PAPER P

POST-CDP-MAPPED MIGRATION IN VERTICAL SEISMIC PROFILE

Le-Wei Mo

ABSTRACT

In this paper, I investigate the post-CDP-mapped migration of dipping reflectors. VSP-CDP maps reflection of a dipping reflector into a third-order polynomial. Under certain conditions, this third-order polynomial can be approximated by a line. Under the guidance of forward modeling linear regression, this line is rotated in slant-stack tau-p space. Inverse slant stack gives the correctly imaged dipping reflector in space. This VSP post-CDP-mapped migration scheme is designed to be accurate from 0 to +/- 15 degrees.

INTRODUCTION

In vertical seismic profiling (VSP), a source is placed at the Earth surface and a string of receivers are placed in the borehole to record both the downgoing direct arrival and the upgoing reflections, Figure 1. The advantages of vertical seismic profiling over the conventional surface seismic reflection surveys are many. Since the receivers are buried in the borehole within the earth rather than on the earth surface, the source excited seismic waves propagate only once through the severe attenuating near-surface weathered zone.. The frequency contents of the seismic waves as recorded are richer than in surface seismic reflection survey. As VSP data are recorded inside the earth during the wave propagation process, VSP data are in-situ recorded data. VSP data has been used for correlating seismic and well log data, for identifying multiple reflections, for analyzing source signature effects, and for studying the effects of attenuation. As in surface seismic reflection survey, vertical seismic profiling data can also provide structural information of the earth subsurface, in partilcular near the borehole. Since the receivers are placed within the earth and the resulting recorded frequency bandwidth is wide, vertical seismic profiling data can provide higher resolution structural images in the vicinity of the borehole, revealing small features otherwise unseen in conventional surface seismic reflection survey images. High resolution structural images near the boreholes are very useful in reservoir characterizations. It has been reported vertical seismic profiling can detect waterflooding and CO2 injection fluid fronts. However, the vertical seismic profiling can only provide high resolution information in the vicinity of the boreholes, it is a complementary survey method to the convential surface seismic method which provide low resolution information but over a large area.

The methodology of structural imaging in vertical seismic profiling has largely been influenced by surface seismic reflection data processing. For example, in migration imaging, many authors have reported applying pre-stack depth profile migration methods. These pre-stack migration methods, e.g., Kirchhoff migration, reverse-time, phase-shift plus interpolation, are equivalent, they only differ in the way wavefields are extrapolated. In surface seismic reflection surveys, pre-stack depth migration has been popularly applied to all survey areas, and it has enjoyed many successes in subsurface structure imaging in the complexity of 3-D saltdomes. The success of pre-stack depth migration in surface seismic survey lies in the wide recording aperture and that there are many shots and receivers in surface seismic survey. In vertical seismic profiling, there is usually only shot gather data or in a better survey there are a few shot gathers,; and in each common shot gather there are usually less than 100 receiver traces data. This means the surveying aperture in VSP is very small, there are not enough pre-stack profile migration images to stack to attenuate out the edge diffractions and increase signal/noise level. Thus, even though pre-stack depth profile migration is a powerful imaging method, when applied to vertical seismic profiling where the conditions for its utilizations are not met, the results might not be satisfactory. In surface seismic survey, a less sophisticated structural imaging method is the sequence of CDP stack and post-stack migration, which has a better noise tolerance even though suffering in some lower accuary than the pre-stack depth migration.

Wyatt et al (1981) introduced the CDP technique of surface seismic reflection survey into vertical seismic profiling. In surface seismic reflection data processing, CDP stack is followed by a post-stack migration. because CDP stacking does not place the dipping reflectors at the correct positions. As noted in Wyatt et al (1981), post-CDP migration is an indispensible step in VSP-CDP structural imaging. But, this post-CDP migration has been lacking for more than a decade. In migration, curves are correctly migrated by migration operating on lines as a curve is the envelope of lines of various dips.

VSP reflection traveltime from a dipping interface

The VSP geometry for a single dipping interface at an angle θ is shown in Figure 1. In this survey geometry, L is the well-to-shot offset; d is the depth to the geophone receiving the reflected ray; and h is the depth to the point where the dipping interface intercepts the well.

