WS5-P15

Fracture Detection via Beam Imaging and Image Spectrum Analysis

M. Protasov* (Institute of Petroleum Geology & Geophysics SB RAS), V.A. Tcheverda (Institute of Petroleum Geology & Geophysics SB RAS) & G.V. Reshetova (ICMMG SB RAS)

SUMMARY

An approach to seismic imaging of fractures by multicomponent surface data is presented and discussed. It is based on a specific imaging procedure, which consists in a weighted summation of multicomponent multishot/multioffset data. These weights are computed by tracing a specially chosen Gaussian beams. In order to get image of fractures these beams are taken in a way forming so called selective images (Pozdnyakov and Tcheverda, 2006; Protasov and Tcheverda, 2011). Their geometry provides suppression of regularly reflected waves and, thus, emphasizes the presence of small-scale heterogeneities that give rise to diffracted/scattered waves. Additionally spectral removal is applied for more essential suppression of regular reflections footprint. Numerical experiments with synthetic data set computed for the typical seismogeological model of Yurubcheno-Tokhomskoye area are presented and discussed.

Introduction

A major challenge in carbonates environments is to map microheterogeneities which have a positive impact on oil and gas production. For example in many carbonate reservoirs, matrix porosity contains the oil in place but the permeability is mainly provided by fracture corridors. In some carbonate reservoirs the oil in place is essentially contained in karstic caves. Therefore the ability to precisely locate these microstructures and to characterize their properties is of a high importance. The approach presented in the paper is a modification of the method of Focusing Transformation (Pozdnyakov and Tcheverda, 2005). We have kept the concept of selective images, but construct them on the base of Gaussian beams. This way happens to be very natural in order to optimize summation apertures by exponential decrease of Gaussian beams outside the small vicinity of the central ray. This approach is validated on a synthetic dataset simulated for a typical seismogeological multiscale 3D heterogeneous model of Yurubcheno-Tokhomskoye area.

Imaging method

We start with the imaging formula proposed by Protasov and Tcheverda, 2012:

$$f_\beta \approx \iint_{X_{par}(\bar{x})} d\bar{p} \iint_{V(\bar{x})} f_\beta(\bar{y}) \cdot \exp\left(i \cdot \bar{p} \cdot (\bar{x} - \bar{y})\right) d\bar{y} \approx \int \mathrm{T}^{s}_{gbp}(x_s;\omega,\alpha,\beta) \cdot \vec{\mathrm{T}}^{r}_{gbp}(z_r;\omega,\alpha,\beta) \cdot \vec{\varphi}(z_r;x_s;\omega) dx_s dz_r d\alpha d\omega. \quad (1)$$

Here $f_\beta = \lambda_1 + 2\mu_1 \cos^2(2\beta) + v_0^{p^2} \rho_1 \cos(2\beta)$ - the recovered function, $\vec{\varphi}(z_r;x_s;\omega)$ - multicomponent surface seismic data in the frequency domain, $\mathrm{T}^{s}_{gbp}(x_s;\omega;\alpha,\beta), \vec{\mathrm{T}}^{r}_{gbp}(z_r;\omega;\alpha,\beta)$ - normal derivatives of Gaussian beams together with their potentials at the source positions (for details see paper of Protasov and Tcheverda, 2012). The beams are computed on the basis of ray tracing from every image point. X_{par} - set of partial reconstruction, see (Protasov and Tcheverda, 2011). This subdomain is a circular sector which is defined by the frequency bandwidth (ω_1, ω_2) of the source function and available range of dip angles (α_1, α_2): $X_{par}(\bar{x}) = \left\{ (p_x, p_z) : \omega_1 \le \frac{V_{0p}(\bar{x})\sqrt{p_x^2 + p_z^2}}{2\cos\beta} \le \omega_2; \alpha_1 \le -arctg \frac{p_x}{p_z} \le \alpha_2 \right\}$.

