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Planning, Configuration and Usefulness of Microseismic Monitoring on Eastern-Europe Platform – Example from East Pomerania

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Abstract. The microseismic monitoring is a method of monitoring of fracture propagation during hydraulic fracturing process. The method uses array of geophones to localize micro tremors induced by liquid pumped underground at high rate and pressure. The acquired information helps to optimize fracturing process and prevents fracture growth to aquifer levels. It was proved to be useful on several unconventional hydrocarbon reservoirs in the USA. Conducted investigation was aimed at evaluation of the possibility of using the technology on Polish unconventional reservoirs. In order to stand better chances of success the analysis of several variants of monitoring was made. East Pomerania geological structure was compared to similar structures in the USA. With this knowledge, financially feasible configuration was selected. The array of geophones was dispatched around the drilling site and data acquisition was performed. The present paper is mainly focus on geological structure, hardware selection, damping factor and noise level analysis. The usefulness of used receiver configuration is also assessed.

Keywords: Microseismic monitoring, noise analysis, hydraulic fracturing, detectability.

Conference topic: Environmental protection.

Introduction

During the period of high prices of oil, which started in the beginning of a century, and instability in the Middle East, oil and gas companies started to look towards unconventional reservoir extraction. The main difference between conventional and unconventional reservoirs is porosity and permeability of rock formation intended for extraction (Soeder 1988). Porosity of rock is connected with space available in the bedrock for organic matter such as oil and gas, and permeability is the capability of conducting fluid flow through a unitary volume of rock. Conventional reservoirs tend to have lower porosity and bigger permeability, whereas unconventional such as shales have bigger porosity with very low permeability (Zoback 2007). In order to extract organic matter from pores, permeability needs to be improved. Hydraulic fracturing is most popular method to achieve this. The fracturing liquid, which consist mainly of water, clays and small ceramic spherical particles is pumped under high pressure into the borehole. Through the previously obtained openings in production tubing, the fluid penetrates and cracks the rock around the borehole. When the pressure gets low, ceramic particles remain in the cracks preventing them from collapsing. The heightened permeability allows oil and gas to flow into the borehole and to be extracted. The cracks and fractures should overlap the perspectives volume of rock rich in organic matter. Unfortunately in the reality those are highly dependent on pre existing stress field in the area, pre-existing discontinuities in rock formations. With limited information about real parameters of rock beneath it is hard to give a good estimation of fractured volume. It is worth to notify that hydraulic fracturing is performed in stages. There are usually between 10 and 20 stages per horizontal well. Cracking and fracture growth are small seismic events, i.e. they generate shear and pressure waves. Fortunately, these ground motions have relatively small magnitudes and does not result in any serious damages observed during tectonic earthquakes (see, for example, Falborski, Jankowski 2013; Jankowski 2007, 2015; Jankowski, Mahmoud 2016; Naderpour *et al.* 2016). Using a very sensitive set of microphones it is possible to register the waves and localize coordinates of the seismic event. Localization of multiple events within the volume of rocks can give a good view of reservoir penetration, and in some cases: correct the fracturing plan and parameters. It can also alarm the rig crew if fracture growth. The planning of microseismic registration grid must take into account several factors. The first and most important is geological structure of rocks above and below reservoir. Mechanics of wave propagation are strictly connected to the characteristics of medium. Porous and soft material can attenuate the waves significantly. Furthermore, the wave diffracts and reflects on the boundaries between different rock layers. This phenomenon, in case of classical seismic surveying, allows us to find different geological layers and identify them, but in case of microseismic monitoring, they alternate the path of wave propagation. The more complicated geological structures the harder way to find the exact position of microseismic event due to useful signal degradation. Above all technical issues, the terrain on which the geophones are to be placed, plays important role. Swamps, forests, public roads and villages generate noise or attenuate signal. The ownership of ground, local law and permitting are also important issues.

Geological structure

The first step to fit the best configuration to the given environment was to identify the geological structures possible in East Pomerania (Baltic Basin). As at that time no precise information which of the boreholes will undergo hydraulic fracturing, all the Baltic Basin was taken into account. As it can be seen on Fig. 1 perspective region of Pomerania lays in Baltic Basin. Fortunately moving from Fault Zone north-east bound there is a region of homogeneous stratigraphic structure called Eastern European Platform or locally Mazurian-Polesian Monocline.

