Technology of 2D and 3D VSP processing: workflow and case story examples

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INTRODUCTION

The topic presents optimal processing flow for walkaway and 3D VSP data aiming at obtaining high-resolution seismic images at the distance of several kilometers from well. The emphasis is done on wavefield decomposition and new technique for wave selection based on multidimensional Radon transform is proposed. The subject also includes representative examples of 2D and 3D VSP processing results.

Need in detailed exploration of small hydrocarbon reservoirs with complex structure, and thus, in obtaining high resolution seismic images provides strong interest in the walkaway method of borehole seismic surveys. Being an extent of conventional VSP technique at big offsets the walkaway (or 2D VSP) geometry is formed by source surface profile and multilevel borehole receiver sonde. The latter is normally positioned under hard seismic boundary corresponding to the bottom of weathering zone in order to prevent registration of multiple reflections within it. Therefore the walkaway method is extremely effective in regions characterized by large weathering zone or complex subsurface structure where other seismic methods can't provide reliable data.

In this paper we present optimal processing flow for walkaway and 3D VSP data that allows getting high resolution images at the distance of several kilometers from well (that significantly exceeds usual VSP sections of about hundreds meters in length). The key point in achieving enhanced results is improved wavefield decomposition. Besides using a combination of conventional methods we introduce here the new instrument for wave selection derived from multidimensional Radon transform. To illustrate application of this technique as well as all processing chain we present two examples of real 2D and 3D surveys conducted in China.

WALKAWAY DATA PROCESSING

We have developed processing chain that includes the following procedures:

I. Preprocessing

1. Uphole-based statics calculation and application
2. First break (FB) hodograph determination; velocity model correction using all available walkaway FB hodographs
3. Polarization parameters determination; orientation to PRT-system
4. Impulse shape estimation for every shot point; impulse shape correction
5. High-frequency statics calculation based on down-going p-waves and its application
6. Predictive deconvolution and band-pass filtering; harmonics filtering
7. Divergence compensation
8. Energy balancing through different levels

II. Wavefield decomposition

9. Wave selection in the f-k and time domain (for common receiver gather)
10. Iterative multi-level wave selection (i.e. for common shot-point gathers)
11. Wave selection in the τ-p-q domain
12. Calculation and application of up-going p-waves-based statics
13. Spike deconvolution and band-pass filtering

III. Imaging (Migration)

Wavefield decomposition is the most important part of walkaway data processing. It may be done by conventional means such as f-k filtering, wave correlation and subtraction in time domain at common receiver gathers. However, these methods often can't provide perfect wave selection because of edge effects of filtering and significant signal's variation at far offsets of shot point. At the same time, walkaway data are also characterized by second spatial variable that denotes receiver's position. Therefore it is also possible to perform wave decomposition in vertical direction, i.e. at common shot-point gathers. Better results can be achieved by iterative approach. It implies accurate repeated selection of each type of waves in the absence of all others. Nevertheless, standard subtraction of waves cannot be managed appropriately at the base of 6-10 traces (that usually equals the aperture of common shot-point gathers) due to high statistical errors. On the other hand, arrival times of any wave along spatial coordinate for several traces can be approximated by a line. It gives opportunity to perform *τ-p* transformation that is convenient tool for wave separation. Forward *τ-p* transform is determined by the following integral: $v(p,\tau) = \int_{-\infty}^{+\infty} u(x,\tau + px)\,dx$.

So, any set of seismic traces *u(x,t)* may be transformed to the *τ-p* domain where waves with different apparent slowness (*p*) and intercept times (*τ*) will be distinguished from each other. As the walkaway data set is described by two spatial variables (*x* - coordinate of the shot point and *z* - depth of the geophone), this provides the possibility to apply 2-dimentional *τ-p* transform. It implies a need for two slowness parameters (along *z*- and *x*-directions correspondingly) called here *p* and *q*: $v(p,q,\tau) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} u(x,z,\tau + pz + qx)\,dz\,dx$

While in *z*-direction walkaway data usually has a short aperture, in *x*-direction there is a wide range of shot point coordinates, therefore a sliding base is implemented in *x*-direction.

However, relatively small aperture of the input data results in smearing of the events in the *τ-p* domain with linear artifacts. The number of these artifacts equals to the number *Nx* of traces within aperture while their amplitude is *Nx* times smaller than the amplitude of the real event. The artifacts hamper the wave selection and cause impulse shape distortion after inverse transformation. For artifacts' suppression the so-called p-direction deconvolution is performed (Zhou and Greenhalgh 1994). This procedure requires regularization and isn't always efficient due to presence of noise in data. Instead of it we apply an iterative from-strong-to-weak search that helps to clearly focus and locate events in the *τ-p-q* domain. Extraction is performed for those events that appear to exceed the pre-defined threshold level which is derived for every time sample as the share from the maximum energy distribution. Then using reference velocity model filter nodes (parameters p(*τ*), q(*τ*) for every node time *τ*) for a given type of wave are evaluated. At the next step time location in the *t-z-x* domain of all events outside the filter is determined and subtracted from the original seismic data set (Tabakov et al. 2005).

