Finite difference modeling to evaluate the effect of acquisition and processing parameters on the resolution of seismic land data, an example from SE Siberia.

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Introduction

Main aim of this modeling study is to evaluate the discrimination power of the seismic method under harsh conditions found in southeastern Siberia. To solve this particular problem, a two dimensional physico-mathematical modeling exercise was done using a realistic data configuration as a starting point. The calculated synthetic data was subsequentially normally processed and interpreted.

The target productive intervals in the studied fields are characterized by sub-horizontal deposits with a rather small vertical thickness. These particular conditions make it almost impossible to directly analyze the kinematical properties of reflected seismic energy and obtain useful information about the reservoir properties. Moreover, experience in seismic data acquisition and processing in the area under investigation shows that the acquired data is highly influenced by different types of coherent noise (surface, converted, multiple waves). These specific geological conditions make that the attenuation of high velocity contrast coherent noise is extremely complicated in this part of the world.

Physico-mathematical modeling of 2D land seismic data was done to estimate the influence of coherent noise on the dynamic properties of reflected data,. The workflow included the following steps: a) Elastic model building using well data, b) 1D seismo-geological modeling, c) 2D finite-differences modeling of the land seismic data, d) analysis of receiver arrays efficiency to attenuate coherent noise, e) synthetic data processing and interpretation.

Method

The physical elastic modeling concerns three main parameters: density, P-wave velocity and S-wave velocity. The most accurate source for such type of information is well data. In this case velocity model building was done on the basis of 10 wells. Acoustic logs on P-waves have been run in all wells. Density logging was done only in two wells. Information about S-wave velocities was present in one well. Velocity for S-waves were derived from the P-wave velocities using a statistical equation from a one well calibration. It turned out that the Vp/Vs ratio is almost constant with varying depth. This creates good conditions for S-waves velocity prediction with high accuracy when using the P-wave velocities. Density prediction was based on linear statistical function derived from gamma-ray logs, neutron gamma-ray logs, acoustic sonic log and also well diameter measurements (calliper) were taken into account.

Initial well-logs were digitized with a step 0.2 m. For the finite–difference modeling the data has been upscaled. This was done using the Backus averaging-method (Backus, 1962). Average layer thickness was determined as 4-6 m. Quality control of new models was done by comparing synthetic traces before and after averaging. Synthetic traces were calculated using the Born approach and the Thompson-Haskella method (matrix propagator; Clearbout 1976), which allows to model all types of multiples. The easiest way to build two-dimensional model is to interpolate the elastic properties between wells. The upper part of the earth usually contains a low velocity layer (LVL) which influences the seismic data greatly. The LVL was built using an analogue to previous processing results on the basis of refraction statics interpretation, including the LVL bottom depth. Total length of the model was 45 km with a depth of 2000 m (Figure 1).

Before 2D finite-differences modeling was done, a feasibility forecast was undertaken to predict reservoir properties based on petrophysical analysis and 1D synthetic modeling. First step was petrophysical analysis using core and well-log data. A statistical equation between acoustic and reservoir properties was established. 1D modeling was done by changing reservoir properties, calculating new acoustic properties and then computing synthetic traces using Thompson-Haskella method (Claerbout, 1976) under the assumption of a zero offset configuration. The wavelet was taken as a delta-impulse filtered 8-16-40-80 Hz.