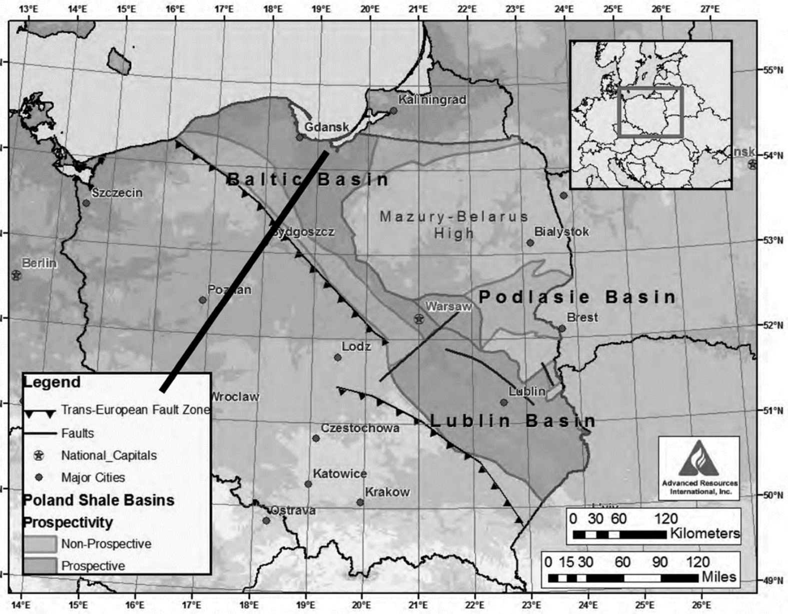

Fig. 1. Polish perspective basin, bold black line denotes the cut – through visible on Figure 2 (adapted form U.S. Energy Information Administration 2011)

Rocks rich in organic matter can be found in Lower Silurian Landovery-Wenlock graptolitic black shales and Ordovician strata on depth between 3.5 and 5 km. In the Cretaceous there are mainly limestones, Juraic and Trias consists mainly of sandstones, Zechstein is built from salts anhydrites and dolomites. There are two problematic regions regarding seismic wave propagation. First one is Cenozoic strata having very low wave propagation speeds and big attenuation. These can be as thick as 300m in eastern Pomerania. The second are anhydrites and salts which although having high wave propagation speeds, have a lot of fault plains which cause refraction (Mavko 2005). Additionally on the interfaces between salts and sandstones there is also high refraction factor due to big differences in wave propagation speed. Most of US Shale deposits lay between 1 and 3 km depth which constitutes to better microseismic visualization. The most analogical basin with successful microseismic monitoring in US is Haynesville Basin (Roche 2010). The deposits lay approximately on 4 km depths and there are salt formations as in eastern Pomerania (Robinson, Hovey 2011).

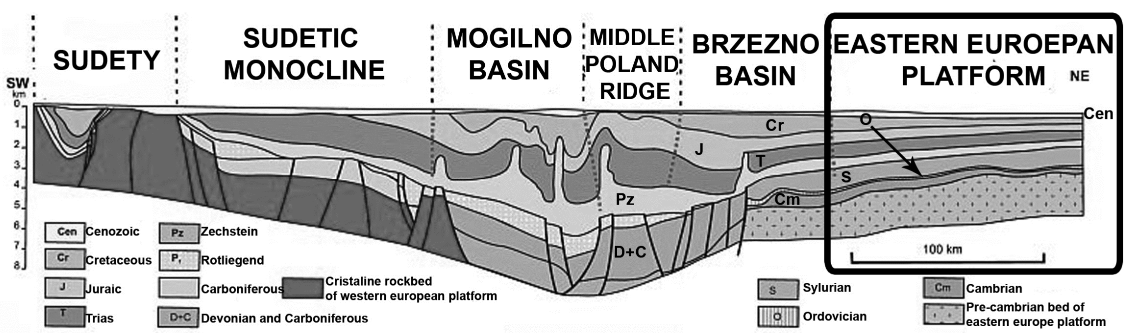

Fig. 2. Geological profile of Poland adapted from (Żelaźniewicz *et al.* 2011)

