Barcelona '10

G040

Separation and Imaging of Seismic Diffractions in Dip Angle Domain

A. Klokov* (Opera), R. Baina (Opera) & E. Landa (Opera)

SUMMARY

Diffraction events containing in seismic data characterize small size geological objects. This information can supplement conventional reflection method. Typically diffracted energy is much weaker than reflection one. Therefore diffractions have to be extracted from the full wavefield before diffraction imaging. We present a method for reflection-diffraction events separation using the hybrid Radon transform.

Introduction

Diffraction events containing in seismic data characterize small size geological objects such as faults, pinchouts, fractures etc. This information can supplement conventional reflection waves analysis and favour the more challenging interpretation task solution. But typically diffracted energy is one or even two order of magnitude weaker than reflected one and it is not easy to distinguish diffracted events in full dataset or diffraction image in full seismic image. Therefore diffracted and reflected energy have to be separated.

To apply wavefield separation it is necessary to define a domain where different waves have different properties, different behavior. There are several approaches intended for reflection and diffraction energy separation which use different domains. Khaidukov et al. (2004) used different moveout properties of the waves, focused reflected waves to their imaginary source location in the pseudo-depth domain, muted it, and after defocusing got gathers where reflection events were suppressed. Taner et al. (2006) showed a possibility to separate reflections and diffractions using plane-wave constant *p* sections. In this domain diffracted waves appear in the quasi-hyperbolic shaped travel times. In turn reflections behave as simply shaped laterally continuous events. Therefore reflection energy can be rejected by the method of plane-wave destruction (Claerbout, 1992; Fomel, 2002). Separation and diffraction imaging using the same basic principles in the post-stack domain are discussed by Fomel et al. (2007). The post-migration dip-angle domain discovered significant distinction between diffractions and reflections (Landa et al., 2008; Reshef and Landa, 2009). In this domain after migration with the correct velocity reflections appear as concave-shaped events while diffractions are flat. Moreover, after PSDM reflections always have a concave shape, regardless of the migration velocity used (Audebert et al., 2002).

In this study we propose alternative procedures for reflections and diffractions separation and diffraction images construction which are valid without the assumption about correct velocity model.

Events separation

Reflection apex removal

In this work we discuss migrated common image gathers (CIG) in dip angle domain. As usual, summation of the CIGs produces seismic image. An image of different subsurface objects (reflectors or diffractors) is formed by that part of the corresponding event on the CIG. Since reflection event on the CIGs always has a concave shape (smile), image of this point is formed by constrictive summation in a vicinity of an apex of the smile. It means that if we want to eliminate reflections on the image it is necessary to subtract part of the reflection event on the CIG which is located in a vicinity of the apex of the smile. A simple way to detect the smile apex position is to parameterize a reflection event by an apex-shifted parabola and to search for a position corresponding to the maximum semblance values for every dip angle and every depth sample. Then we pick maximum semblance value for every depth using an automatic picking procedure with regularization. Obtained curve corresponds to position of reflection apex for each depth sample. We now can destruct part of the reflection event around the apex. After summation the CIGs we obtain migrated image with strongly attenuated reflection energy. Note that due to the fact that reflections on the CIGs have a concave shape regardless of the migration velocity (Landa et al., 2008) the described procedure is efficient for even in case of inaccurate velocity model.

Hybrid Radon transform

Unlike reflection, shape of a diffraction event on CIG depends on migration velocity accuracy. Since reflection and diffraction events have quite different shapes in the post-migrated dip-angle domain they could be separated by a hybrid Radon transform (Trad, 2002). First we define two models in the Radon domain: one describes diffraction events, the other defines reflection events. Each model is connected with the data by its pair of operators.

