Integration
geoConvention 2013
geoscience
engineering
partnership

Using-MultiFocusing 3D diffraction imaging to predict fracture corridors/swarms in the Bazhenov Formation

Marianne Rauch-Davies*, Geomage, Houston, Texas
marianne@geomage.com
and
Alex Berkovitch, Geomage, Modi'in, Israel
alex@geomage.com
and
Danil Pelman, Geomage, Modi'in, Israel
Danil@geomage.com
and
Kostya Deev, Geomage, Modi'in, Israel
kostya@geomage.com

Summary

Unconventional reservoirs are becoming more and more conventional but successful drilling within these reservoirs reservoirs has a unique set of problems. Most wells are drilled horizontally through the reservoir rock and the fracking technology is applied to generate permeabilty and produce hydrocarbons. The pre-drill knowledge of natural fracture swarms and small offset faults is very important as these geological elements can interfere with the drilling and fracking process and influence the production rate. Seismic resolution from conventional reflection imaging is generally not sufficient to resolve these small scale rock properties.

Diffracted waves are events that are produced by the scattering of a wave after it meets a discontinuity such as fracture swarms, small amplitude faults and karsts that cause local sharp changes in the geometrical or lithological characteristics. A method for diffraction imaging that is based on coherent summation of diffracted waves was applied to a 3D data set over an unconventional oil reservoir. An integrated study that includes well information, diffraction energy and seismic attributes showcases the usefulness of diffraction events to predict fracture swarms within the Bazhenov formation, which is a black shale in West Siberia.

Introduction

Exploration and production of unconventional reservoir rocks are becoming more and more important. One of the main challenges is the detection of small scale geological objects such as faults and fracture corridors and swarms. We propose to utilize conventional seismic data to solve this problem as the wavefield generated by such subsurface elements is characterized by the presence of scattering or diffracted energy.

The amplitudes of diffracted waves are usually much weaker than those of specular reflections. Diffractions are essentially lost during the conventional processing/migration sequence, or they are masked in conventional seismic stacked sections. Local structural and lithological elements in the subsurface of a size comparable to the wavelength are usually ignored during processing and identified only during interpretation.

Efforts to image diffraction events were undertaken in Landa et al. (1987), Kanasewich and Phadke (1988), Landa and Keydar (1998) and Fomel et al. (2007), Moser and Harpen (2006), Berkovitch et al. (2009). Separation of diffracted and reflected wavefields based on different kinematic properties was proposed in Khaidukov et al. (2004). Taner et al. (2006), Klokov et al. (2011).

In this paper we present a generalization of the method proposed by Berkovich et al. (2009) to a 3D data set. The method is based on the MultiFocusing moveout time correction, which adequately describes not only reflection but also diffraction events. Optimal summation of the diffracted events and attenuation of the specular reflections allows creating an image that contains mostly diffraction energy. We briefly describe the theory of the MultiFocusing method and demonstrate the efficiency of the proposed diffraction imaging technique on a data case study.

Moveout MultiFocusing correction for diffracted waves

The MultiFocusing method (MF) was proposed by Berkovitch et al. (1994) and it consists of constructing a zero-offset section wherein each trace of this section is computed from prestack traces arbitrarily located around an imaging position. The moveout correction does not require knowledge about the subsurface and is valid for arbitrary observation geometry. For a given source-receiver pair, the MF-moveout equations expresses the time shifts with respect to a zero-offset trace in terms of three parameters:

$$\Delta\tau = \frac{\sqrt{(R^+)^2 - 2R^+\Delta X^+ \sin\beta + (\Delta X^+)^2} - R^+}{V_O} + \frac{\sqrt{(R^-)^2 + 2R^-\Delta X^- \sin\beta + (\Delta X^-)^2} - R^-}{V_O} \quad , \qquad (1)$$

where

$$R^+ = \frac{1+\sigma}{\dfrac{1}{R_{cee}} + \dfrac{\sigma}{R_{cre}}} \;;\; R^- = \frac{1-\sigma}{\dfrac{1}{R_{cee}} - \dfrac{\sigma}{R_{cre}}}; \qquad (2)$$

$$\sigma = \frac{\Delta X^+ - \Delta X^-}{\Delta X^+ + \Delta X^- + 2\dfrac{\Delta X^+ \Delta X^-}{R_{cre}}\sin\beta} \quad . \qquad (3)$$

