How to improve location accuracy when dealing with artifacts in microseismic event locations

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Summary

Some known artifacts observed in the microseismic event locations are described. Presence of artifacts in the data can cause over- or underestimating the fracture dimensions. Since artifacts are closely linked with the localization process, accurate velocity models construction and calibration are required. In most cases artifacts can be eliminated by using a proper velocity model.

Introduction

Microseismic analysis can be a powerful tool to estimate fracture geometries in the unconventional reservoirs. The estimated azimuth, length and height of the fracture can be used to determine if the formation of interest was properly stimulated and later tie it to the production and plan future wells. Artifacts observed in the microseismic event locations can cause fracture dimensions to be over- or underestimated causing inaccurate analysis and potentially become very costly.

Theory and/or Method

Artifacts can be described as patterns in the event locations that do not reflect the real event distribution. There are a few types of artifacts such as an arching effect when events are smeared out around the toolstring in the map view; a stacking effect when events form almost a perfect line at a high contrast velocity border; and a sloping effect when events form obvious trends with a distinct lower boundary. There is also an artifact when events tend to avoid high velocity layers creating gaps in the data. There are more chances of artifacts appearance when using shallow toolstrings for data acquisition.

Artifacts are linked to the localization process and can be caused by improper velocity model calibration. A reasonable amount of velocity layers closely following the acoustic logs should be chosen in order to achieve small travel time residuals on each geophone. Head waves or direct waves should be carefully identified in the calibration data and modeled accordingly. Often thin layers with very high velocities do not have any sufficient effect on arrival times while they can cause errors in the event locations if modeled closer to the logs. Therefore all layers with high velocity contrasts need to be carefully evaluated and in some cases can even be eliminated.

Acoustic logs provide vertical velocities and are measured at higher frequencies while microseismic events occur at a distance to the geophones with a mix of horizontal and inclined travel paths and have signal of a lower frequency. Velocity models built based on the vertical velocities almost always have to be calibrated in order to achieve more reasonable seismic velocities (Stewart et al. 1984). Travel time residual plots showing difference in predicted and measured arrival times on all geophones along with proper location of calibration data provide good quality control for any velocity model.

Examples

Artifacts observed in the map view when events form an arch are more apparent on distant stages as angle error increases with distance and usually caused by poor hodogram quality. Using higher sampling rate and a higher number of tools can significantly decrease the azimuth uncertainty and prevent appearance of such event smearing. Ignoring the artifact and proceeding with estimation of fracture dimensions can lead to underestimating the fracture length and the extent of the proppant placement.

Sloping effect is also visible on distant stages and is caused by presence of a high velocity layer that creates head waves causing events locating too shallow. Figure 1 shows a synthetic data set created using a calibrated velocity model. Synthetic events are located 200m away from the toolstring with 25m increments at three different depths: shallow events right above a high velocity layer 11, events right in the middle of the high velocity layer and events below the layer. Layer 11 then was then sped up in order to achieve better matching with the logs. Synthetic events were relocated using the new model. Figure 2a shows events after relocation. A definite slope is visible and ray paths show that the head wave arriving on the bottom tools is the reason for events to locate shallow. The farther events from the toolstring the shallower they locate. Improper velocity model calibration and wrong phase identification in the signal (picking direct wave while modeling it as the head wave) can lead to overestimating the fracture height.

