S040

Localization of Low-frequency Microtremors by a Modified Diffraction Stack

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SUMMARY

Recently the observation of low-frequency microtremors using passive seismic surface observations was proposed as a direct hydrocarbon indicator. Applying reverse time modeling to such data indicates that observed spectral anomalies from the microtremor data originate from the reservoir area. Here we use a modified diffraction stack to locate synthetic microtremor events. The diffraction stack provided good results for the localization of acoustic emissions (i.e., transient high-frequency signals). Applying the stacking technique to low-frequency microtremor data indicates limitations of this method. For strongly heterogeneous media and low-frequency data we have interfering events due to triplications. The moveout of these events is different from the moveout of first arrival traveltimes used in the diffraction stack. This leads to a focusing of the energy at a wrong depth position. The source images using the stacking approach have an improved S/N ratio for shallow levels when compared to the localization of microtremors with reverse modeling approach. However, for the localization using low-frequency data, or more precisely, data from environments where the spatial wavelength of heterogeneities is smaller than prevailing wavelength of the signal, full wave form techniques like reverse modeling approach locate microtremors at the reservoir location.

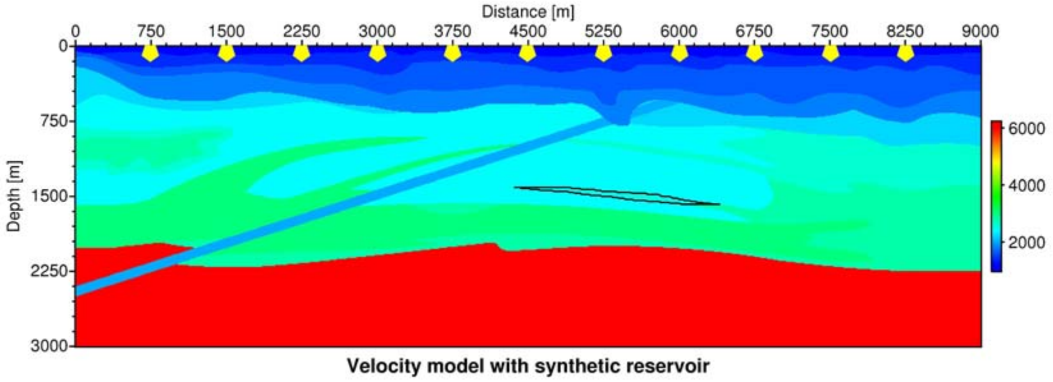
Introduction

New methods of improving hydrocarbon reservoir localization are of great importance for the petroleum industry. Recently the observation of low-frequency microtremor data was proposed as a direct hydrocarbon indicator. Low frequency spectral anomalies between 1-4 Hz were observed above the reservoir area using passive seismic surface observations (see e.g., Graf et al. (2007)). These low frequency seismic signals are supposed to be a result of resonant oscillations of oil within the porous reservoir. Microtremor data are, however, much lower in frequency content than acoustic emissions generated, e.g., by injection. Whether the spectral anomalies really originate from the reservoir was not clear. According to Steiner et al. (2008) time reverse modeling indicates that low-frequency microtremor signals originate from the reservoir and provides a possible method for reservoir localization. In a synthetic and real data case study these authors obtained images showing a focusing of energy in the reservoir area and therefore concluded that the microtremors in fact originated from the reservoir. The images generated by these authors are contaminated by noise at the near surface. This is inherent to the reverse modeling approach, since the amplitudes are always strongest at the receivers if no compensation of spreading losses is applied. It was also necessary to apply a special imaging condition in order to enhance the weak energy of the microtremors. This motivated us to apply the localization method based on a stacking approach to low frequency microtremor data.