In these equations, β is the normal ray; Rcre and Rcee are radii of curvatures of two paraxial wavefront: normal incident point wave and normal wave respectively; ΔX^+ and ΔX^- are the source and receiver offsets for a given ray with respect to the central point X_0; R^+ and *R* are the radii of curvature of the fictitious waves defined by equations (2) and (3); V_0 is the near-surface velocity; and σ is a focusing parameter.

Our goal is to determine the time shift for any shot and receiver in the MultiFocusing super-gather near the central point X_0. According to figure 1, the moveout correction for normal ray OX_0 for the trace corresponding to shot S and receiver R is given by

$$\Delta t = \frac{L_{SO} + L_{OR}}{V_0} - \frac{2R_{cre}}{V_0} \quad , \qquad (4)$$

Where

$$L_{SO} = \sqrt{(\Delta X^- + R_{cre}\sin\beta)^2 + (R_{cre}\cos\beta)^2} = \sqrt{R_{cre}^2 + 2\Delta X^- R_{cre}\sin\beta + (\Delta X^-)^2} \;; \qquad (5)$$

$$L_{OR} = \sqrt{(\Delta X^+ - R_{cre}\sin\beta)^2 + (R_{cre}\cos\beta)^2} = \sqrt{R_{cre}^2 - 2\Delta X^+ R_{cre}\sin\beta + (\Delta X^+)^2}$$

Then

$$\Delta\tau = \frac{\sqrt{(R_{cre})^2 - 2R_{cre}\Delta X^{+}\sin\beta_0 + (\Delta X^{+})^2} - R_{cre}}{V_O} + \frac{\sqrt{(R_{cre})^2 + 2R_{cre}\Delta X^{-}\sin\beta_0 + (\Delta X^{-})^2} - R_{cre}}{V_O} \qquad (6)$$

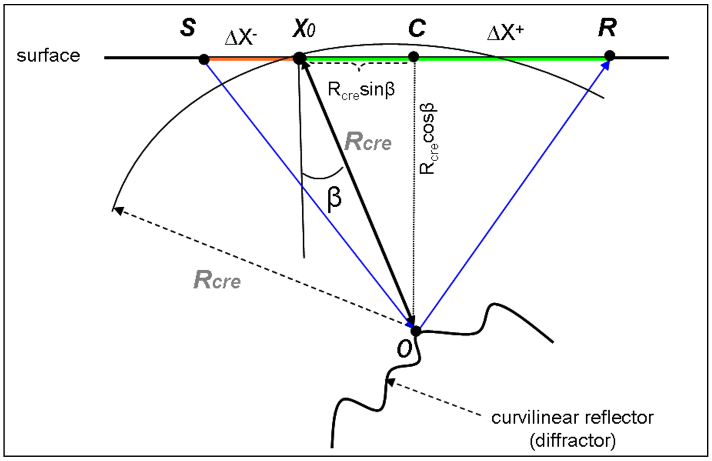

Figure 1: MultiFocusing ray diagram for diffracted wave detection.

As it follows from equation (6), diffraction moveout coincides with the MultiFocusing moveout when reflection interface shrinks to a point, i.e. when $R_{cre} = R_{cee}$.

The practical implementation of diffraction stacking is a special case of MultiFocusing. For diffraction stacking, however, only two parameters (for 2D case) should be searched, namely R_{cre} and β. In the 3D case there are 5 parameters to be estimated from the data: three curvatures and two emergence angles. The parameters are estimated by maximizing the semblance function calculated for all seismic traces in the super-gather. The result of the diffraction imaging is a 3D data set in time that includes mostly optimally stacked diffraction events and residual specular reflections. Such data sets contain important information for identifying local heterogeneities and discontinuities in the subsurface.

