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Enhancement of microseismic events detection sensitivity by taking into account focal mechanism effects

R. Macault, T. Bardainne, CGG

Summary

Nowadays, the detection of microseismic events is a tremendous challenge while monitoring hydraulic fracturing in shale gas/oil reservoir. The improvement of this detection (location of low-energy microseismic events) should provide more details about fractures and fluid motions. Microseimic monitoring is performed both at the surface and in the borehole. Each one has advantages and drawbacks. Surface monitoring allows to determining focal mechanism, but detection is not sensitive. Microseismic data recorded from the surface has low signal-to-noise-ratio and if polarity is not taken into account, stacking is not efficient. The radiation pattern of microseismic events causes differences in amplitude recorded on surface and consequently may induce a destructive stack. One of the methods implemented to enhance detection sensitivity is to take into account focal mechanism effects by weighting the stack. A random-based non-linear inversion method « location – focal mechanism » is introduced and show the capability of detecting more low energy events (twice more microseismic events detected) and improving the resolution.

Introduction

The detection of microseismic events is currently a tremendous challenge while monitoring hydraulic fracturing from the surface. The improvement of this detection should provide more details about fractures and fluid motions. Microseismic monitoring is performed from the borehole or from surface. Both strategies present “pros” and “cons”. The focal mechanism can be determined by the surface monitoring, but detection sensitivity is lower than by performing downhole monitoring. The current method consists of implementing a beamforming method and stacking pre-processed signals. Low signal-to-noise ratio (SNR) signals are recorded at the surface and stacking is not efficient because polarity is not taken into account.

Amplitudes of first arrival motion vary significantly at the surface due to focal mechanism effects and to the resulting coverage of the acquisition network. The summation of traces with different polarities tends to vanish. The amplitude variation due to focal mechanism effects has to be taken into account by weighting the stack. The microseismic event detection will be improved only if the weighting of amplitude is applied with the effective focal mechanism. This means that a joint inversion method “location - focal mechanism” has to be performed. Since the investigated parameter space is huge, an inversion based on a genetic algorithm and simulated annealing was looked into and developed.

Detection method by correcting amplitude

A joint-inversion method is introduced to locate and determine the focal mechanism. Inversion parameters are the three spatial components and four angles (strike, dip, rake, and slope) defining the focal mechanism. The double-couple (DC) component is described by the angles of strike, dip and rake, and the angle of slope characterizes the non-DC component (Vavryčuk V., 2011). The model space is investigated randomly (location and focal mechanism) thanks to an algorithm converging to the correct combination of parameters by a trial-and-error method and the convergence criterion is the value of the diversity stack weighted by the modelled amplitude (amplitudes are assessed at the surface according to the location and focal mechanism). The model space is particularly complex because location and focal mechanism are independent. Thus, it is necessary to build up an algorithm taking into account this complexity of the model space. Random-based non-linear methods as genetic algorithms (Gharti H. N. et al., 2010) and simulated annealing (Kirkpatrick S. et al, 1983) have been studied and tested.

A genetic algorithm is made of four parts: initialization of a parameter array, mutation of this initialized array, crossover of initialized and mutant arrays, and selection amid the entire array. It quickly investigates the space parameters, but the convergence of this algorithm is not appropriate for simultaneously determining focal mechanism as it tends to converge to the local minima of the objective function (value of weighted stack according to model space parameters)