Method

The Localization technique by a modified diffraction stack was introduced for a single point source in homogeneous medium (Gajewski et al. (2007), Anikiev et al. (2007)). In this work we locate a set of separate low frequency sources in an elastic heterogeneous medium with a sparse distribution of receivers. A finite difference (FD) eikonal solver is used for traveltime calculations for the velocity model under consideration. Vertical and horizontal components of the observations are used for the localization. The initial datasets are processed such that we obtain pure longitudinal and transversal polarizations by determining the angle of incidence of the wave arriving at the surface. The availability of horizontal and vertical components provides a possibility to use both v_P and v_S velocities in the stacking algorithm, which enhance image focusing and improves the image.

Numerical study



Velocity model with synthetic reservoir

Figure 1: *The velocity model and acquisition scheme. The color legend on the right shows P-wave velocities in m/s. The recording network of the synthetic experiment consists of 11 receivers at the surface with a 750 m spacing indicated by yellow color. The reservoir area is a thin zone indicated by black lines.*

The velocity model used by Steiner et al. (2008) is reproduced in Figure 1. The green and blue colors represent sedimentary layers of P-wave velocities between 1200 and 3000 km/s with a constant density of 2000 kg/m^3. Velocities of about 6000 km/s indicate the crystalline basin with a density of 3000 kg/m^3. The computational grid for the modeling consists of 901 nodes in horizontal direction and 301 nodes in vertical direction with a spacing of 10 m between nodes. Absorbing layers of 500 m width are introduced to avoid reflections from the model boundaries. The area of the reservoir is indicated by black lines. It is about 50 m thick and 2 km long. S-wave velocities are determined from P-wave velocities by application of a factor of $\frac{1}{\sqrt{2}}$.

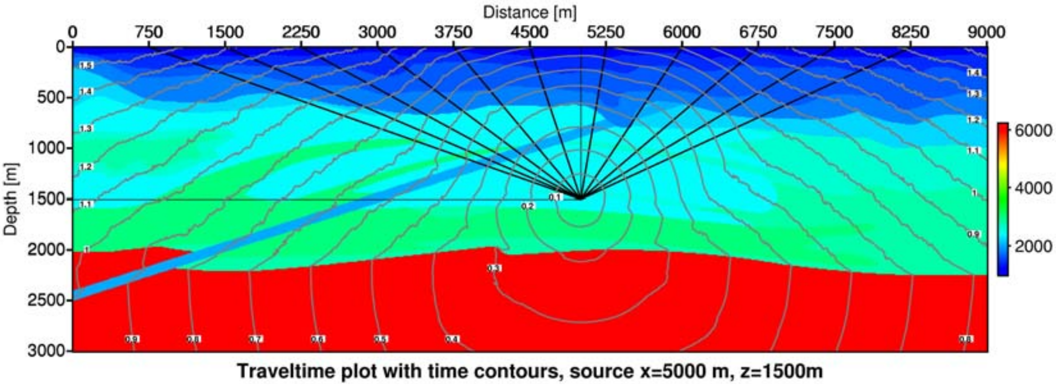


***Figure 2**: Traveltime plot showing time contours for the point source at x=5000m, z=1500m. Straight lines indicate source receiver connections. The angles of incidence at the surface are used to estimate the polarization of the incoming waves.*

We assume that velocity model is known. A finite difference (FD) Eikonal solver (Vidale (1988)) was implemented to generate traveltimes for the velocity model shown in Figure 1. Results of traveltime calculations for a certain source location (x=5000m, z=1500m) is represented in Figure 2. Since no smoothing was applied to the velocity model the traveltime contours display some roughness in areas of strong velocity variations. Traveltimes were calculated from each subsurface location of the discretized model to 11 receiver positions.