Case Study

The studied tight oil reservoir, the Bazhenov Formation is an Upper Jurassic unit deposited in a deep marine environment and is located in West Siberia (Russia). It covers 2.3 million square kilometers, has an average thickness of 40 m and in the study area, the formation is at a depth between 2700 and 2800 m. The Bazhenov Formation reservoir beds are 0.5-3 meters thick and are present at several stratigraphic levels. They are segregated by fine-laminated 3-8 m thick formation members that are rich in organic matter.

The formation is characterized by small faults and fractures that possibly make its oil flow more readily and has been considered a source rock for around 20 years. The aggregate mass of organic matter in the Bazhenov Formation is estimated to be as high as 126 trillion barrels of oil and it is considered to be one of the largest oil accumulations in the world.

MultiFocusing diffraction imaging was applied to a 3D dataset within the boundaries of the Bazhenov Formation. The datasets consist of a 3D land seismic with narrow azimuth and a number of wells with some log, temperature, and pressure and production information. For the validation of the results, information of some additional wells was kept back as a blind test.

In principle for each surface location and for each time sample we need to search three radii parameters ($R_{cre}^{x}, R_{cre}^{y}, R_{cre}^{xy}$) and two emergence angles (β_x, β_y). Since radius R_{cre} is connected to the

RMS velocity in the medium, our search was performed around a priori known RMS/migration velocity. Taking into consideration that migration can be regarded as summation over diffraction surfaces and assigning result to the diffraction apex we put the angle values equal to zero. In this way we reduced the number of search parameters and obtained directly migrated diffraction images. This summation was performed according to the diffraction moveout correction (equation (6)).

Figure 2 shows a migrated arbitrary line section extracted from the 3D PSTM cube, crossing three wells. The horizons of the unconventional reservoir have been picked and are shown on the line display. Figure 3 displays a MF diffraction image in color overlaid on the PSTM data of an arbitrary line intersecting two well locations. There is evidence of diffraction anomalies in areas of uplift and compression.

The PSTM data were amplitude and phase preserved and suitable for attribute calculations such as acoustic impedance, spectral decomposition, curvature attributes and so on. All available data types were integrated and correlated and horizon maps of predicted natural fracturing were produced and analyzed. This information was utilized to predict accurately the natural fracturing at the two blind well locations.

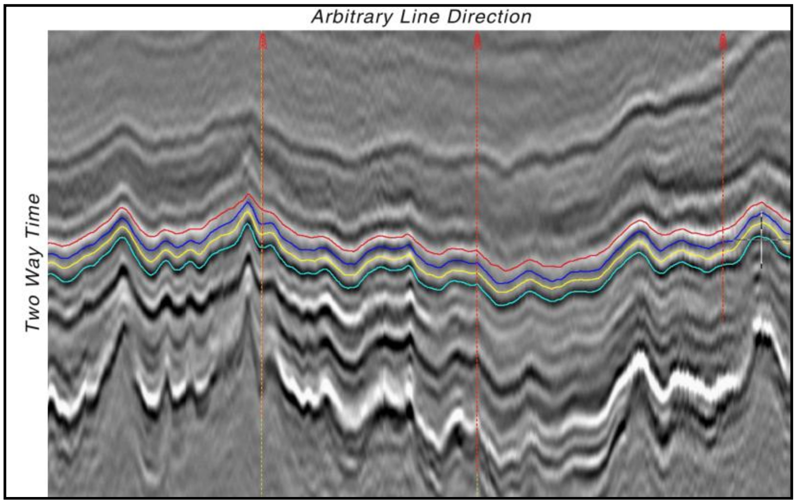

Figure 2: PSTM arbitrary line through 3 wells. The unconventional reservoir interval has been interpreted and is evident by the horizons.