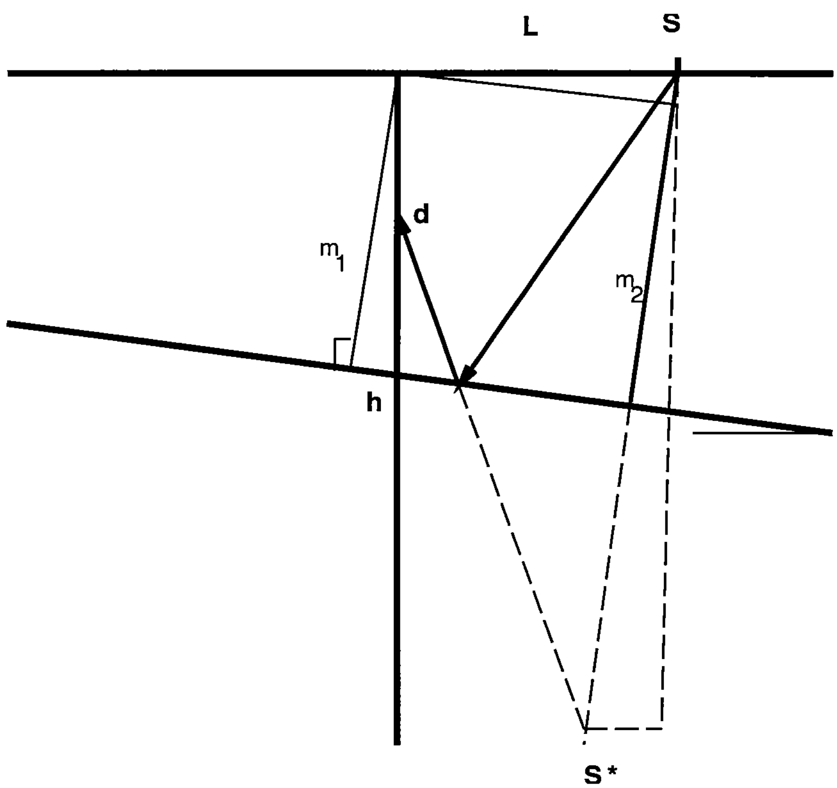

Figure 1: VSP reflection survey and traveltime

In deriving traveltime equation for the reflected ray, m_1 is the perpendicular distance from the top of the well to the interface, m_2 is the perpendicular distance from the shot to the interface. The following relationships follow from this figure:

$$m_1 = h\cos\theta$$

$$m_2 = m_1 + L\sin\theta$$

$$m_2 = h\cos\theta + L\sin\theta$$

The Cartesian coordinates at the image source $S*$ are:

$$x_{S*} = L - 2m_2\sin\theta$$

$$x_{S*} = L - 2(h\cos\theta + L\sin\theta)\sin\theta$$

$$z_{S*} = 2(h\cos\theta + L\sin\theta)\cos\theta$$

If the layer velocity is v and the reflection event traveltime is t,

$$v^2t^2 = x_{S*}{}^2 + [z_{S*} - d]^2$$

$$v^2t^2 = [L - 2(h\cos\theta + L\sin\theta)\sin\theta]^2 + [2(h\cos\theta + L\sin\theta)\cos\theta - d]^2$$

After some algebraic simplications, we arrive at:

$$v^2t^2 - L^2 = 4(h-d)(h\cos^2\theta + L\cos\theta\sin\theta) + d^2$$

When $d=0$ and $\theta = 0$, that is for flat reflector and the receivers being located at the earth surface, it reduces to the NMO traveltime equation for surface seismic reflection survey.

