Mining Science, vol. 22, 2015, 65−73

www.miningscience.pwr.edu.pl

Mining Science
(previously Scientific Papers of the Institute of Mining of the Wroclaw University of Technology. Mining and Geology, ISSN 0370-0798 in polish)

ISSN 2300-9586 (print)
ISSN 2084-4735 (online)

Received: March 10, 2015, reviewed, accepted: April 15, 2015

DIFFERENCES BETWEEN DOWNHOLE AND SURFACE MICRO-SEISMIC MONITORING

Eryk ŚWIĘCH*, Paweł WANDYCZ

AGH University of Science and Technology

Abstract: The article presents usage of microseismic monitoring for location of microseismic events in polish geological conditions. For location of one synthetic microseismic event, two methods of acquisition were applied: surface and downhole monitoring array. Downhole microseismic monitoring is a technique of recording induced seismicity using receivers placed in the monitoring well near to the treatment well. In case of surface monitoring receivers are placed at the surface. For determination of hypocenter location probability density function was used. Based on provided analysis it is concluded that for polish conditions it is better to use downhole microseismic monitoring. Event located with usage of this technique was located correctly and uncertainty of this location was lower.

Keywords: Microseismic monitoring, hydraulic fracturing, probability density function

INTRODUCTION

Great market demand and high prices for energy resources has focused attention of global petroleum business on unconventional reservoirs such as tight gas, coalbed-methane, heavy oil or shale gas reservoirs. Unconventional reservoirs are characterized by unusual petrophysical parameters such as very low permeability and porosity. Exploitation of such reservoirs is much more complicated than in case of conventional ones. Special technology such as horizontal drilling or hydraulic fracturing is required in order to extract hydrocarbons from the subsurface.

---

* Corresponding authors: swiech.eryk@gmail.com (E. Święch)

doi: 10.5277/msc152206

In the last few years, one of the most significant, and exciting events for Polish economy was surprising discovery of large amounts of gas accumulated in the geological formation considered to be completely unprofitable so far. The gas is accumulated in bituminous shale rocks and it is commonly known in the world as "shale gas".

Shale gas refers to natural gas that is trapped within shale formations. Shales are fine – grained sedimentary rocks that can be rich resources of petroleum and natural gas.

But what is more important, in shale gas, shale is a reservoir, source rock and trap for natural gas. The natural gas found in this rocks is considered to be unconventional, similar to coalbed methane.

Figure 1 shows major shale basins in Poland. The red color indicates prospective area and the yellow indicates non-prospective.

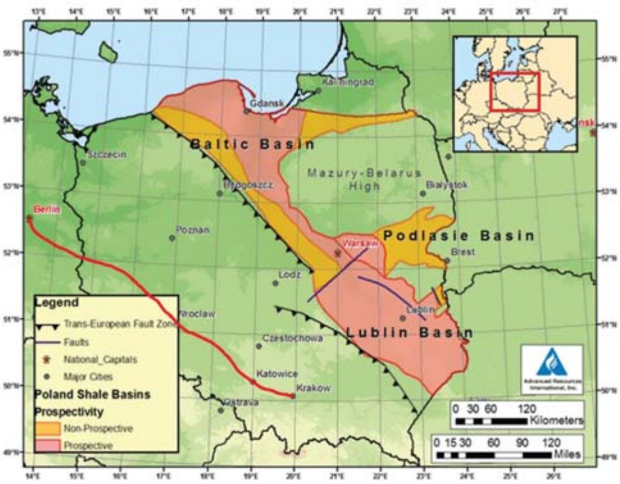

Fig. 1. The assessment of possible occurrence of the most prospective areas for shale gas deposits. (Source: US Energy Information Administration, World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States, US Energy Information Administration (EIA) –prepared for EIA by Advanced Resources International, Inc., 2011)

As it was mentioned before, to use and make shale gas resources economically profitable special technique such as horizontal drilling and hydraulic fracturing have to be used. Hydraulic fracturing, water injection, fluid extraction or another reservoir activities often result in failure of the rocks with release of seismic energy (Eisner et al., 2009). This failure of the rocks are called microseismic events and the technique used to detect, locate and interpret them is microseismic monitoring.

Microseismic monitoring is the observation technique of small earthquakes, called microseismic events, which occur in the ground as a result of human activities or industrial processes such as mentioned hydraulic fracturing.