Geophone Grid Configuration

There are several variants of monitoring used in the microseismic technology. The basic type is a surface array arranged in star configuration starting from the drilling pad and reaching outwards. In some cases there are basic cartesian arrays used (Duncan, Lakings 2006). The modification of the method is to distribute patches of grouped geophones in most convenient places. In case of big drill-pads with several horizontal wells there is also a buried array configuration used (Snelling,Taylor 2013). The number of geophones are reduced but they are placed in shallow 100–300m wells to better isolate from surface noises and minimise the impact of surface Cenosoic high damping layers. According to case study on Haynesville shale, the buried array would be good match for Baltic basin geological conditions. However, considering insufficient budget and uncertainty in case of the wellbore which will be fractured by our industry partner PGNiG S.A., longer law procedures for drilling shallow wells and more risk connected with permitting for drilling, it has been decided that the surface monitoring option is the only feasible for this project. However, taking into account the fact that star configuration has been tested on other drilling site in Baltic Basin without success, i.e. no microseismic events have been detected, it has been decided to use patch array configuration as the most flexible and noise reducing. The small dense patches of geophones reduce noise by 20dB in every direction in contrary to star configuration in which the noise is only cancelled in linear direction (Auger *et al.* 2013).

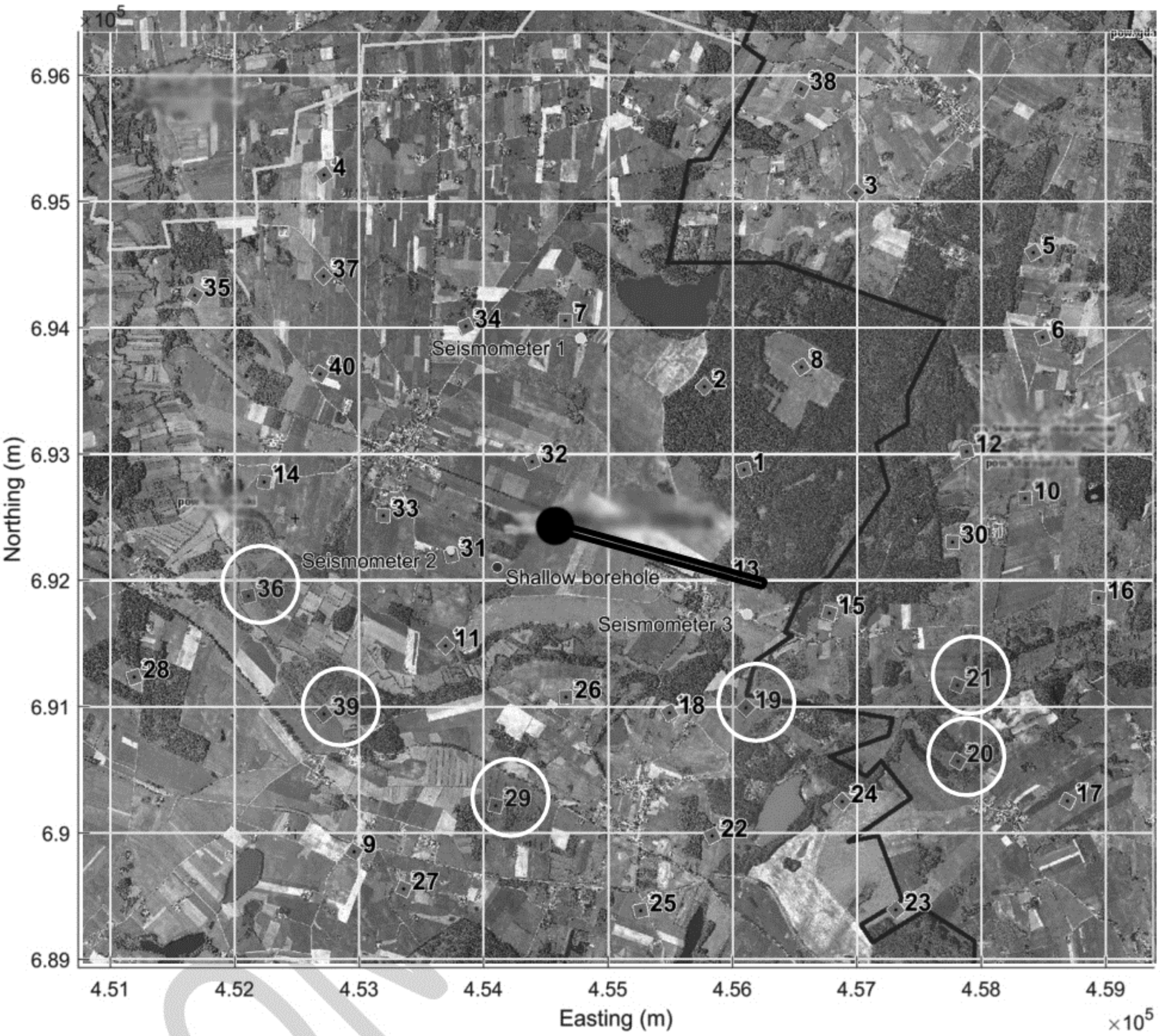

Fig. 3. Map of patch deposition with noisiest patches circled