The shape of diffraction event in the dip angle CIG is described by the following equation (Landa et al., 2008):

$$z_i = \frac{\gamma \cos(\alpha)(\gamma \Delta x \sin(\alpha) + D)}{1 - \gamma^2 \sin^2(\alpha)}, \quad D = \sqrt{(z^2(1 - \gamma^2 \sin^2(\alpha) + \Delta x^2)} \tag{1}$$

In the equation above z_i – depth of the image, α – the current dip, Δx – lateral distance between a diffractor and an observation point, γ-characterizes migration velocity accuracy and equal to V_m/V. Using this approximation we construct a pair of the transform operators: for direct transform from the data domain d to the diffraction model domain m_d:

$$m_d(\gamma, \Delta x, z_i) = \sum_h d(h, z = z_i + f(\gamma, \Delta x, z_i)), \tag{2}$$

and from the diffraction model domain to the data domain:

$$d(h, z) = \sum_\gamma \sum_{\Delta x} m_d(\gamma, \Delta x, z = z - f(\gamma, \Delta x, z_i)). \tag{3}$$

where f is a function connected to diffraction shape description (1).
Reflections are approximated by apex-shifted parabolas. Curvature of the parabola is limited by minimum and maximum moveout on far offset.
To define the hybrid model that best fits the data in a least-squares sense we minimize the objective function F:

$$F(m_d, m_r) = \|L_d m_d + L_r m_r - d\|_2 + \varepsilon_d \|W_d m_d\|_2 + \varepsilon_r \|W_r m_r\|_2, \tag{4}$$

where L_d, *and* L_r are diffraction and reflection Radon operators respectively, W_d and W_r are model space weights, ε_d, *and* ε_r are diffraction and reflection measures of sparseness respectively. To find the minimum of F we use a limited-memory quasi-Newton method (Guitton and Symes, 2003).
When the models m_d, *and* m_r are found we invert them separately and get two datasets, one of which contains diffraction events only and another one – reflection events.
It is important to note that this separation procedure may leave relatively strong residual reflection energy in the diffraction component of the Radon domain. It is connected to the fact that part of the energy connected to the apex area of the reflections leaks into diffraction component. This is why to separate reflection and diffraction components we use two step combination of apex removal described above and Radon separation.

Example

To illustrate application of our method we use a part of the Sigsbee synthetic data set. We computed dip angle CIGs and a depth image using the correct velocity. Figure 1*a* shows a common image gather located above two diffraction points. Reflection events have the form of smiles while diffractors are expressed by two horizontal events in the figure. Our purpose is to separate diffraction and reflection events. To determine positions of the reflection apexes in the CIGS we firstly ran a procedure described above and create a semblance panel (Figure 1b) when maximum semblance indicates position of the apexes. The red line on the figure shows the picked positions. For each depth sample we mute areas in a vicinity of the picked positions and in such way we eliminate part of the reflection energy connected to the apexes of the shifted hyperbola (Figure 1 *c*). At the second step we apply the hybrid Radon transform to the residual field. Since the migration velocity is correct the diffraction model was restricted to one plane $\gamma=1$. The Radon transformation for diffraction part of the hybrid diffraction-reflection model is shown in Figure 1d. The lateral distance between observation point and diffractor was chosen ± 500 m and the reflection model contains seven planes for the apex shifts. The curvature parameter for reflection parabola was limited by minimum value 3 km and maximum value 21 km (Figure 1 *e*).
After applying diffraction model inversion for every input common image gather we get dataset which contains mostly diffraction events. Figure 2 shows three neighbour CIG gathers (Figure 2a) and the corresponding gathers after separation (Figure 2 *b*). Notice that besides two point diffractors (at depth of 5.1 and 7.5 km) weaker diffraction events are preserved (at depth 4 km).