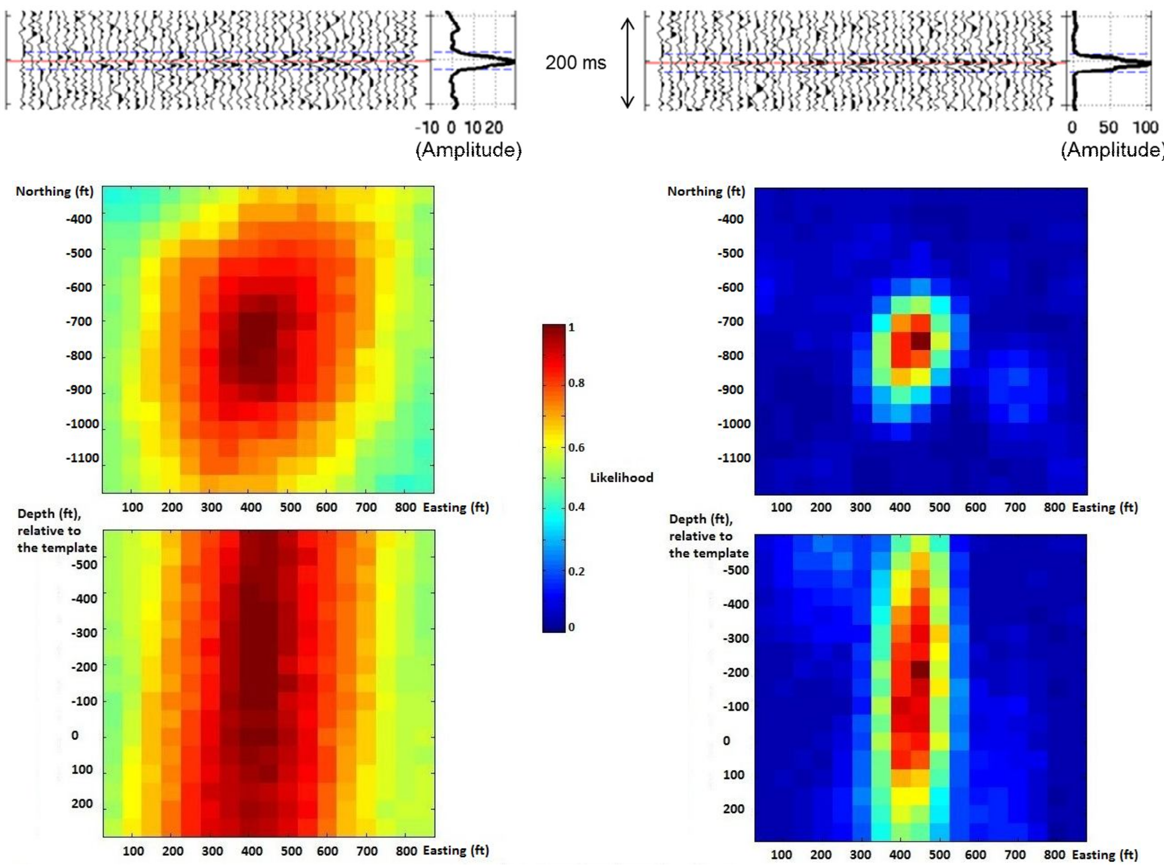
On the other hand, one property of simulated annealing is prominent in our case. It has the capability of investigating a multi-parameter space and efficiently converging to the global minimum of the objective function (Kirkpatrick S. et al, 1983). Local minima of the objective function can be avoided, but it requires to perform more iterations for locating microseismic candidates.

The implemented solution was to merge a simulated annealing and a genetic algorithm. This type of algorithm is called GA-SA (Genetic Algorithm – Simulated Annealing). It has the cumulated benefits of a genetic algorithm for efficient investigation of location parameters and of simulated annealing algorithm to avoid local minima (Xie X., 2012). This GA-SA inversion based on a trial-and-error method (maximization of the diversity stack weighted by modelled amplitude) allows a random search of microseismic events: we will show its efficiency on synthetic and real data in the next section. The method has been implemented on synthetic and real data. In both cases, we studied data from surface patch acquisition (Rebel E. et al, 2013).

Synthetic data

The synthetic dataset was built from a real acquisition geometry and real noise data of hydraulic fracturing (seismic traces without events). Synthetic microseismic events were then added to the noise records. A 1D anisotropic velocity model was used to generate the synthetic seismograms. A large range of signal-to-noise ratio was studied (SNR is defined in our case as the ratio between the maximum of amplitude and the RMS of noise). Note that processing was performed using a simple RMS velocity model without assumption on the 1D anisotropic model used for synthetic generation.

Below, we show the improvement provided by the correction of signed amplitude. ***Figure 1*** represents the alignment of traces, the detection curve (beside the traces) and the focalization maps. We observe a better contrast (detection curve) and focalization.



a) b)

Figure 1 – Comparison of results obtained with:

- **a)** squaring signal
- **b)** correcting amplitude sign

The method offers a better sensitivity of microseismic events because synthetic microseismic events were detected with a lower SNR (***Table 1***).

	conventional method	GA-SA inversion
SNR	0.19	0.08

Table 1: Comparison of SNR reached while detecting microseismic events.

Real data

Furthermore, more microseismic events are supposed to be detected by the method, and it is relevant to show the outcome on real data. Two microseismic images are presented in

Figure 2. Raw data was recorded during a stage of hydraulic fracturing, and the template is created from a main event of the studied stage for the two types of processing. The first one is from the conventional method (142 events detected), and the second one is obtained by GA-SA inversion (277 events detected). Almost twice as many microseismic events are detected and the comparison of the two maps highlights an improvement of the microseismic imaging. The alignment of the microseismic events is better. Therefore, the interpretation of damage in reservoir can be more accurate. In our case, one more alignment can be emphasized thanks to the GA-SA inversion.