The article presents usage of surface and downhole microseismic monitoring to check if it is possible to detect and locate synthetic microseismic event, which can appear during hydraulic fracturing process, in polish conditions where prospective intervals of shale gas occur at average depth of 2900 m and where thick layer of Zechstein sediments which strongly attenuates the signal is present.

HYDRAULIC FRACTURE MONITORING

Hydraulic fracturing is the one of the primary technologies for improving well productivity. The main purpose of hydraulic fracturing is to create effective fracture system in the rock. During this process, fracturing fluids, which contain proppant, grains or sands, are pumped into a formation to hold the cracks open and keep oil and gas flow (Akram, 2014). Microseismicity which occur during the hydraulic fracturing process can be detected by sensitive sensors placed in monitoring well nearby treatment well (Pereira & Jones, 2010). The recording of microseismic events is very important. Known distribution of microseismicity can be extremely helpful in deducing how the reservoir rocks are responding to the production activity and can be useful for evaluating the efficacy of the stimulation of the unconventional reservoir, for example by constraining the geomechanical model of fractured formation (Eisner et al., 2009). Moreover the ability to integrate the characteristics of induced fracture systems, such as fracture length, width and height, with well stimulation parameters responsible for such characteristics can help to improve reservoir management. Microseismic monitoring is also useful for identification of hydraulically conductive fault structures acting as flow channels for fluid, which might affect pressure maintenance (Pereira & Jones, 2010). Those are the reasons why the correct location of microseismic events is a crucial thing in stimulation of the unconventional reservoirs. One of the most important thing in microseismic event locations is to investigate the uncertainties in these event locations.

MICROSEISMIC METHOD

ACQUSISITION

There are two most common acquisition techniques which are used in microseismic data monitoring: surface and downhole array. In special conditions also shallow buried arrays are used. In this article authors investigated both arrays.

Surface microseismic monitoring is a technique of recording induced seismicity using receivers placed at the surface. This technique provides a good coverage but also has poor signal to noise ratio (S/N) due to registered noises from e.g. rig, roads or wind. This poor S/N ratio can be improved by placing the receivers (three - component 3C geophones or accelerometers) in shallow boreholes (Pereira & Jones, 2010). This technique is highly recommended in polish conditions. In case of surface array very precise velocity model is not essential because the raypaths are not horizontal unlike downhole monitoring. The use of surface array requires 1000 or more stations in different pattern. However, this number is significantly reduced when receivers are buried in shallow boreholes.

For our calculations we used 21 receivers placed in the pattern like in the figure 2. Spacing between them equals 60 m.

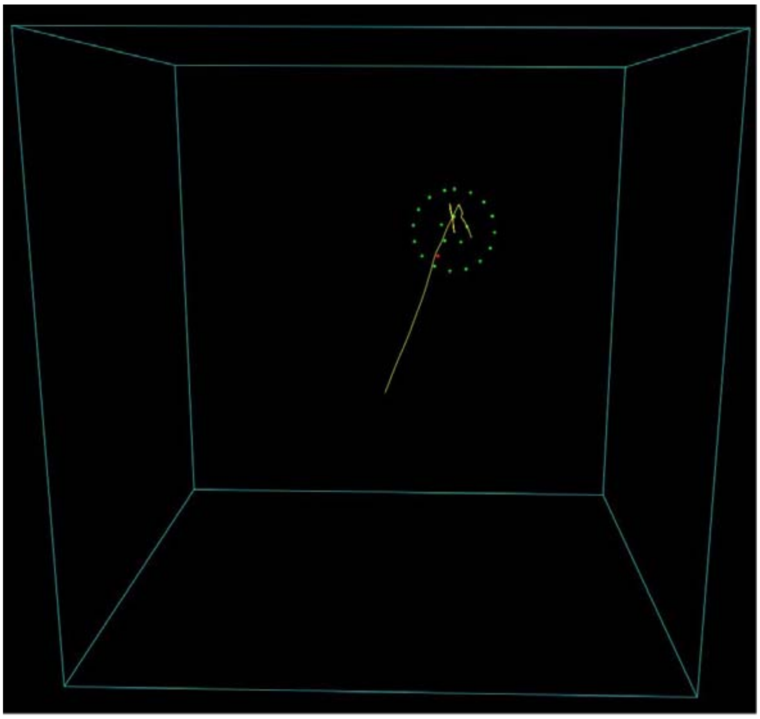

Fig. 2. Surface monitoring array

Downhole microseismic monitoring is a technique of recording induced seismicity using receivers placed in the monitoring well near to treatment well. This technique is characterized by high signal to noise ratio (S/N) in the recorded data but also provide poor coverage of the monitoring field.

