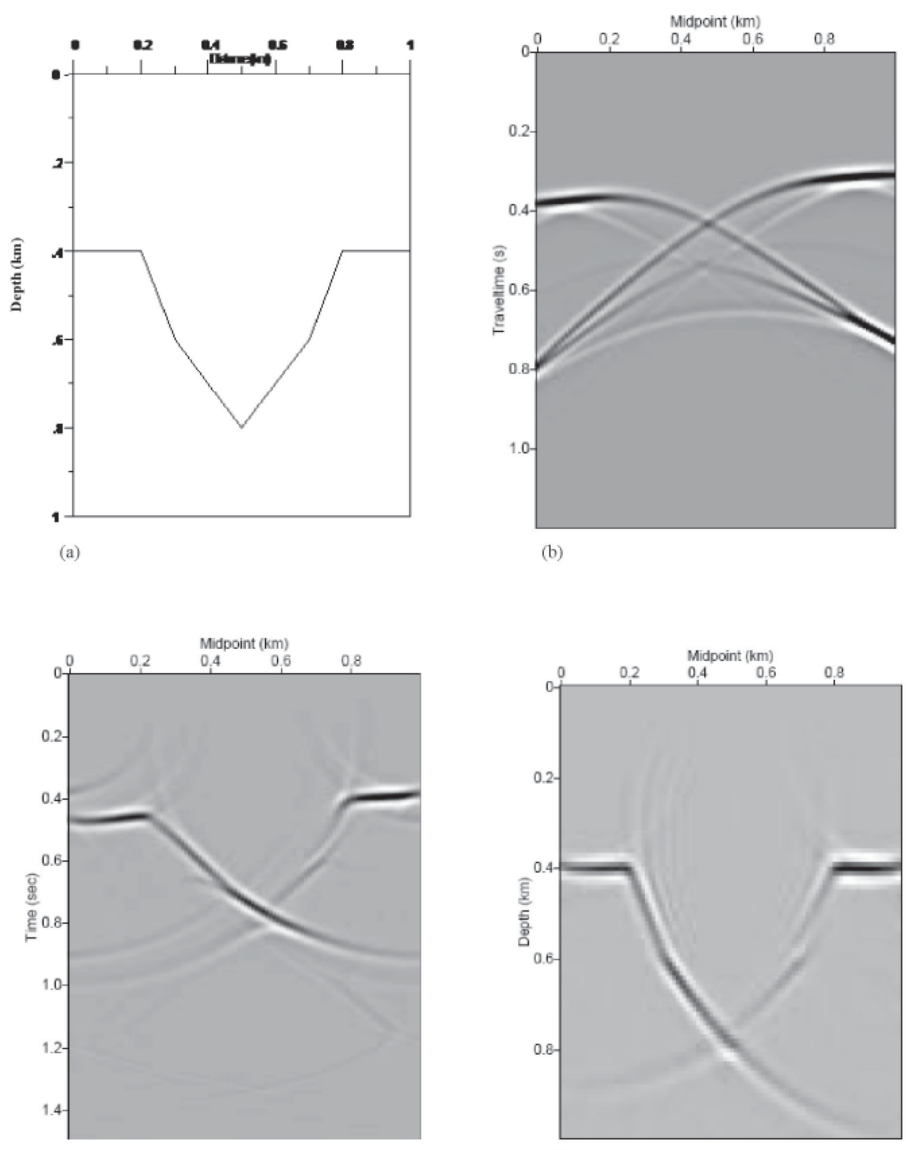

Figure 1. Comparison of migration analysis with PS and PSPI methods over a syncline model : (a) Velocity depth model with background velocity = 2.0 km/sec, dv/dz = 0.5 and dv/dx = 0.5, (b). Zero offset section, (c). Migrated time section using PS method and (d). Migrated depth section using PSPI method.