Image spectrum analysis

The structure of the set of partial reconstruction lies at the heart of the proposed method. Changing opening β and dip (α_1, α_2) angles one controls geometry of visible and invisible elements of the geological cross-section. If the spatial spectrum of a local object lies entirely outside of the set of partial reconstruction, this object is absolutely "invisible". If the spatial spectrum of a local object possesses nonempty intersection with a set of partial reconstruction its selective image will be made from orthogonal projection of desired perturbation onto the set of partial reconstruction. On this base one can conclude, that any small scale (subseismic) object like diffractor/scatterer, crack, fault, pinch and so on possesses extended spatial spectrum and, so, will be presented for a wide range of sets of partial reconstruction. On the contrast, any regular interface possesses very narrow spatial spectrum and, so, one can easy choose geometry of the Gaussian beams providing the set of partial reconstruction without of this spectrum. But in the cases when scattering objects have significantly lower contrast than regular reflections they will give significant footprint on almost any set of partial reconstruction. This happens because of smooth behaviour of the kernel of the imaging operator with respect to dip angle. In such cases it is suggested additionally to remove the part of the image spectrum that corresponds to the regular reflections that have significant footprint on all images corresponding to the different dip angles. For that it is suggested to perform spatial Fourier transform of the recovered image for (every dip angle) and remove the part of spectrum corresponds to the reflections(they corresponds to some dips) that have significant footprint on the image. It means one needs to remove narrow parts of spectrum that corresponds to these reflections. After that one needs to perform inverse spatial Fourier transform. As a result ideally there will be an image without regular reflections. But on that image there should be scattering objects because they have wide spatial spectrum so they will not be removed.

Numerical examples

Let us now present results of imaging for some synthetic data sets generated for 3D heterogeneous model. To study the features of fracture imaging provided by the method and evaluate the limits of its applicability and resolution, we have synthesized surface seismic data for some 3D multi-scale realistic geological model with subseismic heterogeneities typical for Yurubcheno-Tohomskaja area (East Siberia). On the Fig.1 one can see the set of the recovered selective images for dip angles -45^0, -35^0, 45^0, 0^0. As one can see, selective image for $\alpha=0^0$ does not present any fractures at all, but regular horizontal interfaces only. At the same time, with increasing of absolute value of dip α there is a clear decrease of regular interfaces and increase of the intensity of the footprints of cracks. But the influence of regular reflections is significant. So additionally there was applied removal of narrow parts of spectrum that corresponds to horizontal reflections. The results are presented on the Fig.2. One can clearly observe now the footprint of the cracks only on the selective images and on the sums.

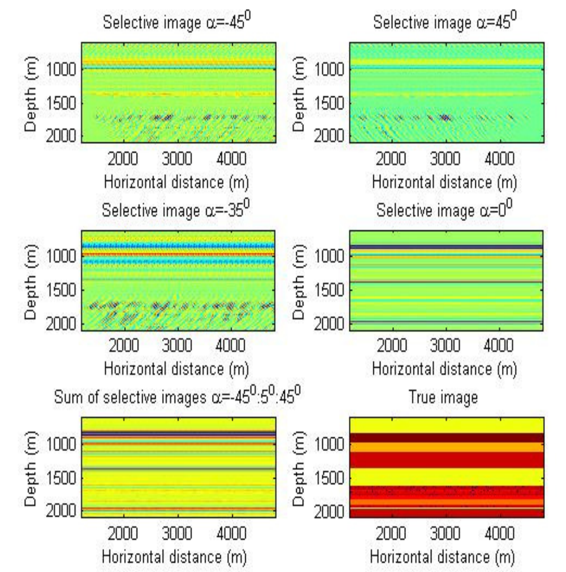

***Figure 1** Selective images and their sum after imaging procedure.*

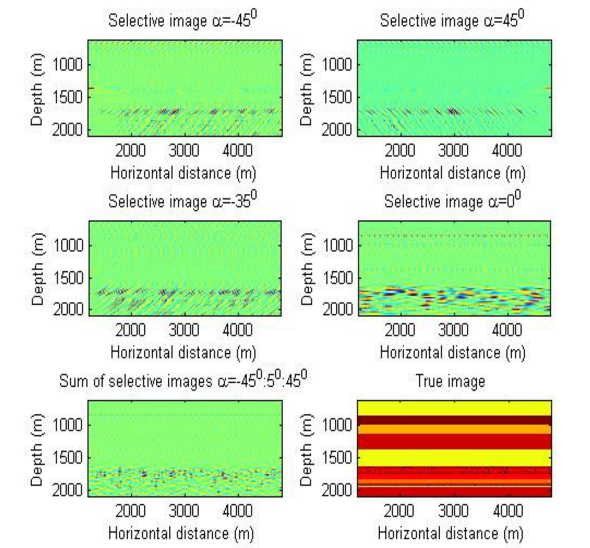

***Figure 2** Selective images and their sum after imaging procedure and spectral removal.*

Conclusions

The presented results show developed procedure provides reliable imaging of the low amplitude diffraction and scattering. On this basis the procedure allows to map small scale heterogeneities very reliably and does not presume any preliminary wave-field separation.

Acknowledgements

The research described in this publication was partially supported by RFBR grants 12-05-00943, 13-05-0076, 13-05-12051, 14-05-93090, 14-05-31257 and grant no.MK-2909.2014.5 of Russian Government.

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