Total amount of 12000 geophones grouped by 12 in 1000 receivers were divided into 40 patches. The single patch was designed as a 88 by 92 meters rectangle. The centre of each group of 12 geophones was shifted by 20 meters. The initial patch locations were planned considering surface damping factor, local maps, vicinity of roads and human settlements. After the permitting phase some patches had to be moved because of lack of permission do to deploy patches on private ground, 2 patches had to be moved because they were planned on swamps that weren't visible on the map. The deployment was conducted using DGPS method. The patch locations are shown in Figure 3. Geophones had 22.8v/m/s sensitivity and were covered with approximately 30 cm of ground to attenuate noise. The sampling rate was

500Hz. Receivers used portable battery powered data storage units with wireless connectivity. The data was harvested every day in the early morning when no operations on the pad were conducted.

Noise Analysis

After the geophone deposition, system and receivers integrity tests, the noise analysis was conducted. For two days the system was recording the background. The data was plotted into multiple diagrams and analysed. Only two of them which contain most condensed data are presented.

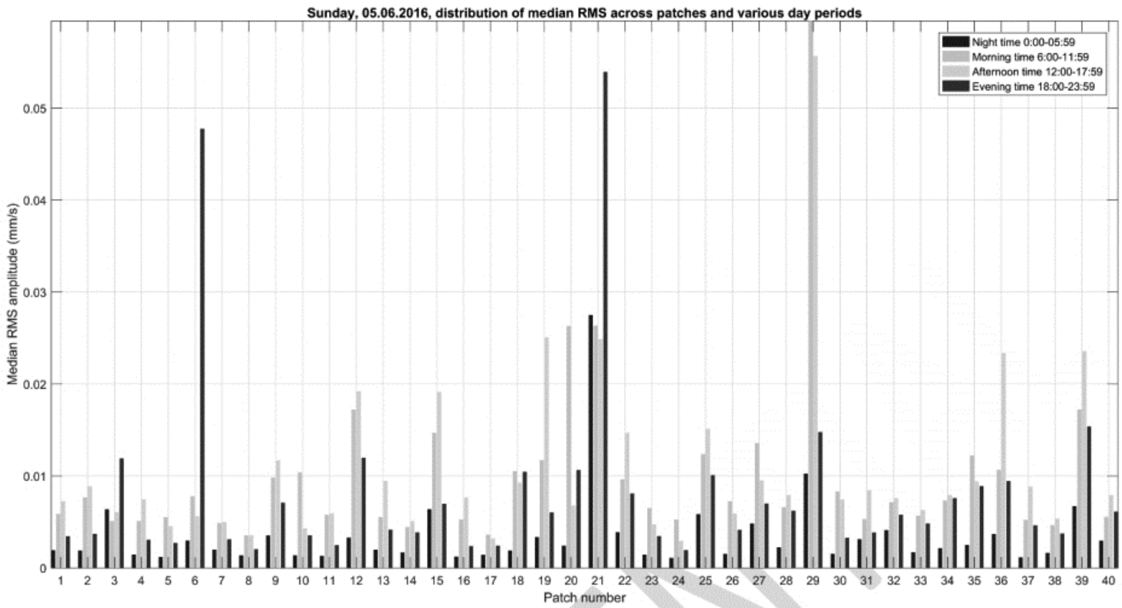

Fig. 4. Noise level during the day

It can be observed form Figure 4 that the southern patches 19, 20, 21, 29, 36, 39 have consistently some of the highest levels of the noise. This means these patches deteriorate the stacked signal to noise ratio. Note, that the north patches are missing and hence this deteriorates further north-south resolution in locations. This is due to problems with permitting in the south of monitored region.