Anticline model

Figure 2a represents velocity depth model for a anticline structure. The background velocity was taken 2.0 km/s with dv/dz = 0.5 and dv/dx = 0.5 indicating velocity variation in lateral as well as vertical direction. The model indicates two horizontal layers followed by four folded anticline features. Figure 2b represents corresponding zero offset section for the anticline model. The zero offset section indicated two horizontal layers followed by two folded anticlines. The bottom two folded structure are not very clear due to diffraction from the edges. Subsequently, the zero offset section migrated by PS and PSPI methods. Figures 2c and 2d represent time migrated and depth migrated section corresponding to PS and PSPI migration methods. Figure 2c indicates broad futures of the sub surface with restoration of two horizontal reflectors along with three folded limbs. The migrated time section restores the sub surface structure with poor imaging condition. Figure 2d indicates depth migrated section with proper restoration horizontal reflectors along with three folded limbs. In addition, one to one correlation can be made with velocity depth section (Fig. 2a). However, numerical artifacts are seen in both the migrated sections.

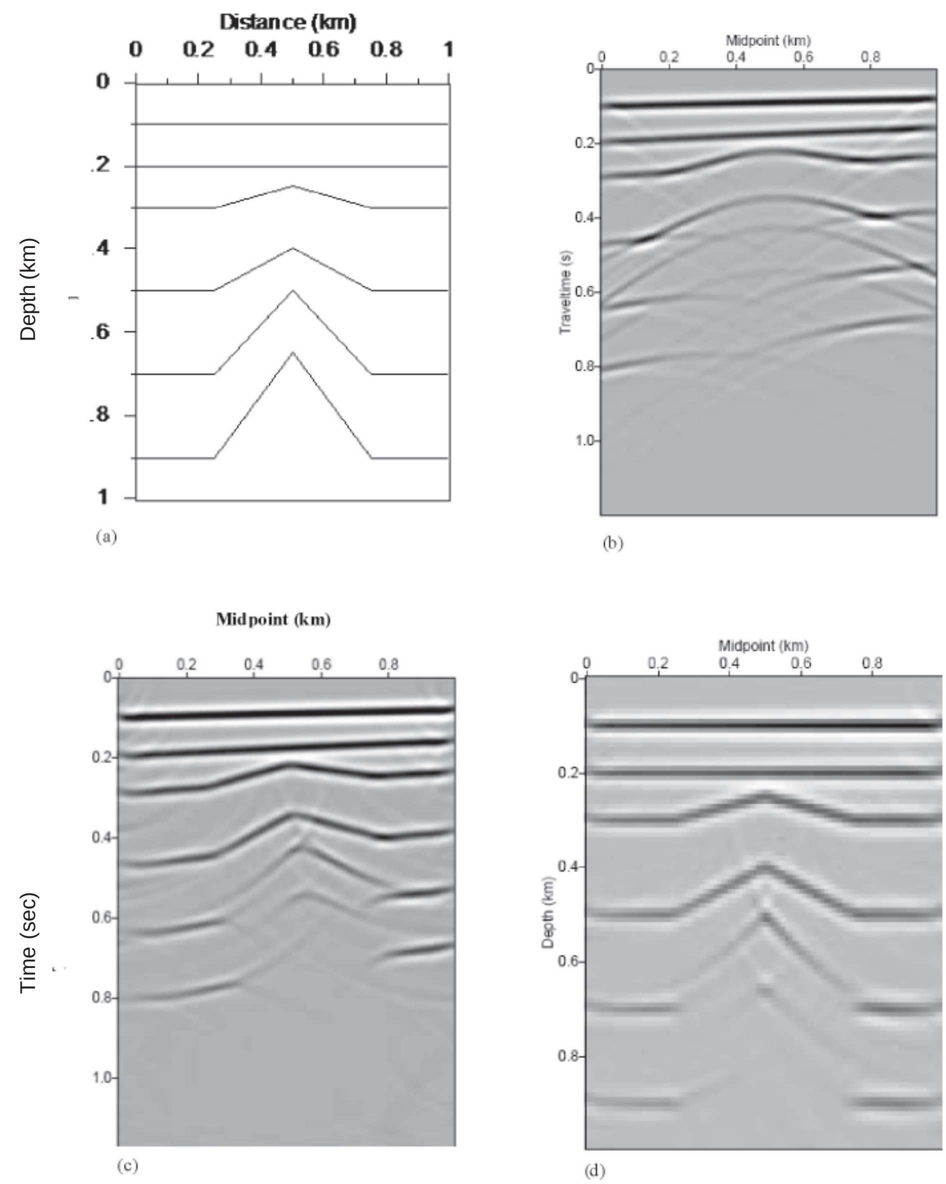

Figure 2. Comparison of migration analysis with PS and PSPI methods over an anticline model: (a) Velocity depth model with background velocity = 2.0 km/sec, dv/dz = 0.5 and dv/dx = 0.5, (b) Zero offset section, (c) Migrated time section using PS method and (d) Migrated depth section using PSPI method.