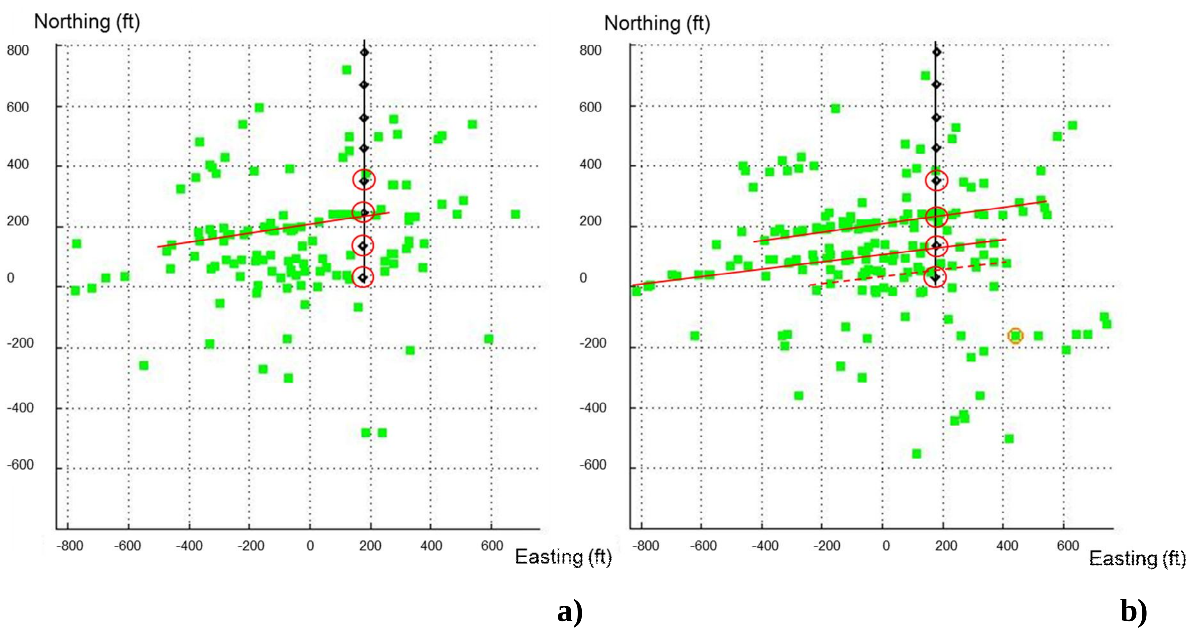
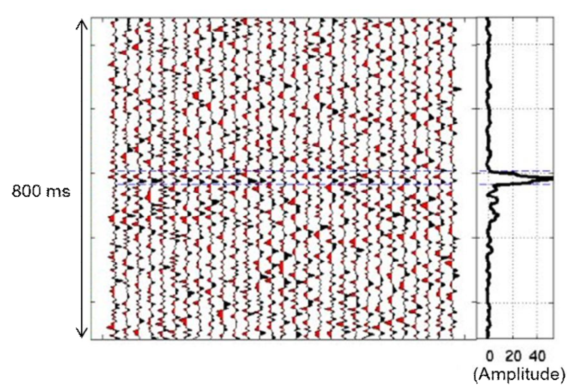


Figure 2 – Microseismic imaging: a) Conventional method, b) Correction of signed amplitude. The black diamonds show the perforation shots (horizontal well is in black), and the red circles those shots studied at the fracturing stage. The green squares are the detected events, and the red lines correspond to the interpreted fracturing planes (dashed line is low likelihood). The brown circle represents the microseismic event described in ***Figure 3***.

Figure 3 shows the alignment of recorded traces and the focalization maps related to an event detected only by the GA-SA inversion.



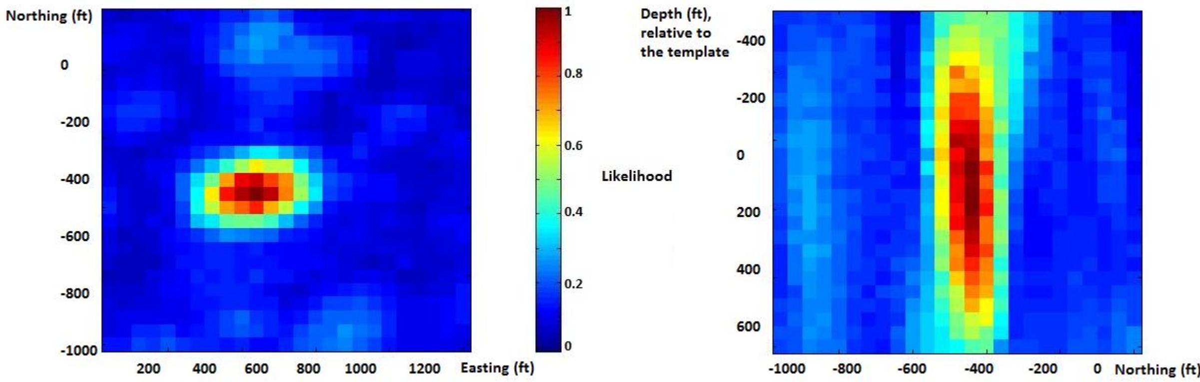


Figure 3 – Example of an event only detected by correcting amplitude sign.

Conclusions

We implemented a random-based joint-inversion method in order to locate and determine focal mechanism of microseismic event. The method is able to detect lower SNR events with more accuracy (likelihood density function is sharper). Microseismic imaging is improved making the interpretation of fracture orientations more robust.

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