For our calculations we used also 21 receivers placed in the monitoring well, which is located 500 m from treatment well. The depth of bottom receiver in well equals 2800 m and the spacing between receivers is 20 m (Fig. 3).

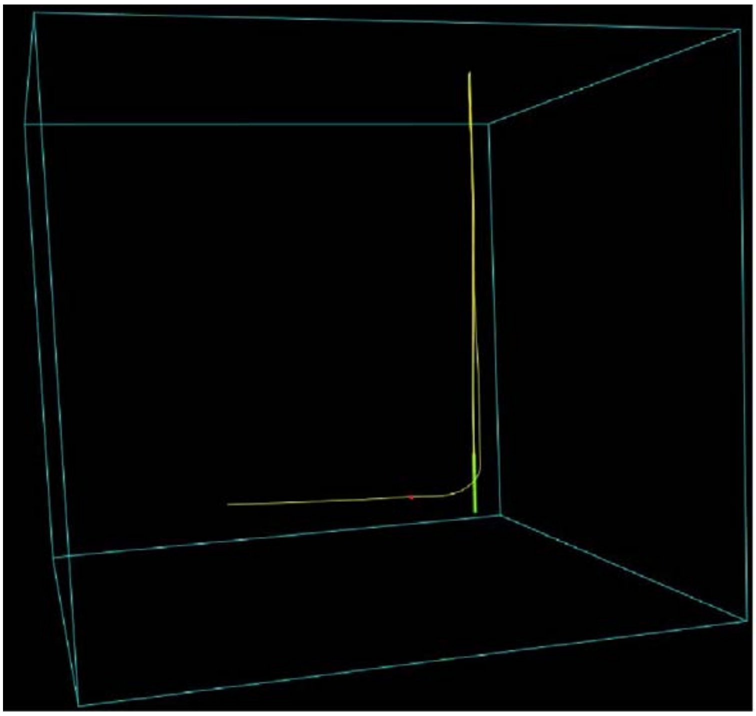

Fig. 3. Downhole microseismic monitoring

For our calculations we located 2800 m deep event monitored from both surface and downhole arrays to investigate which array introduces bigger uncertainties in microseismic event locations in polish conditions.

PROCESSING

Next step after recording of microseismic data, with surface or downhole array, is to process them to get hypocenter locations, magnitudes and source mechanisms.

In this study we have provided only events locations with different arrays. The workflows used for downhole data are slightly different from those used for surface monitoring.

First step in processing of downhole microseismic data is to build velocity model based on sonic logs and then calibrate it using calibration shot. In this case the receiver orientations are unknown in the borehole and are determined using an orientation shot. To determine geophone orientations, we used method based on energy maximization. Next step is to rotate data into radial and transverse components using geophone orientations to maximize P and S wave energy and improve waveforms quality. After that we have to detect events and pick P and S first arrival time on each receiver (Arkam, 2014). Final step is to locate picked events using PDF function (1).

In processing workflow for surface microseismic data we do not have to provide receivers orientations and trace rotations since we know it from acquisition. The rest of the processing workflow is similar to downhole monitoring.

The probability density function (PDF) which is used for determination of hypocenter location is shown below (Eisner et al., 2009):

$$PDF(x,y,z) = Ne^{\sum_{i=1}^{receivers} \frac{(T_p^S(x,y,z,i)-T_p^M(i))^2}{2dT_p(i)^2} - \frac{(T_s^S(x,y,z,i)-T_s^M(i))^2}{2dT_s(i)^2}} \quad (1)$$

where: N – normalization constant which ensures that value of integration over all potential locations is equal to one.
TPM and TSM are measured travel time of P and S wave.
TPS and TSS represent computed travel time.
dTp and dTs measures uncertainty of the fit of arrival times to travel times at each receiver.

As it was mentioned, our goal in this study was to provide locations of synthetic microseismic event using both surface and downhole monitoring array. We have used synthetic event with magnitude 0, located in 2830 m deep. The ricker center frequency which we have used to create this event equals 50 Hz. We have created this event using velocity model from figure 4. This model consist of 12 layers with different velocities. The very thick layer of Zechstein strata is also included. Such model very well corresponds to the real polish conditions.