Graben Model

Figure 3a represents velocity depth section. The background velocity was taken 2.0 km/s with dv/dz = 0.5 and dv/dx = 0.5 indicating velocity variation in lateral as well as vertical direction. The model shows two horizontal reflectors followed by half graben structure associated with two normal faults. Figure 3b represents corresponding zero offset section over the graben structure. The section indicates two horizontal reflectors clearly. But the half graben features associated with the faults could not be observed clearly due to diffraction events. Their shape are not properly delineated. Later, the zero offset section is migrated using PS and PSPI migration methods. Figures 3c and 3d represent time migrated and depth migrated sections corresponding to PS and PSPI migration respectively. Figure 3c indicates broad sub surface structure with inproper delineation of graben structure. Figure 3d indicates significant improvement over the graben structure with proper restoration of faults. The depth migrated section indicates no numerical artifacts compared to time migrated section.

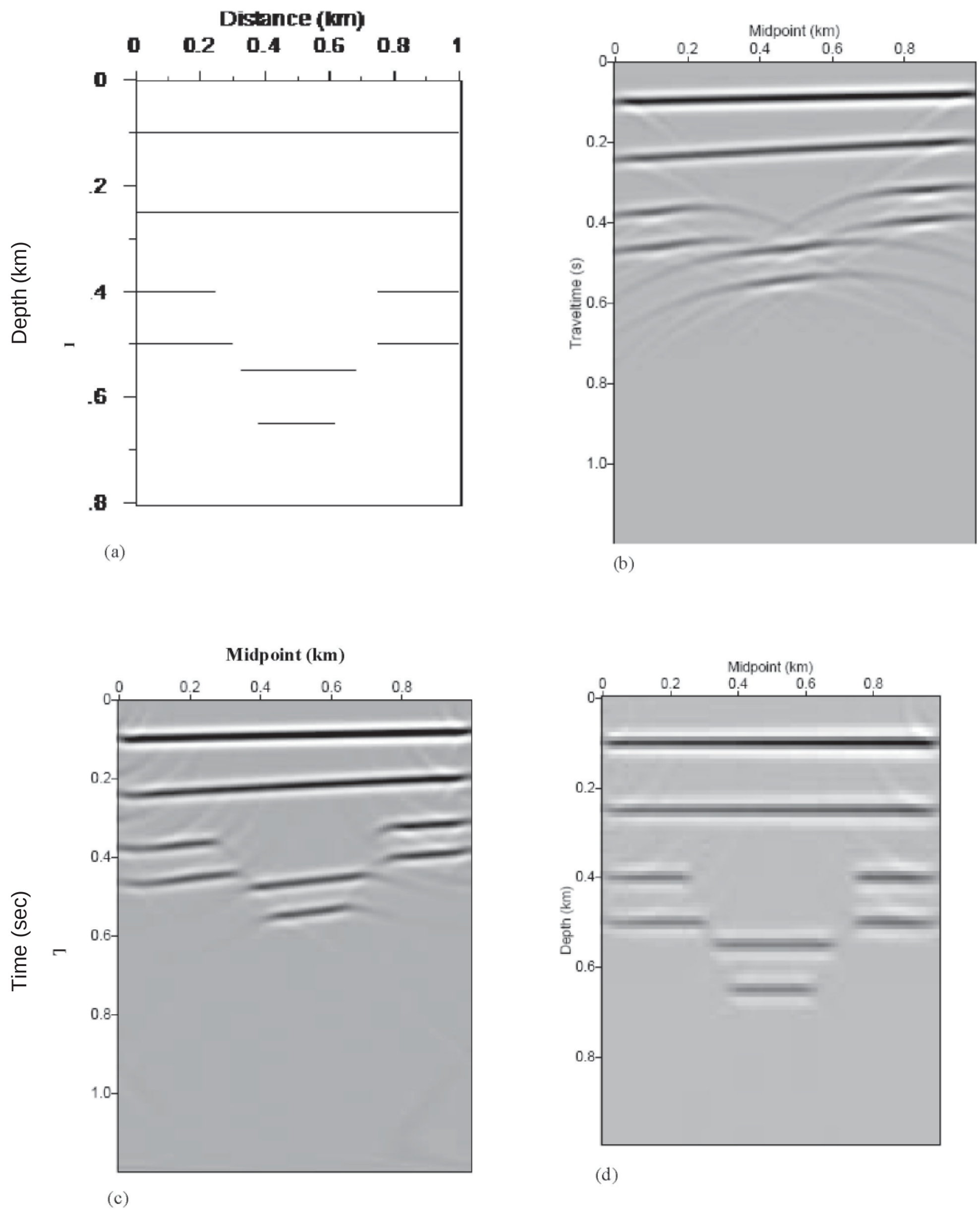

Figure 3. Comparison of migration analysis with PS and PSPI methods over a graben model : (a) Velocity depth model with background velocity = 2.0 km/sec, dv/dz = 0.5 and dv/dx = 0.5, (b) Zero offset section, (c) Migrated time section using PS method and (d) Migrated depth section using PSPI method.

Salt Model

A complex salt structure (2D SEG/EAGE salt model) is considered for this analysis. Figure 4a represents velocity depth model for the salt structure. The host rock velocity is 2.0 km/sec with salt velocity equal to 4.2 km/sec. The top layer is the water layer with velocity 1.5 km/sec. The 2D SEG/EAGE salt model indicates a complex geological structure associated with several normal faults. Figure 4b represents corresponding zero offset section for the SEG/EAGE salt model. The time section indicates complicated signature due to diffraction events over several faults. It is extremely difficult to delineate the sub surface features at all. Figures 4c and 4d represent time migrated and depth migrated section corresponding to PS and PSPI migrated methods. Figure 4c indicates poor image of the sub surface. Strong numerical artifacts are seen in the central part of the salt. However, few faults are seen at the top. Figure 4d shows significant improvement in the sub surface structure with proper restoration of the salt shape. All the major faults have been identified with proper throw. But less intense numerical artifacts are seen in the depth migrated section.