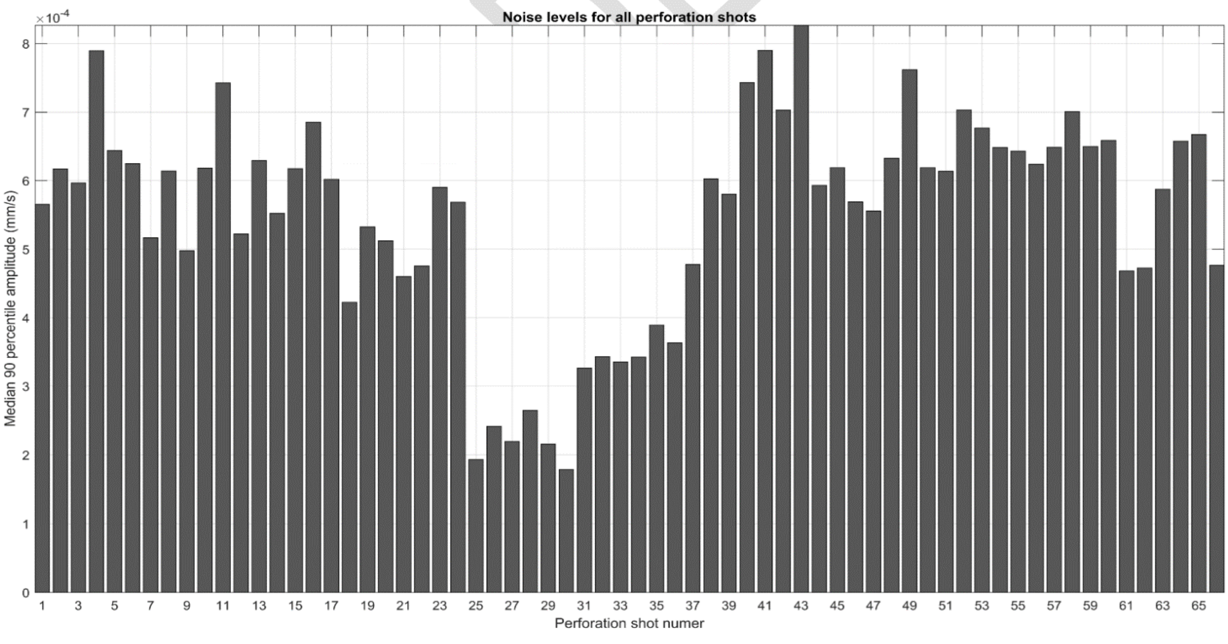

Fig. 5. Median noise during perforation shots

The noise is not dominated by the central pad or fracking crew activity. Nights and weekends are significantly less noisy. Average noise level is approximately twice higher for weekday morning/afternoon when compared to weekend or night/night. Detection of seismic events was significantly better during the night hours and on weekends. It can be seen from the figures that the weekday level of noise is more homogeneous. Moreover, distribution of noise on the patches is more homogeneous during the nights and weekends. This means the noise levels are more evenly distributed during the nights and weekends. This further supports better detectability during the nights and weekends. Absolute noise levels are medium to low in the range 50–100 µm/s which is common for surface receivers. Detection should be possible with normal attenuation (QP ~ 80) (Wcisło, Eisner 2016) based on our previous experience and modelling for similar arrays and noise levels. As the noise levels were known and identified, the second step was to evaluate signal to noise ratio. Hydraulic fracturing of subsequent stages started with perforations shots. Small cumulative charges were placed in the horizontal part of production tubing. When exploding, they penetrate tubing, cement sheat and nearby rock allowing fracturing liquid to flow into the rock. Those charges have known position in the wellbore and the exact time of shoot was also recorded. The seismic wave was comparable but stronger than those generated by usual microseismic event. There were 65 perforation shots. Noise analysis was performed to determine noise levels of time intervals corresponding to the perforations. This allowed us to select the most promising perforation shots for calibration and also to select patches and receivers appropriate for stacking in each case. To test if the data contain sufficient signal, 11 patches were selected nearest to the well head, band pass filtration was applied (4th order Butterworth bandpass filter from 10Hz to 40Hz) and the patches were sorted by increasing distance from well head to patch. This allowed us to identify the surface waves associated with the perforation shots and stack signal preceding these waves to analyze the P-wave body wave. This methodology allowed us to identify the optimal data intervals and calibrate the velocity model. The median noise levels were estimated for each file that contains perforation shot signal. Distribution of noise levels is shown in Fig. 5. Individual noise levels for each trace were computed as 90-ieth percentile of all absolute amplitudes in the trace. The lowest noise levels correspond to perforation shot files recorded during the Stage 5 (shots 25–30). This is consistent with the previously identified lower noise levels in the morning and on weekends.