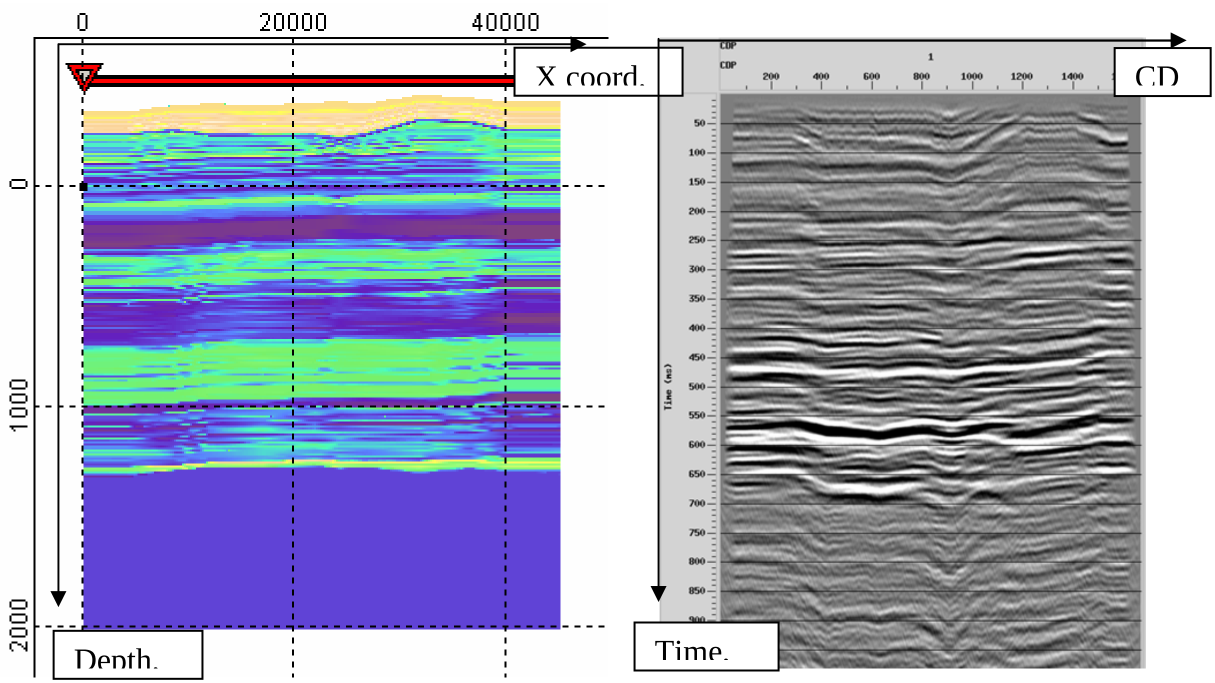

Figure 1: Elastic model (colour show compressional velocity amplitude) and time migrated synthetic CDP stack section from synthetic data calculated for elastic model.

It is convenient to describe influence of petrophysical reservoir properties on the acoustic properties in barycentre coordinate system shown in Figure 2. The main petrophysical parameters are here porosity and the quantity of cement. The position of points inside the triangle corresponds to the mineral phase in percent, amount of cement in percent and porosity as a ratio. Consistent layer parameter changes can be seen as a line inside the triangle. Also it facilitates to understand which parameter the biggest impact on the acoustic properties and in what way it influences the dynamic properties of the reflected seismic waves. Information obtained during the 1D synthetic modeling allows to increase the reliability of the later forecast.

Finite-difference 2D modeling was done with help of the Tesseral 6.0 software package. The elastic input model was created with realistic rock physical assumptions. Main parameters for modeling are seismic wavelet shape, time and space grid step. Wavelet testing was done to ensure that the synthetic gather looked close to real field gather. After testing a spiked delta-impulse, filtered in band 2-4-50-90 Hz. was chosen. The low frequency bandpass cut was selected in order to include also low frequency high amplitude surface waves. The high frequency cut was chosen based on results of the real seismic dataset in the area of investigation. Drawback is that increasing the high frequency content also leads to a substantial increase in computation time.