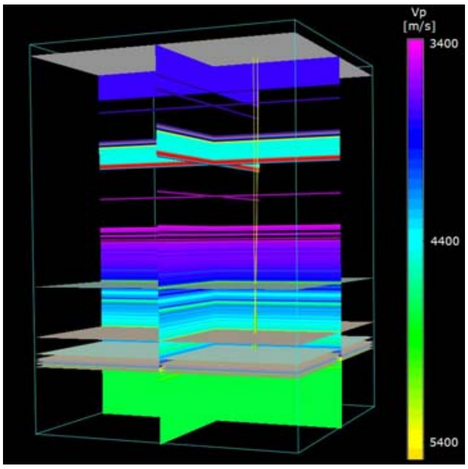

Fig. 4. Velocity model used for the analysis

Since we have used synthetic data we did not have to do trace rotation and receivers orientation. Our first step in data processing was to pick P and S waves on each receiver and provide polarization analysis which we have made using hodograms. Figures 5 and 6 show picked events recorded using respectively surface and downhole monitoring array. From this pictures we clearly see that higher amplitudes can be obtained with usage of downhole array. The reason is that waves are attenuated during traveling through all layers.

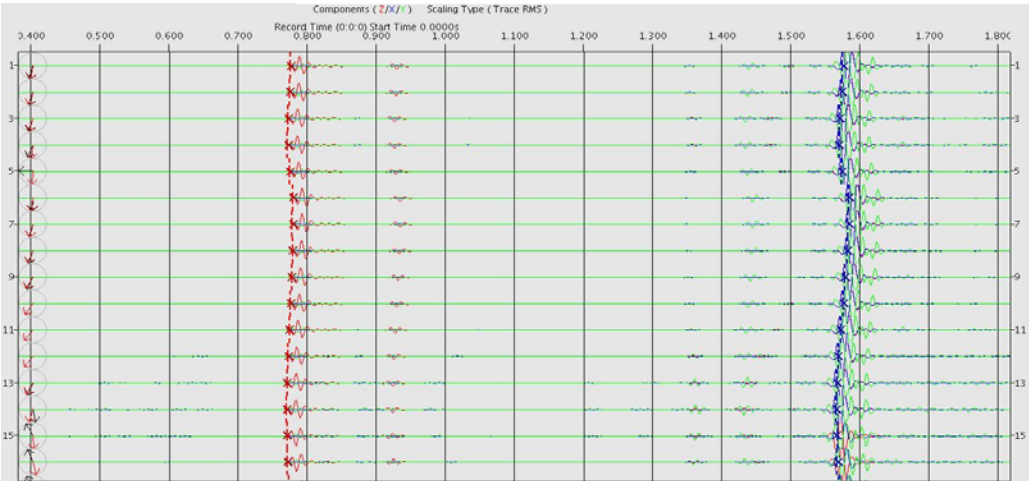

Fig. 5. Picked event recorded with surface array (polarization analysis at left)

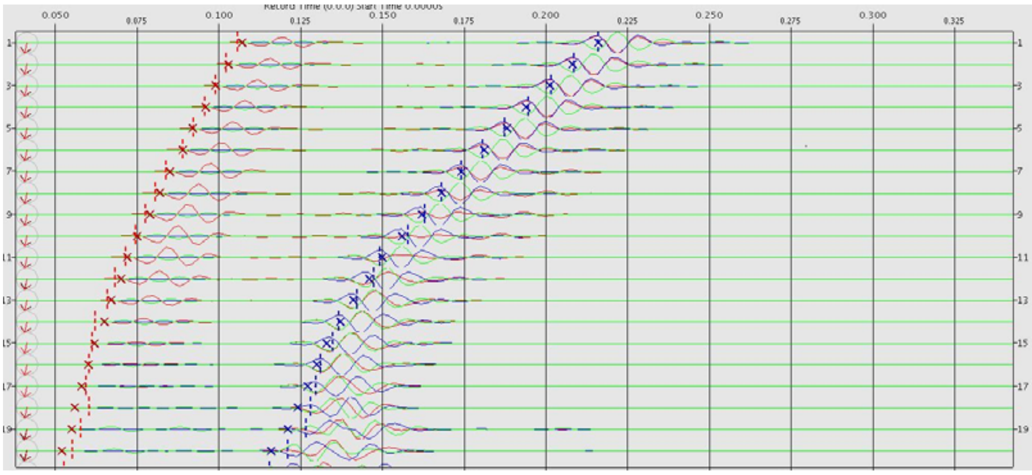

Fig. 6. Picked event recorded with downhole array (polarization analysis at left)

The final step, after picking all traces, was location events with usage of PDF function with previously provided velocity model. Results of this step are shown below (figure 7 for surface monitoring and figure 8 for downhole array).