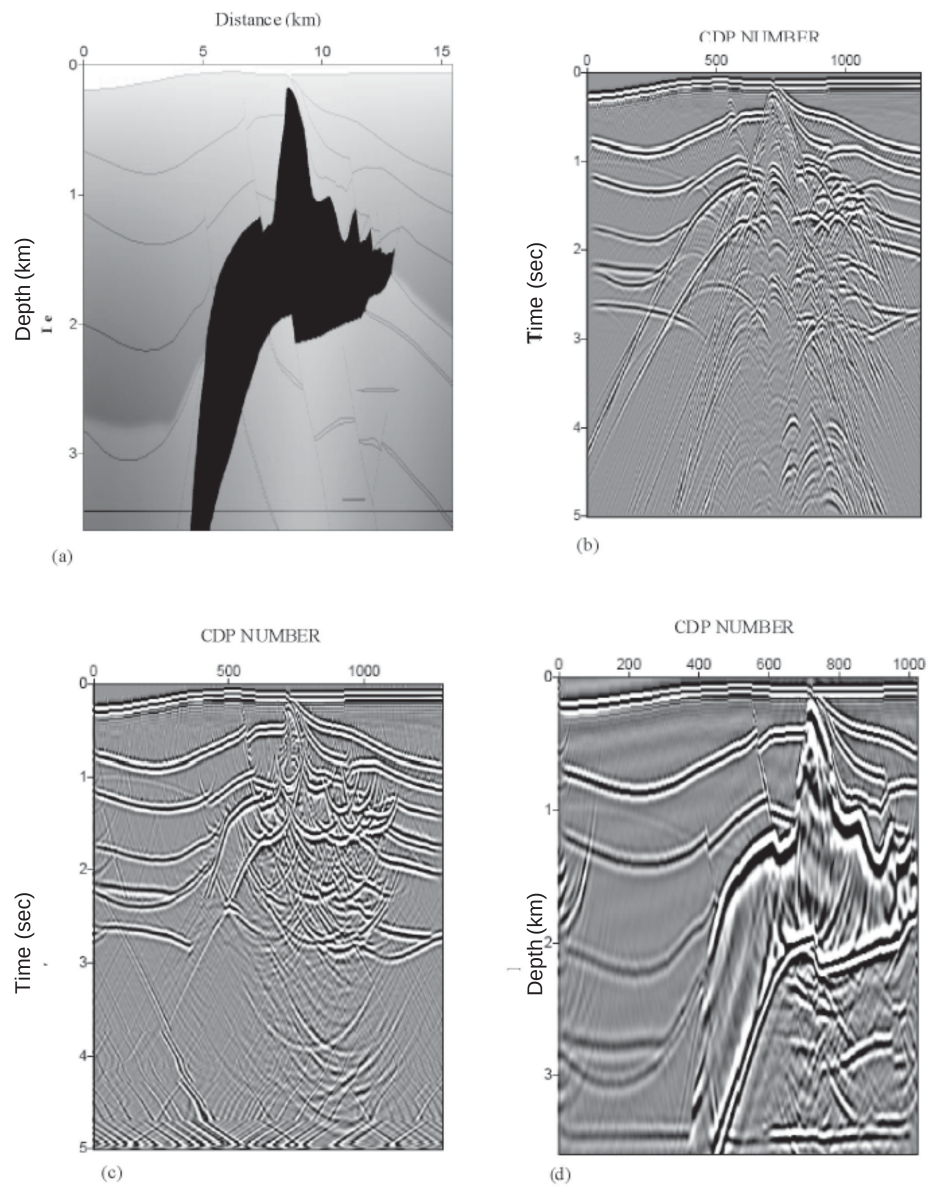

Figure 4 Comparison of migration analysis with PS and PSPI methods over a salt model : (a) Velocity depth model with background velocity = 2.0 km/sec and salt velocity = 4.2 km/sec, (b) Time section over SEG/EAGE SALT Model, (c) Migrated time section using PS method and (d) Migrated depth section using PSPI method.

CONCLUSIONS

The following conclusions are arrived from the present study:

(i) Phase Shift (PS) migration corresponding to syncline, anticline and graben structures has delineated the reflectors roughly. Whereas, PSPI method provided clear images in retaining their shape and size.

(ii) PS method provided poor image of the salt structure (SEG/EAGE Salt model) without delineating the reflectors properly. In contrast to PS method, PSPI migration scheme has proved to be accurate in imaging the complex salt structure in delineating major faults with restoration of correct throw. The velocity depth section is exactly matching with the reflectors and faults position in the PSPI migrated section.

(iii) Computational noise in form of numerical artifacts was more prominent in PS migrated sections compared to PSPI section for all the four structures.

(iv) PSPI scheme proved to be superior in comparison to PS in terms of imaging capability, handling steep dip and strong lateral velocity variation.

REFERENCES

Gazdag, J. F., 1978. Wave equation migration with phase-shift method, Geophysics, 43, 1342-1351.

Gazdag, J. & Sguazzero, P., 1984. Migration of seismic data by phase shift plus interpolation, Geophysics, 49, 124-131.

SeismicUnix, Version 2.6, 1999, Centre for Wave Phenomena, Colorado School of Mines, Golden, USA.

Wu. R. & Jin, S., 1997, Windowed GSP (Generalized Screen Propagators) migration applied to SEG-EAGE salt model data: 67th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, 1746-1749.

(Revised accepted 2009 November 30; Received 2009 July 7)

P R Mohanty is working as an Associate Professor in the department of Applied Geophysics, Indian School of Mines (ISM) since 1988. He obtained his PhD Degree in 1997 from ISM Dhanbad. He did his Master's degree in Earth Science (Geophysics) from Memorial University of Newfoundland, Canada in 1984. He also worked in ONGC and OIL as a Geophysicist for nearly six years. He specializes in reflection seismology and has published more than 20 technical papers in national and international conferences and journals.