Key parameters for calculating synthetic seismic gathers, using the finite-difference method, are time and space grid size. Decrease of step size of grid will increase calculation time and also memory limitations do exist. The solution stability of finite-difference modeling is related to both time and spatial grid sizes. When applied to first order difference schemes using the wave equation, there is a condition is given by (Levi-Courant condition) to be fulfilled: $v \cdot t < h$, where t = time and h = spatial grid step size, v = wave velocity. This condition does not contain any information on the estimation error itself. Some additional tests were carried out to evaluate the correctness of the modeled wave fields. The initial model was digitized with different space grid size. Time grid size was calculated according to velocity and frequency content of the input wavelet. Synthetic traces were calculated with different grid sizes choosing a finite difference method in assumption of slanted plane acoustic wave propagation. The results were compared with traces calculated by a matrix propagator method. Results show that if the grid step size is increased from 2m up to 2.4m, then random noise frequency decreases. The results are however still located at in the high frequency domain (about 300-400 Hz). Synthetic reflected data and its power spectra don't vary much with grid step size changes and look close to the data calculated by the matrix propagator method. The difference between analytical solution (matrix propagator) and numerical solution (finite-difference) in RMS amplitude is about 5%. This is more-or-less appropriate for dynamic analysis of synthetic data. If the interest lies only in reflected waves, then a spatial grid size of 2.4 m would be enough. It turned out that the modeling of surface waves is quite sensitive to grid size changes. This happens due to phase velocity dispersion in finite-difference methods (Aki and Richards, 1980). In addition to natural surface wave dispersion there is also numerical dispersion. In order to model surface waves with the least prediction errors, the smallest possible grid step size was taken – 2m for acoustic modelling and 1.4m for elastic modelling.

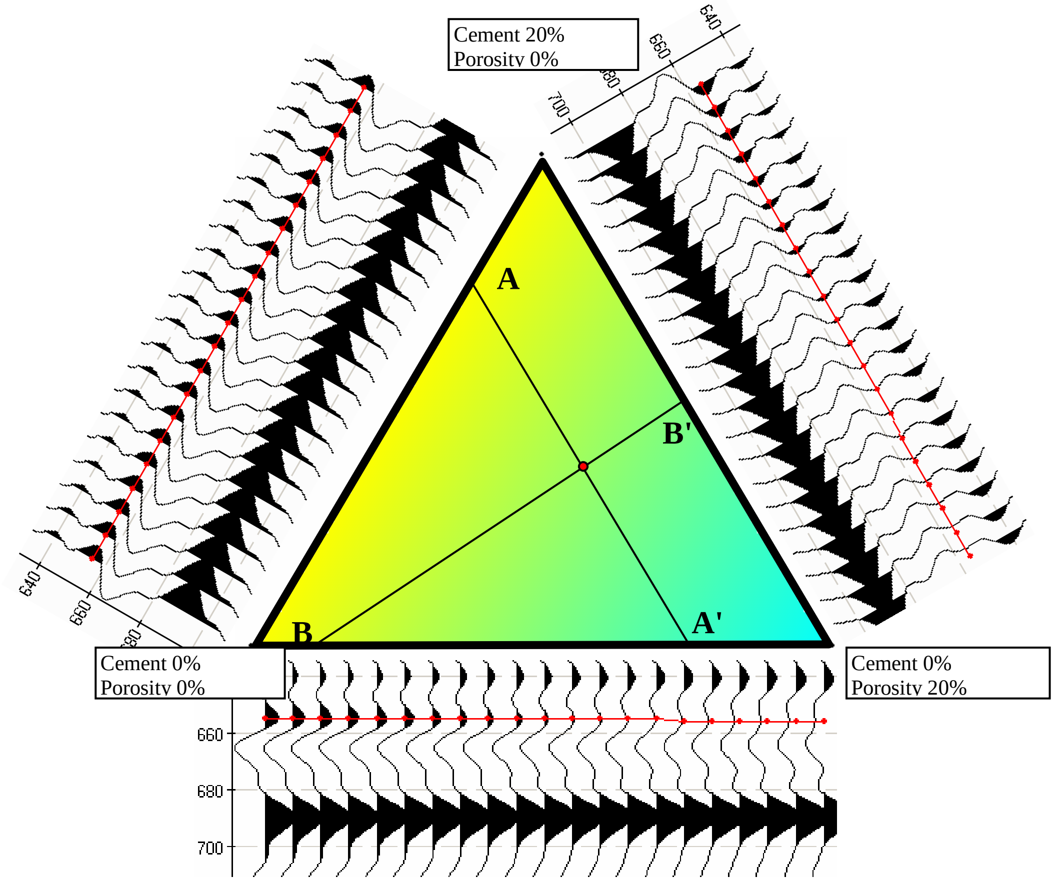

Figure 2: Example of barycentre coordinate system for one of reservoir layers. Colour shows P-wave velocity.