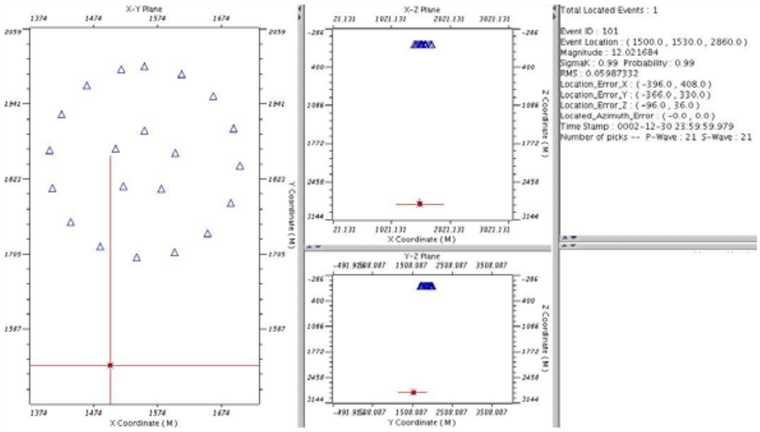

Fig. 7. Location of synthetic event in velocity model from figure 5 using surface array

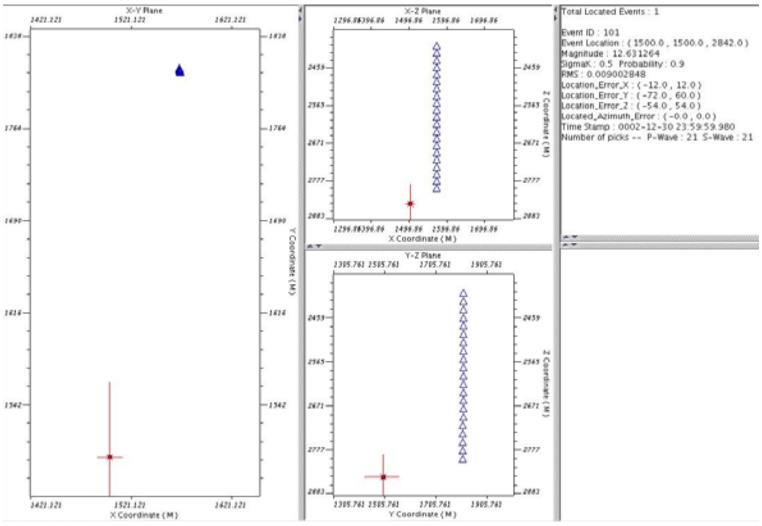

Fig. 8. Location of synthetic event in velocity model from figure 5 using downhole array

Value of uncertainty for located microseismic event is much higher in case of surface array.

RESULTS AND CONCLUSIONS

Knowledge obtained from provided analysis can be helpful to choose which microseismic acquisition technique is appropriate in polish condition. Such knowledge allows to save money and time during the hydraulic fracturing by choosing adequate technique. Correct interpretation of the real data also may help target new production or injection well.

In this study we have proved that in polish conditions where we meet very thick layer of Zechstein which attenuates the signal and where prospective intervals of shale gas are placed in 2830 m deep the most reasonable is to use downhole array to monitor the hydraulic fracturing process. By using this array we are able to locate event very precisely with very low uncertainty. Moreover we think that using accelerometers instead of geophones in surface array may help with getting better signal to noise ratio of recorded data and provide better event locations.

REFERENCES

AKRAM J., 2014. *Downhole microseismic monitoring: processing, algorithms and error analysis*. Department of geoscience. Calgary, Alberta.

EISNER L., DUNCAN P.M., HEIGL W.M., KELLER W.R., 2009. *Uncertainties in passive seismic monitoring*. The Leading Edge.

PEREIRA A.M., JONES M., 2010. *Fundamentals of borehole seismic technology*. Schlumberger.