It is important to note that proposed method of *τ-p-q* transform can be easily extended to 3D case by considering one more parameter of slowness in the third spatial direction. It may be extremely useful tool for wavefield decomposition when dealing with 3D VSP data.

EXAMPLES

We applied processing presented above to walkaway data acquired in China. The 6-level sonde was positioned in a well at the depth of 1000-1100 m with receivers' spacing of 20 m. Shot points lied along four perpendicular profiles 4 km long crossing at the wellhead-point. Shot-point spacing was 25.3 m. The aim was to obtain high-resolution seismic images below weathering zone.

Figure 1a shows an example of raw common receiver gather. Reflected P-waves can't be clearly observed at all offsets. However, after described processing and stacking of all levels (fig.1b) they are excellently distinguished. Fig.2 presents obtained images that correlate with VSP primary reflection trace very well.

Another example is 3D-VSP survey that we process by the same way. The raw data and the results are shown in fig.3, 4.

CONCLUSIONS

Expanded to multidimensional observation systems τ-p transformation presents the effective way of wave selection for 2D and 3D VSP data processing that may be more informative in some details than seismic exploration on the surface if adequate processing chain is applied.

REFERENCES

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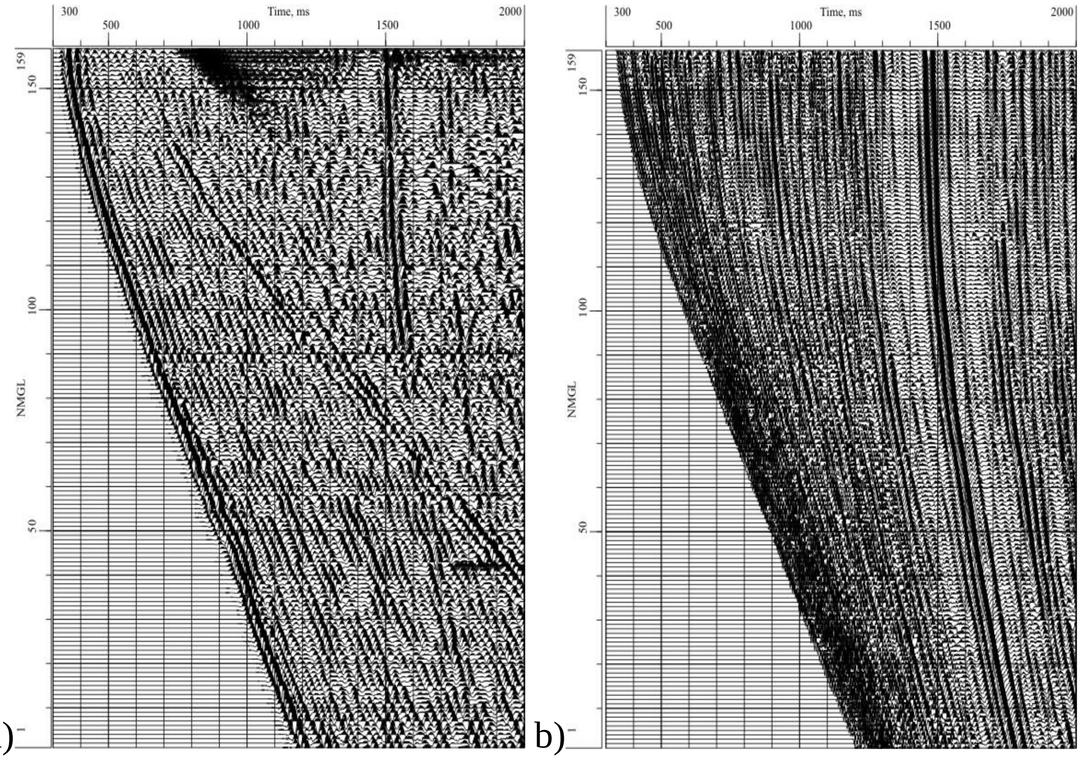

a) b)

Figure 1. Walkaway data: a) – a raw common receiver gather; b) – reflected P-waves after selection, spike deconvolution, and stacking of all levels.