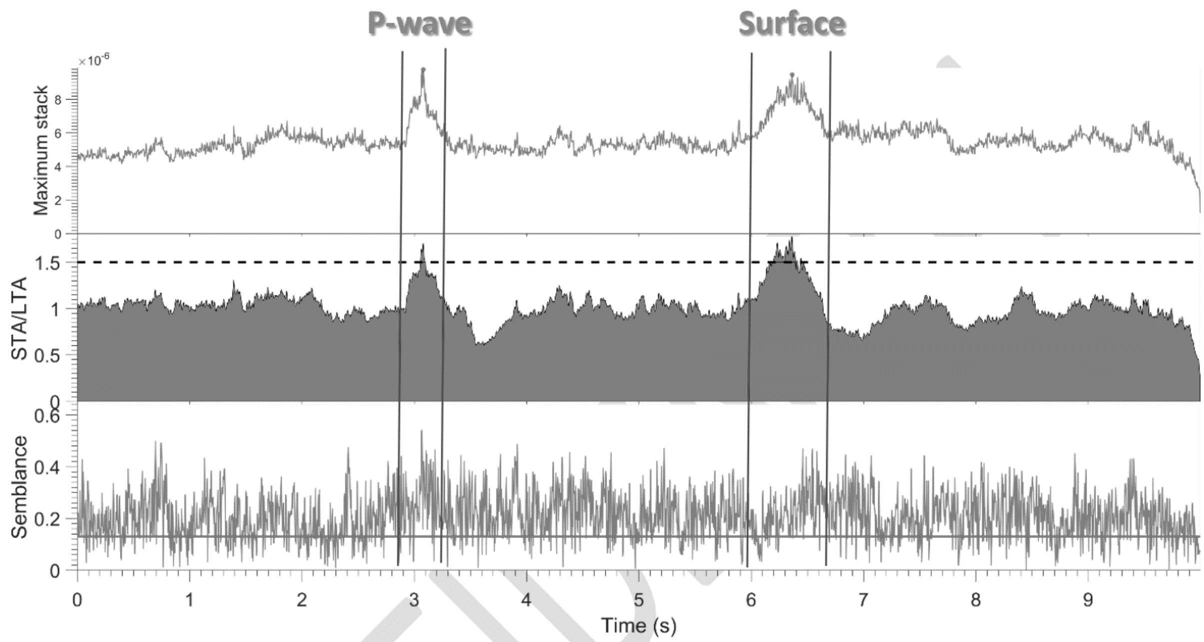

Fig. 6. Perforation 28 stack function, STA/LTA and semblance

The second lowest noise levels are observed for the Stage 6 recorded during the same day (weekend) but later (18:00–19:00). Perforation shots 25–30 were also the earliest in the morning and hence are the most possible candidates for velocity model calibration. Analysis of median noise levels for receiver patches for perforation shows that patches 9, 16, 18, 20, 21, 23, and 39 have higher noise levels for the Stage 5 and do not contribute to stack with high SNR. These results are consistent with the fact that the patches 20, 21, 39 had high noise on weekend-weekday noise measurements before (Fig. 4). For other calibration shots the signal to noise ratio was too small for precise detection of the signals. Types of summation of signals from all patches (except the noisiest 6th one) are shown in Fig. 6. As it can be seen from the figure, with the simple short time to long time average picking method the perforation is merely detectable, the more complex method of maximum stacking can detect the perforation shop, whereas semblance does not show any sign of event (Eisner *et al.* 2008). Given the fact that the strongest events, like perforation shots, were on the verge of detectability, smaller events were not detected.

Conclusions

The microseismic monitoring was planned and conducted during hydraulic fracturing of a wellbore in Baltic Basin, eastern Pomerania. The patch array configuration was selected as the most promising one. Background noise analysis was conducted and the results indicates that the largest noise come from human activity during weekdays. Using perforation shots, the signal to noise ratio was calculated. The possibility of detecting hydraulic fracturing induced microseismic events without the precise information of time of their occurrence was excluded. Burried array configuration may have been more successful due to isolation from surface noises.

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