Calculated synthetic data can be used for many purposes, one of them is receiver array analysis. Most common receiver array is equidistant linear with a rectangular envelope of sensitivity. In case of a slant plane wave, the receiver array can be described by:

$$K_{г} = e^{-j\omega\frac{(N-1)\Delta x}{2c}\sin\alpha}\left(\frac{\sin\left(\frac{\omega\Delta x(N-1)}{2c}\sin\alpha\right)}{\sin\left(\frac{\omega\Delta x}{2c}\sin\alpha\right)}\right)$$

As a first step synthetic shot gathers were calculated with receiver arrays lengths of 15, 25, 35, 50, 75 m, step of receivers 1 in array 1m. By looking at the F-K spectrum of the shot gather without receiver arrays, it can be clearly seen that surface wave energy is highly aliased. The use of arrays help to attenuate the high frequency aliased part of the seismic surface waves. When the length of array is increased, a better attenuation of surface wave energy is achieved. At the same time almost no attenuation of reflected waves takes place. Brute CDP stacks were computed to estimate the effect of receiver's arrays on reflected and multiple wave energy. Visual analysis shows that no attenuation of high frequencies happens; while with increase of array length the energy of primary reflections becomes higher than that of the multiples. In ideal conditions, receiver arrays increase the quality of the seismic data. Heterogeneous random surface-consistent shifts were applied to the data to simulate LVL. First the maximum shift was set at 8ms, in the second run the maximum shift was 32 ms. receivers arrays summation was applied to data with shifts. Analysis shows that in case of 8 ms shifts, the receiver arrays are still efficient. If a 32 ms maximum shift is applied, the frequency bandwidth decreases dramatically with using receiver arrays. It is impossible to draw a specific conclusion on the most optimal receiver array without detailed knowledge of the near surface geology. Hence it should be done when designing a real seismic survey.

Calculated synthetic data was sorted into receiver arrays with a length of 33m and a distance of 3m between receivers. The array parameters were selected in line with common parameters used under the harsh conditions of southeastern Siberia. After that synthetic data was processed using standard processing graph with assumption of no knowledge about the seismic wavelet shape and the velocity distribution. Processing included following procedures: a) first break picking, b) tomography velocity model building c) and static correction, d) true amplitude recovery, e) zero-phase spiking deconvolution, f) F-K shot domain coherent noise attenuation, g) velocity analysis, h) residual static correction, i) shot and receiver domain coherent noise attenuation using median filtering, j) poststack processing, k) poststack migration.

Results of synthetic data processing (Figure 1) were interpreted with standard tools available to the petroleum industry. Well-to-seismic tie was done, main horizons were picked and correlated. Next step was the time-depth conversion of the data with estimation of the depth accuracy. An attempt was made to do quantitative analysis of reservoir properties using geostatistic analysis. Furthermore an seismic inversion was done. Results of the interpretation show that reservoir elastic properties can be recovered using a geostatistical approach, although in some part of synthetic lines there are rather errors that exceed estimated errors limits.

Conclusions

Finite-difference modeling has been done to evaluate the effect of acquisition and processing parameters on the resolution of seismic data. Land data from SE Siberia served as analogue to built the initial model and to determine realistic rock physical parameters. The workflow included elastic model building, finite-difference parameters estimation and the simulation itself. Receiver array efficiency analysis was done. Results show that reservoir properties estimation under harsh conditions of southeast Siberia has serious limitations due to high level residual coherent noise that is present after standard processing. In perfect near surface conditions the use of receiver arrays may help to attenuate such type of noise.

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