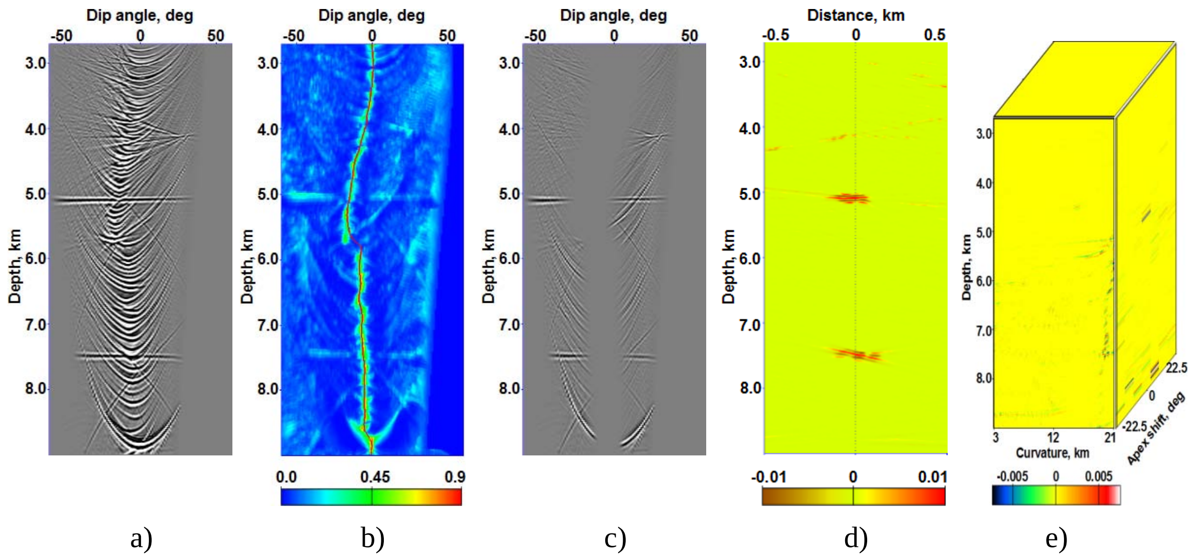

Figure 1: *a) Initial CIG; b) semblance section; c) the CIG after the apex destruction; d) diffractions in the Radon domain; e) reflections in the Radon domain.*

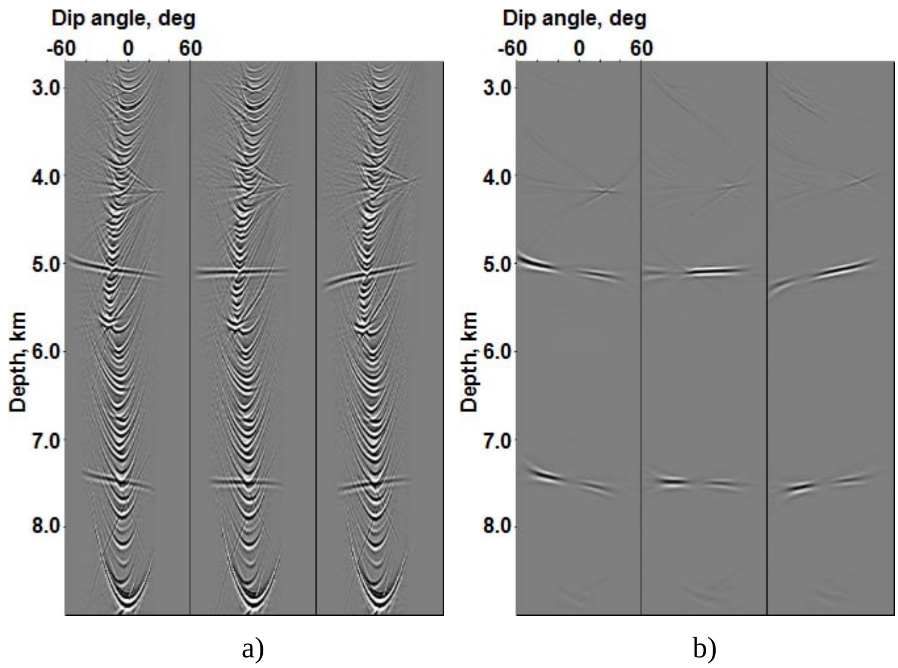

Figure 2: *a) Original CIGs; b) the CIGs after separation.*

Figure 3a shows conventional depth migration results of the processed part of the data. Results of depth imaging after reflection apex removal and additional wavefield separation in the Radon domain are shown in Figure 3b and 3c respectively. Six point diffractors are imaged very well. Besides it, the image contains several strongly pronounced faults. Notice that image constructed after the apex destruction only (Figure 3 *b*) has acceptable quality – all point diffractors and faults are imaged. The event separation makes it more clear removing many artefacts.

Conclusions

We proposed a new method for separation reflection and diffraction wavefield components in the migrated dip angle domain. This method is based on the two step procedure which contains reflection apex removal and filtering in the hybrid Radon domain. Diffraction image constructed by CIGs summation after destruction of reflection apexes has low computational cost but has relatively strong residual reflection events. This weakness can be improved by applying events separation in the hybrid Radon domain using apex-shifted parabola parameterization for reflections and analytical expression for diffractors. Application the proposed method to synthetic and real data illustrates potential of using diffractions for imaging of small scale elements of the subsurface.