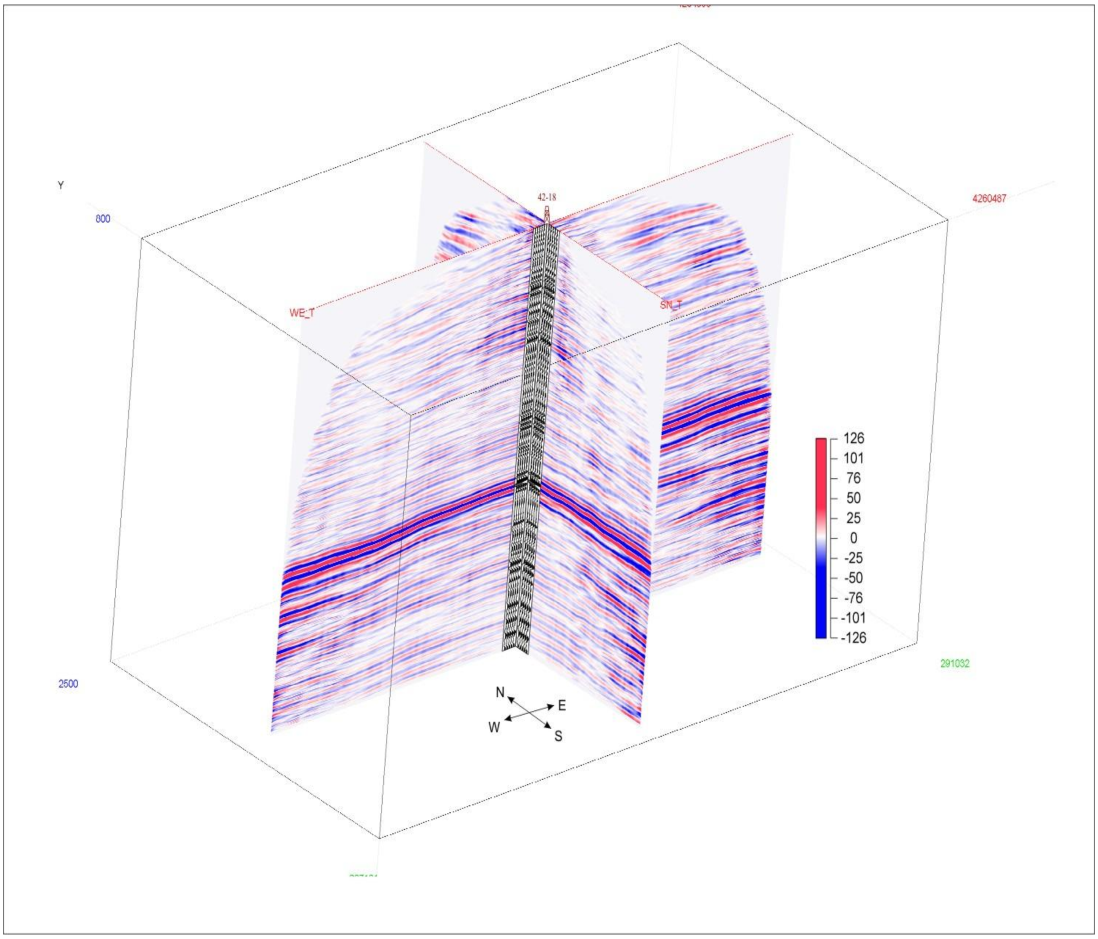

Figure 2. Seismic images obtained from walkaway data in comparison with VSP primary reflection trace.