VSP reflection CDP depth mapping

The CDP mapping algorithm assumes flat reflectors, Figure 2. The reflection point coordinates are related by

$$\frac{x}{z-d} = \frac{L-x}{z}$$

From this equation we obtain

$$d = z - \frac{xz}{L-x}$$

The CDP mapping traveltime equation is

$$v^2t^2 = L^2 + (2z-d)^2$$

$$z = \frac{\sqrt{v^2t^2 - L^2} + d}{2}$$

Using the traveltime equation (A-6), we get

$$z = \frac{\sqrt{4(h-d)(h\cos^2\theta + L\sin\theta\cos\theta) + d^2} + d}{2}$$

Plug in the CDP mapping relation for d, we obtain

$$xz^2 = [(L-x)h + (2x-L)z](h\cos^2 + L\sin\theta\cos\theta)$$

This is a third-order nonlinear equation.

Let $\delta = h\cos^2 + L\sin\theta\cos\theta$, and fix x, it becomes a second-order equation for z,

$$z = \frac{(2x-L)\delta + \sqrt{(2x-L)^2\delta^2 + 4x(L-x)h\delta}}{2x}$$

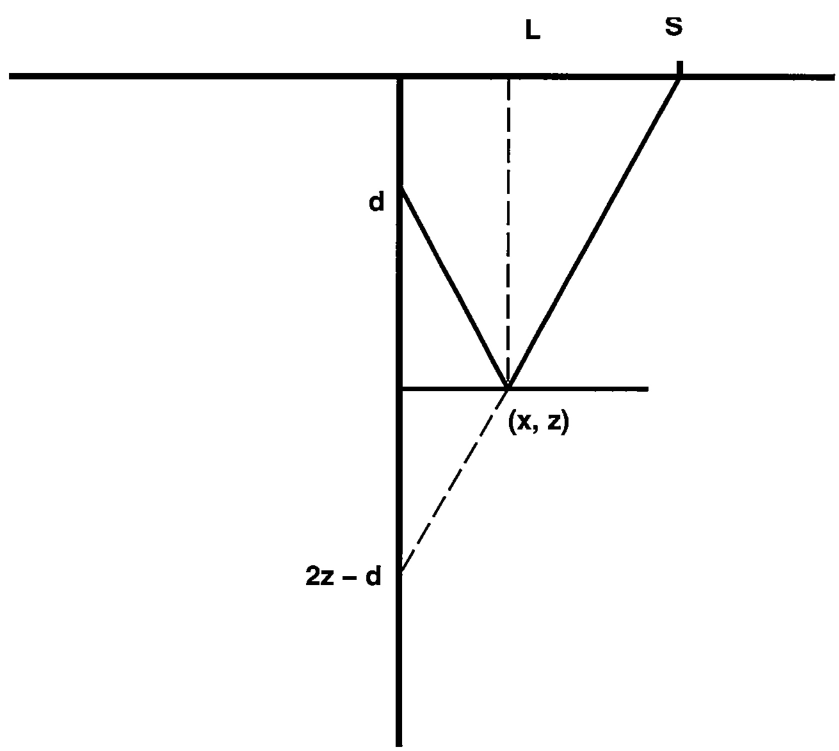

Figure 2: VSP reflection CDP mapping.

REFERENCES

Cassell, B. R., Alam, M. A., and Millahn, K. O., 1984, Interactive VSP-CDP mapping in complex media: 54th Ann. Internat. Mtg., Soc. Explor. Geophys., Expanded Abstracts, 842-845.

Chang, W. F., and McMechan, G. A., 1986, Reverse-time migration of offset vertical seismic profiling data using the excitation-time imaging conditions: Geophysics, 51, 67-84.

Dillon, P. B., and Thomson, R. C., 1984, Offset source VSP surveys and their image reconstruction: Geophysical Prospecting., 32, 790-811.

Dillon, P. B., 1988, Vertical seismic profile migration using the Kirchhoff integral: Geophysics, 53, 786-799.

Hardage, B.A., 1983, Vertical seismic profiling part A -- principles: Geophysical Press.

Wiggins, J. W., Ng, P., and Manzur, A., 1986 The relation between the VSP-CDP transformation and VSP migration: 56th Ann. Internat. Mtg., Soc. Explor. Explo.,Geophys., Expanded Abstract, 564-568.

Wyatt, K. D., and Wyatt, S. B., 1981, Determinating subsurface structure using the vertical seismic profiling: 51st Ann. Internat. Mig., Soc. Expl. Geophys., Expanded Abstracts, 99-102.