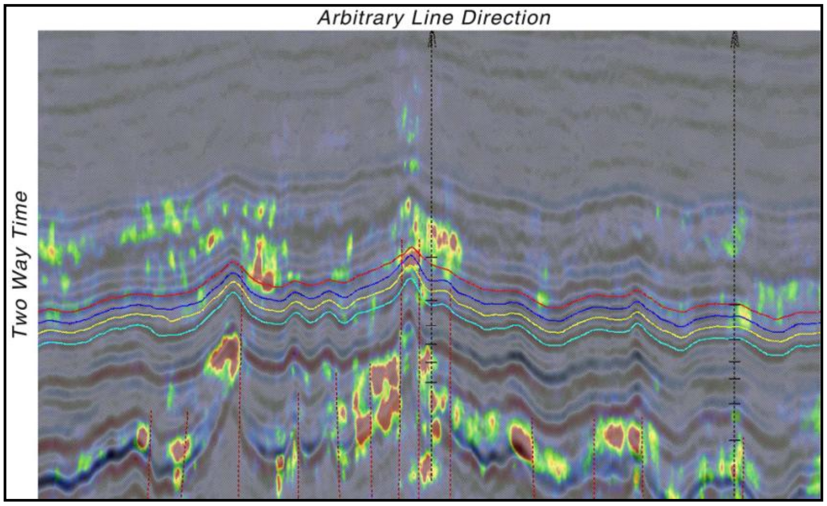

Figure 3: Arbitrary line showing migrated diffraction image in colour on top of PSTM data over 2 well locations. Dark red colors are indicative for large diffraction amplitudes.

Conclusions

We are proposing a new algorithm for 3D diffraction imaging based on the MultiFocusing methodology. This method consists of an optimal summation of seismic data in accordance with a diffraction-moveout formula. The diffraction-oriented 3D data cube can be used for a reliable interpretation of non-smoothed geological interfaces and for identification of local heterogeneities such as faults, carsts, fractures etc. We demonstrate this application for a 3D dataset and calibrate the results to well information. The final results are very encouraging and confirm that diffraction imaging of conventional seismic 3D data contains reliable information of areas with higher fracture density, which is important for a better flow and higher oil recovery rate in the Bazhenov Formation.

References

Berkovitch, A., Gelchinsky, B., and Keydar, S. [1994] Basic formulae for multifocusing stack. 56th Mtg. Eur. Assoc. Expl. Geophys., Expanded Abstracts, **140**.

Berkovitch, A., Belfer, I., Hassin, I., and Landa, E.[2009] Diffraction imaging by multifocusing. Geophysics, **74**, WCA75.

Fomel, S., Landa, E., and Taner, T. [2007] Poststack velocity analysis by separation and imaging of seismic diffractions. Geophysics, **72**, No 6, 89-94.

Harlan, W., Claerbaut, J., and Rocca, F. [1984] Signal to noise separation and velocity estimation. Geophysics, **49**, 1869-1880.

Hubral, P., Schleicher, J., Tygel, M., and Hanitzsch, C. [1993] Determination of Fresnel zones from traveltime measurements. Geophysics, **58**, No 6, 703–712.

Kanasewich, E., and Phadke, S. [1988] Imaging discontinuities on seismic sections. Geophysics, **53**, 334-345.

Khaidukov, V., Landa, E., and Moser, T. [2004] Diffraction imaging by focusing-defocusing: An outlook on seismic superresolution. Geophysics, **69**, 1478-1490.

Klokov, A., Baina, R., and Landa, E. [2010] Separation and imaging of seismic diffractions in dip angle domain. 72rd EAGE Conference and Exhibition.

Landa, E., Shtivelman, V., and Gelchinsky, B. [1987] A method for detection of diffracted waves on common-offset sections. Geophysical Prospecting, **35**, 359-373.

Landa, E. and Keydar, S. [1998] Seismic monitoring of diffraction images for detection of local heterogeneities. Geophysics, **63**, No. 3, 1093–1100.

Moser, T. and Howard C., [2008] Diffraction imaging in depth. Geophysical Prospecting, **56**, No 5, 627-641.

Reshef, M. and Landa, E. [2009] Poststack velocity analysis in the dip-angle domain using diffractions. Geophysical Prospecting, **57**, 811-821.

Taner, T., Fomel, T., and Landa, E. [2006] Separation and imaging of seismic diffractions using plane-wave decomposition. 76th Annual International Meeting, SEG, Expanded Abstracts, **25**, 2401-2405.