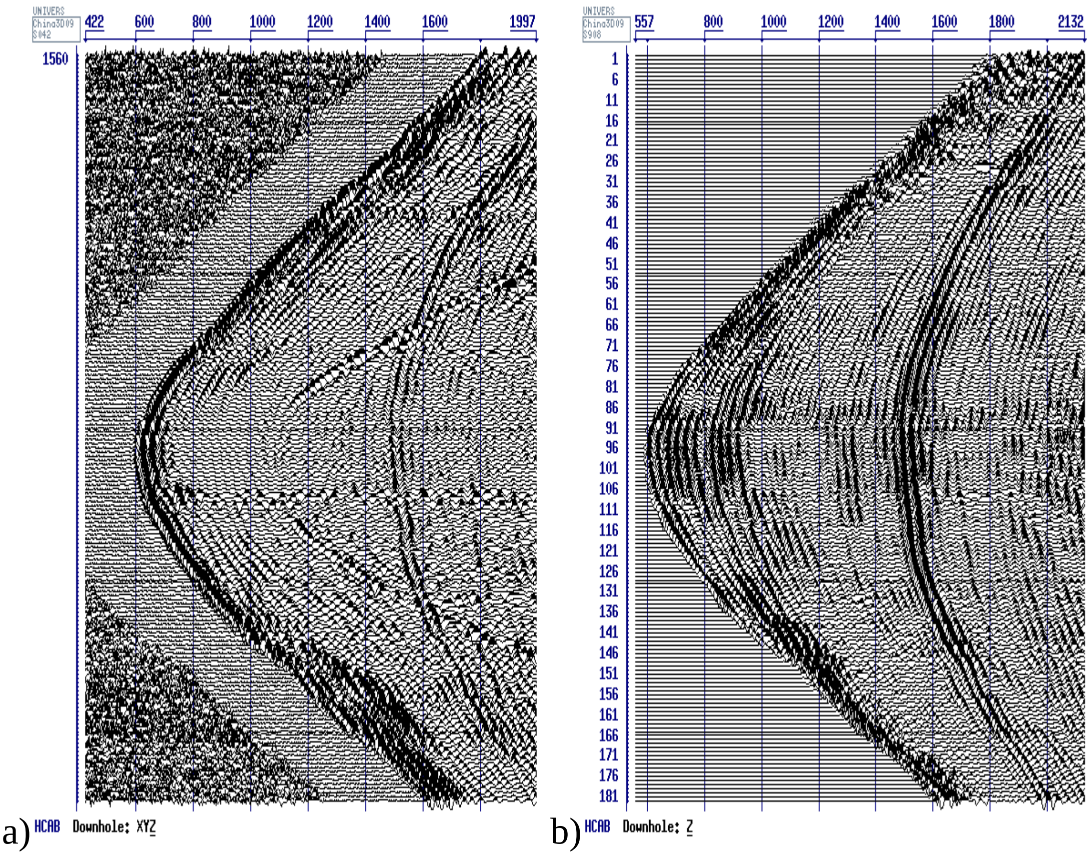

Figure 3. 3D VSP data: a) – a raw common receiver gather; b) – reflected P-waves after selection.

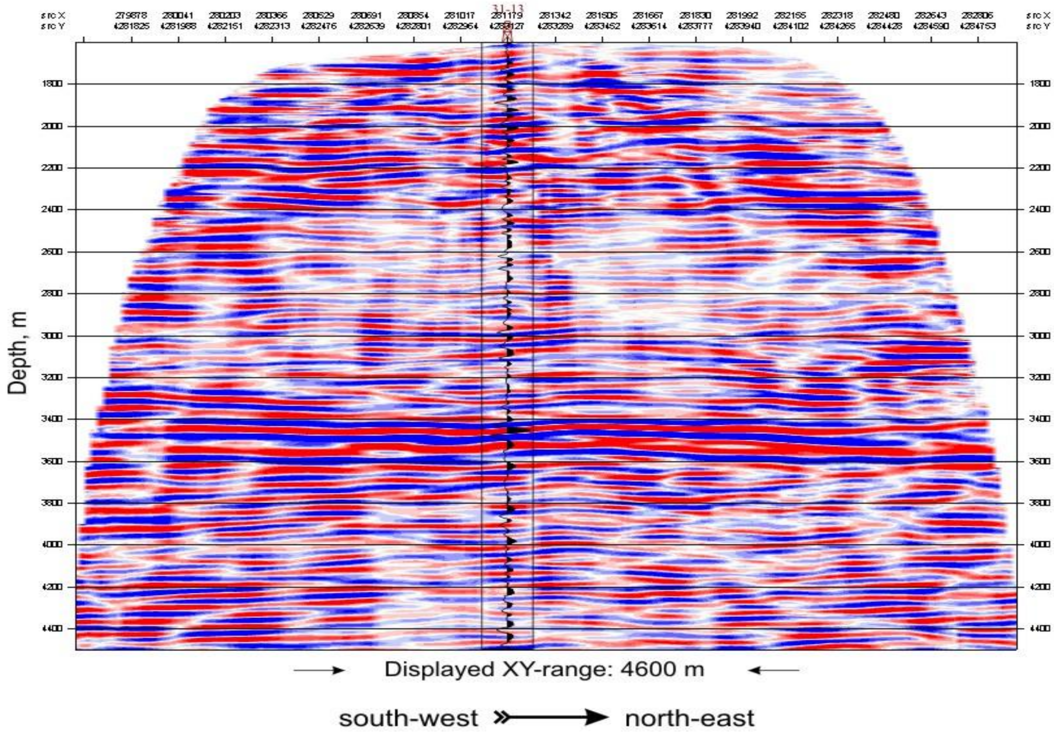

Figure 4. A seismic image obtained from 3D VSP data in comparison with VSP primary reflection trace.

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