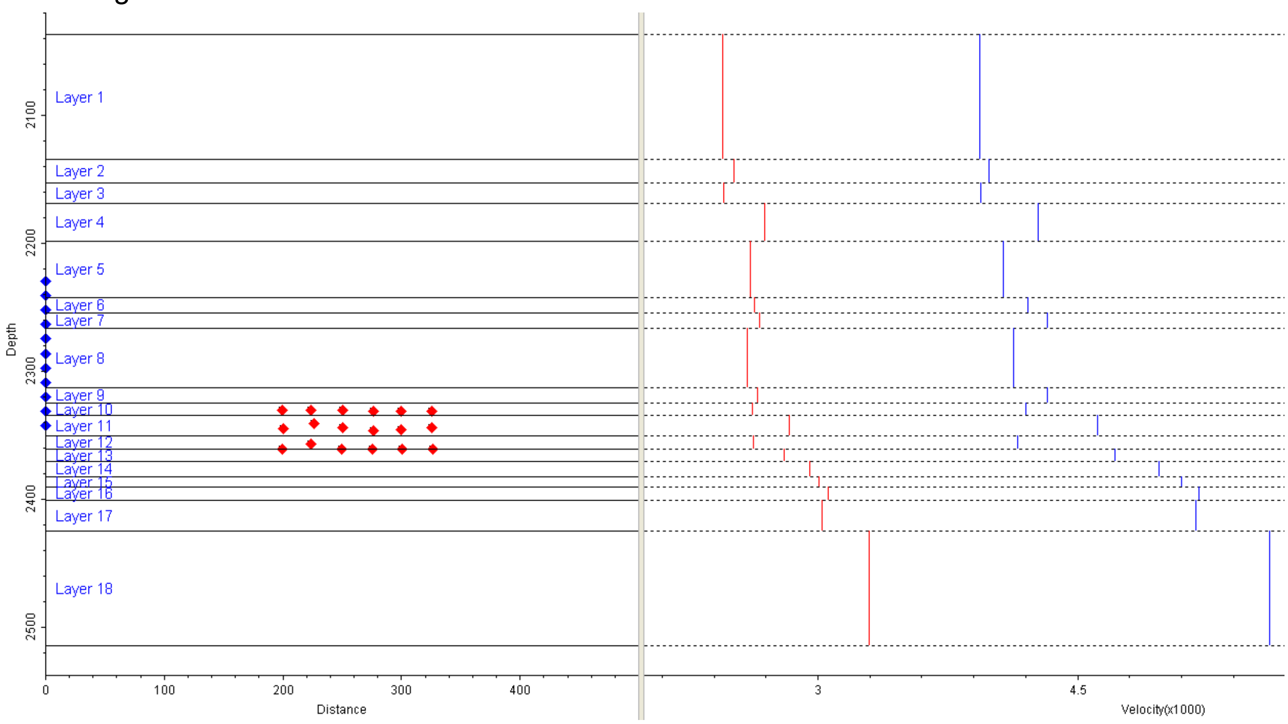

Figure 1: Synthetic event locations (left) based on the final calibrated velocity model (right)

The layer 11 was then slowed down by 15% and events were relocated again. Figure 2b shows that after relocation the events are not located in the high velocity layer 11 but above and below it except for the closest ones. Shallow events clearly form the stacking artifact. Travel time residual contours calculated for each event can provide useful information on how sensitive the event locations are. As seen in the Figure 2b, the innermost contour suggests that the event will most likely move down if arrival picks are slightly changed.

When experiencing the artifact in the actual data, the velocity model needs to be verified against the calibration data along with evaluation of travel time residuals on each geophone to determine if velocity model was proper calibrated. Another way to determine that it is an artifact and not the real event locations is to create synthetic waveforms and compare them with the actual microseismic events. Identification of correct phases in the signal – either direct or head wave is also very crucial for more accurate event locations (Zimmer 2010). Making interpretation of fracture dimensions when artifacts are present can lead to underestimating the fracture height.

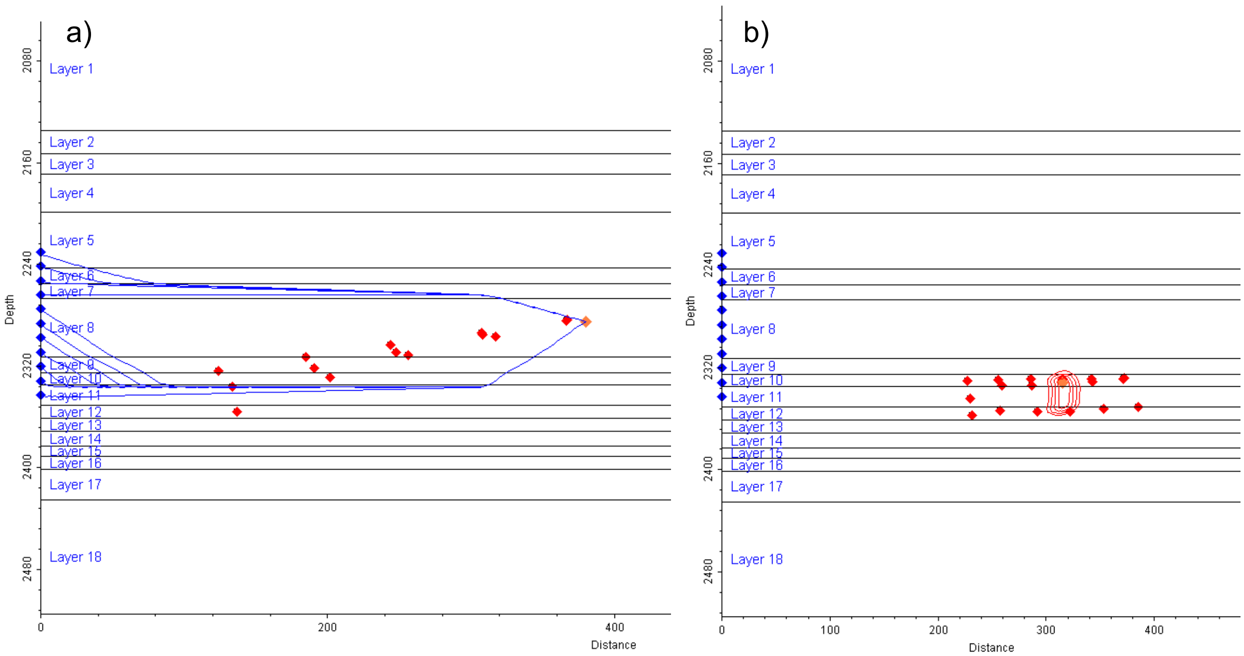

Figure 2: Synthetic event locations: a) after applying velocity model with layer 11 modeled as fast as in the acoustic logs; b) with layer 11 slower by 15% than in the logs

Conclusions

There are some known artifacts observed in the microseismic event locations which in most cases are caused by improper velocity model calibration. Presence of artifacts can lead to over- or underestimating the fracture dimensions therefore they need to be eliminated before the fracture modeling analysis. In most cases they can easily be fixed by using a more accurate velocity model that predicts correct arrival phases in the data along with small travel time residuals on each geophone.

References

Stewart, R. R., Huddleston P. D., and Kan T. K., Seismic versus sonic velocities: a vertical seismic profiling study: Geophysics, 49, NO. 8, 1153-1168.

Zimmer, U 2010, Localization of microseismic events using headwaves and direct wave: SEG Denver 2010 Annual Meeting