Prior to the application of the method to microtremor data we need to study its performance for complex models and sparse receiver networks as well as its dependence on the frequency content of the data. For this purpose we consider the model of Figure 1 and an explosive point source at x=5000m and z=1500m, i.e., only P-waves are generated at the source. For the elastic modelling of the wavefields we used a pseudospectral Fourier method (Kosloff and Baysal (1982)). The numerical time step is 0.5 ms and the total recording time is 4 seconds. Forward modelling generates seismograms of particle velocity for the horizontal and vertical component. A Ricker signal with 4.5 Hz cutoff frequency is considered since the low frequency events are most relevant to simulate microtremors. Data are rotated into their principal components, i.e., longitudinal and transversal polarization. A straight ray path is assumed to determine the angle of incidence They are almost perpendicular to the time contours in a wide range (see Figure2). Result of applying a diffraction stacking localization procedure to the longitudinal component is represented in Figure 3. The focal area of the image function is about 600m, which is two times less than prevailing wavelength (about 1100m). The center of the focal area does not coincide with the source location but it is shifted upwards. We assume that this is an effect of the complexity of the model since triplications may form arrivals with a different moveout that the first arrivals. If the moveout of these interfering events is larger than for the first arrivals it is located at a too shallow depth using first arrival traveltimes for the stack. FD eikonal solver computes first arrivals in the high frequency (HF) assumption which might not be met for this model and frequencies under consideration. Computing HF maximum energy arrivals, e.g., by ray tracing instead of first arrivals may produce an image function where the focal area better coincides with the source location.

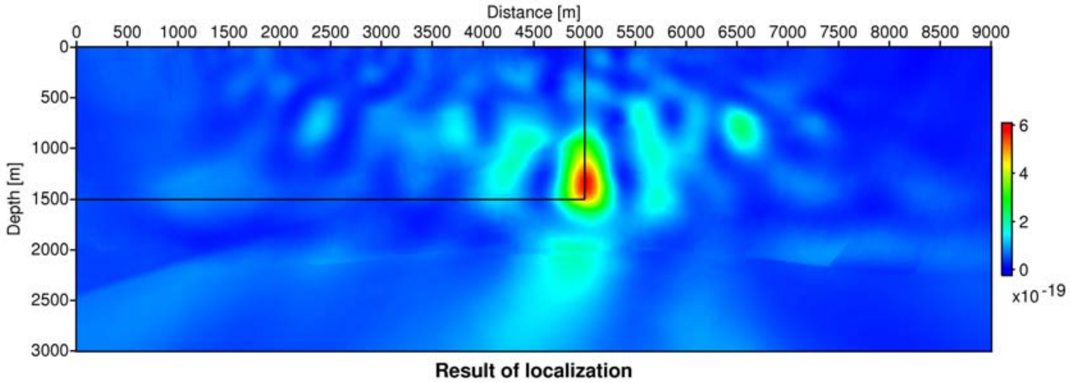


Figure 3: *Result of localization of an explosive point source in a complex medium using the longitudinal component. Color legend on the right shows amplitudes of the image function. Exact source location is x=5000m, z=1500m.*