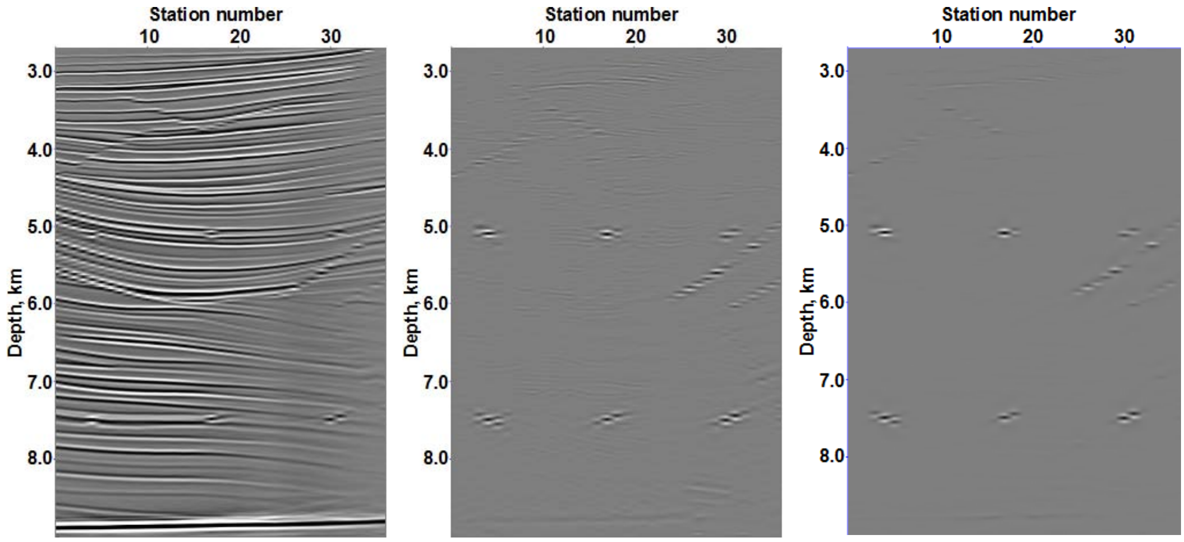

Figure 3: *a) Initial seismic image; b) diffraction image obtained by the apex destruction; c) diffraction image obtained after Radon transform.*

Acknowledgements
The authors thank TOTAL for supporting this research. OPERA is a private organization funded by TOTAL and supported by Pau University whose main objective is to carry out applied research in petroleum geophysics.

References
Audebert, F., Froidevaux ,P., Racotoarisoa, H., Svay-Lucas, J . 2002. Insights into migration in the angle domain. Expanded Abstract, SEG, 1188-1191.

Claerbout J.F., 1992. Earth soundings analysis: Processing versus inversion: Blackwell Scientific Publications, Inc.

Fomel S., 2002. Applications of plane-wave destruction filters, Geophysics, 67, 1946–1960.

Fomel S., Landa E., and Taner M.T., 2007. Poststack velocity analysis by separation and imaging of seismic diffractions,Geophysics, 72, U89–U94.

Guitton A. and Symes W., 2003. Robust inversion of seismic data using the huber norm, Geophysics, 68, 1310–1319.

Hargreaves N., verWest B., Wombell R., and Trad D., 2003. Multiple attenuation using an apex-shifted Radon transform,SEG Expanded Abstracts, 22, 1929.

Khaidukov V., Landa E., and T. J. Moser T.J., 2004. Diffraction imaging by focusing-defocusing: An outlook on seismicsuperresolution, Geophysics, 69, 1478–1490.

Landa E., Fomel S., and Reshef M., 2008. Separation, imaging, and velocity analysis of seismic diffractions using migrateddip-angle gathers, SEG Expanded Abstracts, 27, 2176.

Reshef M., 2007. Velocity analysis in the dip-angle domain, 69th EAGE meeting, Expanded Abstracts.

Reshef M. and Landa E., 2009. Post-stack velocity analysis in the dip-angle domain using diffractions, GeophysicalProspecting, 2009, 57, 811–821.

Taner M.T., Fomel S., and Landa E., 2006. Prestack separation of seismic diffractions using plane-wave decomposition, SEG Expanded Abstracts, 25, 2401.

Trad D., Sacchi M., and Ulrych T., 2001. A hybrid linear-hyperbolic Radon transform, J. Seis. Expl., 9, 303–318.