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SEISMIC IMAGING BY FOCUSING TRANSFORM

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Summary

We have studied influence of prestack Kirchhoff migration aperture weight function on resulting images. It has brought us to focusing transform methods of imaging that suppress mirror reflections and reveal depths details that remain invisible at conventional imaging.

Introduction

Migrated seismic image consists of components produced by reflected and diffracted waves. It may be decomposed in accordance with position of SP and OP focus apertures with respect to image (focus) point and dip at this point. We can choose the positions in such a way that reflected (at focus point) wave does not hit OP aperture. This leads to suppression of reflection component at resulting image and implies amplification of previously invisible details, e.g. smooth porosity variations that were previously masked by sharp variations of stiffness (reflecting boundaries). Computation and processing of common image point (CIP) gathers are essential for reliable detection of scattering objects. Focusing transform methods imply computation of CIP gathers via a parameter that expresses departure from reflections (a parameter of aperture weight function). Test of diffraction signal presence hypothesis (non-zero mathematical expectation) may be carried out as comparison of semblance (at focusing transform CIP gather) with its significance level.

Theory

Although prestack processing is essential for statistical diffraction objects detecting, focusing transform images may be investigated in a model of zero-offset data. The following theory is also based on Born diffraction approximation (neglect of multiples) and constant propagation velocity assumption. Lone diffractor image, produced by zero-offset monochromatic data Kirchhoff migration in the far field approximation $w\ c^{-1}z >> 1$, may be written as

$$I_w(x,y,z) = -ik^3 \iint dx'dy' \frac{\exp\left(ik|\mathrm{r}'-\mathrm{r}| - ik|\mathrm{r}'-\mathrm{r}_0|\right)}{|\mathrm{r}'-\mathrm{r}_0|}\cos(j),$$

where $\mathrm{r}=(x,y,z)$, $\mathrm{r}'=(x',y',0)$, $\mathrm{r}_0=(x_0,y_0,z_0)$ is diffractor point, $k=2w\ c^{-1}$, j is angle between z-axis and $\mathrm{r}'-\mathrm{r}_0$, gain control is assumed proportional to t^2. Taking into account $|\mathrm{r}'-\mathrm{r}|-|\mathrm{r}'-\mathrm{r}_0| \cong (\mathrm{r}-\mathrm{r}_0, \mathrm{r}_0-\mathrm{r}')|\mathrm{r}'-\mathrm{r}_0|^{-1}$, passing to spherical angles b, j (j is azimuth) and designating $x''=x-x_0$, $y''=y-y_0$, $z''=z-z_0$,

we have $$I_w(x'',y'',z'') = -ik^3 p \int_0^{p/2} dj\ \sin j\ \exp(ikz''\cos j\ )\int_0^{2p} db\ \exp\left(ik(x''\cos b + y''\sin b)\sin j\ \right).$$

If $s(t)$ is an incident wavelet and $\hat{s}(w)$ is its spectrum, then focusing transform determined by aperture weight function $y(j)$ produces the following image of the lone diffractor (discarding a constant factor):

$$I\left(x'', y'', z''\right) = -i\int dk\, k^3 \hat{s}\left(ck/2\right) \int_0^{p/2} dj\;\; y\left(j\right) \sin j\;\; \exp\left(ikz'' \cos j\right) J_0\left(k\sqrt{x''^2 + y''^2}\, \sin j\right), \qquad (1)$$

where J_0 is Bessel function. Now we assume that density of Born diffractors:

$$\begin{aligned} g\left(j, x, y, z\right) &= \iint dk_x dk_y\; \hat{g}\left(j, k_x, k_y, z\right) \exp\left(ik_x x + ik_y y\right) \\ &= \iiint dk_x dk_y dk_z\; \hat{\hat{g}}\left(j, k_x, k_y, k_z\right) \exp\left(ik_x x + ik_y y + ik_z z\right) \end{aligned}$$

determines media scattering for j -direction. In particular, a model of consistent reflections corresponds to density g independent from j (for zero-offset data). In this model g is equal to relative variation of stiffness and $\left|\nabla g\right|$ gives distribution of reflection coefficient (for normal incidence). According to (1), for the generalized model of j -dependent density we obtain desired focusing transform image of arbitrary media:

$$\begin{aligned} I\left(x, y, z\right) = -i\int dz' \iint dk_x dk_y \int dk\, k^3 \hat{s}\left(ck/2\right) \int_0^{p/2} dj\;\; y\left(j\right) \hat{g}\left(j, k_x, k_y, z'\right) \sin j\;\; \exp\left(ik\left(z - z'\right) \cos j\right) \\ \times \int_0^{2p} db \iint dx' dy' \exp\left(ik\left(\left(x - x'\right)\cos b + \left(y - y'\right)\sin b\right)\sin j + ik_x x + ik_y y\right). \end{aligned}$$

Accurate integrating for appearing here Dirac d -functions yields the spatial spectrum $\hat{\hat{I}}\left(k_x, k_y, k_z\right)$ of the image:

$$-ik_z\sqrt{1 + \frac{k_x^2 + k_y^2}{k_z^2}}\; \hat{s}\left(\frac{c}{2} k_z \sqrt{1 + \frac{k_x^2 + k_y^2}{k_z^2}}\right) y\left(\arctan\sqrt{\frac{k_x^2 + k_y^2}{k_z^2}}\right) \hat{\hat{g}}\left(\arctan\sqrt{\frac{k_x^2 + k_y^2}{k_z^2}}, k_x, k_y, k_z\right), \qquad (2)$$

discarding a constant factor. It may be easily proved that, for $y \equiv 1$ and consistent reflectors of small curvature, expression (2) is turned to vertical convolution of reflectivity series and incident wavelet. Generally, result (2) signifies that focusing transform with appropriate weight can selectively determine scattering in different directions. If $y \equiv 0$ for all reflector dips, then we have suppression of reflected waves at resulting image, depicting scattering inhomogeneities. In reality, unwanted energy suppression requires CIP gather's processing.

Conclusions

Proposed focusing transform technique has been tested at tens of prospective areas in Sibiria. The results appeared to be valuable for interpretation. At some areas the results led to earth geological model change. Color printing is essential for focusing transform images.