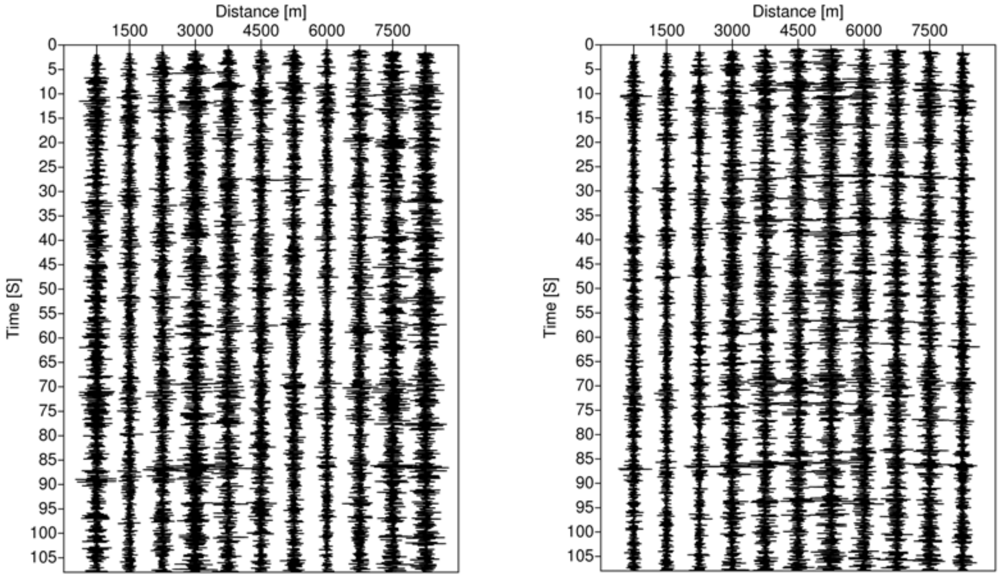


Figure 4: *Full time (108 sec.) synthetic seismograms simulating microtremors. A set of 11 receivers records horizontal (right) and vertical component (left) of particle velocity.*

In a second numerical example we applied the localization method to microtremors data. The diffraction stacking method should be applicable to microtremor data too since it considers all coherent energy at each time step. The dataset used here is the same as in the in work of Steiner et al. (2008). A special forward modelling generates continuous microtremor signals similar to natural ones by applying 574 individual explosive point sources with prevailing frequencies ranging between 1.5 Hz and 4.5 Hz (Ricker wavelet). These sources are randomly distributed within the reservoir zone (black lines in Figure 1) and randomly distributed within the 108 second time window. The numerical time step is $2.9{\cdot}10^{-4}$ seconds. Horizontal and vertical particle velocities are computed throughout the time window for a recording network of 11 seismometers at the model surface. Seismograms are shown in Figure 4. The data were rotated into their principal components. Figure 5 shows the result of the localization for the longitudinal component of the data. We used the same approach to obtain regular polarizations as in case of a single source. A zone of high amplitudes is observed above the reservoir area where the lateral extent of this zone covers mostly the left part. The focal area of the image function could be treated as the possible reservoir area. The center of the zone is, however, about 300 m higher than the reservoir zone. This coincides with the localization of single low frequency source and can be explained similarly.

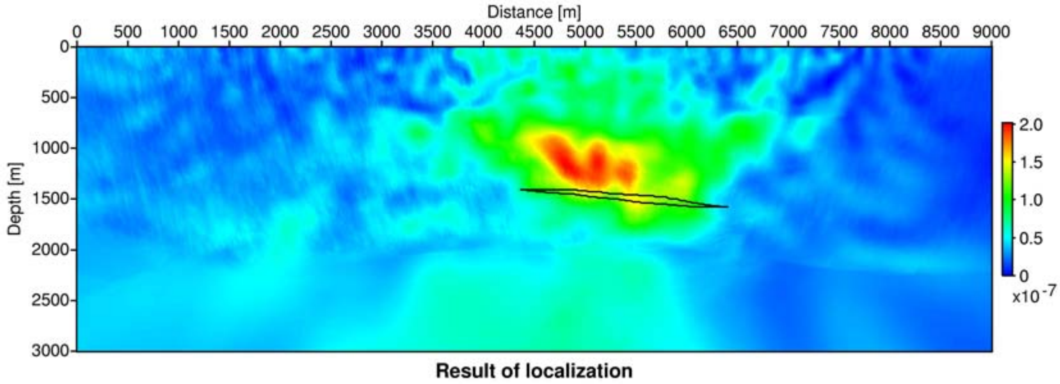


***Figure** 5: Result of localization of microtremors in a complex medium (from longitudinal component of the data). Color legend on the right shows amplitudes of the image function. The reservoir area is marked with black line.*

Conclusions

The localization of microtremor by the stacking approach appears principally possible. The source images using the stacking approach have an improved S/N ratio for shallow levels when compared to other approaches for the localization of microtremors, like the reverse modeling approach. This can be of particular importance if shallow reservoirs are considered. Reverse modeling also requires a special imaging condition and some image processing (see Steiner et al. (2008)). However, neither the depth nor the lateral extent are properly imaged by the current stacking approach due to low frequency domain and strong model inhomogeneity. This may be improved by considering most energetic later arrival traveltime trajectories instead of first arrivals which is subject of an ongoing study.

Acknowledgements

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