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Advantages and disadvantages of array depth placement and longer toolstring apertures

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Summary

The purpose of this study is to show how longer microseismic toolstring apertures can affect data quality. Toolstring length should be chosen wisely depending on the formation of interest, observation well conditions and expected data quality. In addition, long toolstrings can introduce their own set of challenges. Feasibility studies are a helpful tool in order to decide on the most suitable toolstring for a project. Based on the observation well availability, velocity structure in the area and expected signal quality it is possible to design a toolstring which can provide better location accuracy under the given conditions.

Introduction

Early efforts to monitor hydraulic fractures with downhole geophone receivers employed single receivers in nearby wellbores. It was obvious, early on, that a single receiver per well would not provide results with sufficient accuracy to be useful in most applications. As a result, microseismic monitoring did not advance until multi-level receiver arrays became available.

In the last decade, a standard downhole microseismic array consisted of a 12-level receiver system, with each receiver usually separated by about 12m. However data now indicate that extended arrays provide better location accuracy, particularly in formations with larger viewing distances. As the industry developed more experience with microseismic technology, we have learned that the more receivers we can place in a wellbore, the better our location accuracy will be. There are also some other issues of sampling rate, sensors, noise, coupling, resonances, depth resolution, location accuracy, larger travel time residuals and others that will come into play for any project.

Theory and/or Method

Adding larger geophone interconnectors of 30m, in order to extend the toolstring, can significantly decrease locations errors. It must also be noted that longer toolstring apertures are only helpful in increasing the depth accuracy if a signal is visible on all sensors. Therefore, for those formations with low microseismic activity and small viewing distances, increasing array aperture will have no improvement on the overall data quality of a project.

The effective aperture of a sensor array is a major factor in the accurate localization of a microseismic event (Zimmer 2010). The velocity model plays a major role in the apparent event apertures and therefore should be carefully considered when deciding on the optimal toolstring placement. Presence of high velocity layers can create head waves and decrease location accuracy for the distant events. In some cases, combination of longer interconnectors along with the shallower toolstring position can be used in order to increase the apparent event aperture and therefore decrease the location uncertainty.

By performing a pre-job modeling study to predict waveform arrivals and location accuracy, combined with logistical considerations, appropriate microseismic toolstrings can be designed for optimal data acquisition.

Examples

For downhole microseismic monitoring, an observation well needs to be chosen. In most cases it is a nearby vertical or deviated well that was producing some time ago. Ideally, the most optimal position for downhole microseismic monitoring is the straddling one as it provides better location accuracy and better resolution of event depths. However, due to presence of perforation intervals, a plug needs to be set above the zone in order to place the tools. As a result the only position available for the geophones is above the formation of interest.

In Figure 1, a standard 12 level array with 12m interconnectors is shown to be set above the zone of interest. Traveltime residual contours of 0.2ms intervals as well as Monte-Carlo solutions are shown. The points indicate an event's other possible locations that result from small perturbation of interpreted wave-arrivals on the array's tools (200 trials with a maximum traveltime error of 2ms). For the most inner time residual contour, the errors vary from 50m for events 250m away from the toolstring, up to 200m for events 750m away from the toolstring.

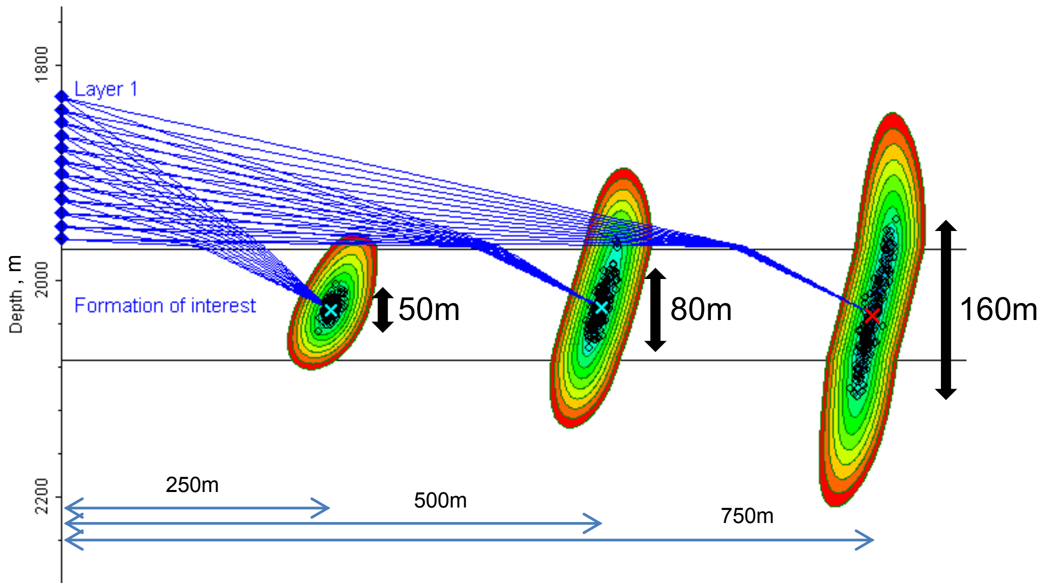

Figure 1: Monte Carlo solutions for each of the theoretical events (X's) (200 trials with a maximum traveltime error of 2ms) placed in 250m increments away from the standard 12 level toolstring placed above the zone of interest

Figure 2 shows an extended 12 level toolstring with top three tools separated by 30m interconnectors. Traveltime residual contours and Monte-Carlo solutions are also shown. Location errors decreased from 50 m (for the standard toolstring) to 40 m with the extended toolstring for events 250m away. For events 750m away, the location error was reduced from 160m to 120m. The depth accuracy of the events increased as a result of increasing the "apparent aperture" of the sensor array having more effect on the most distant events locations.

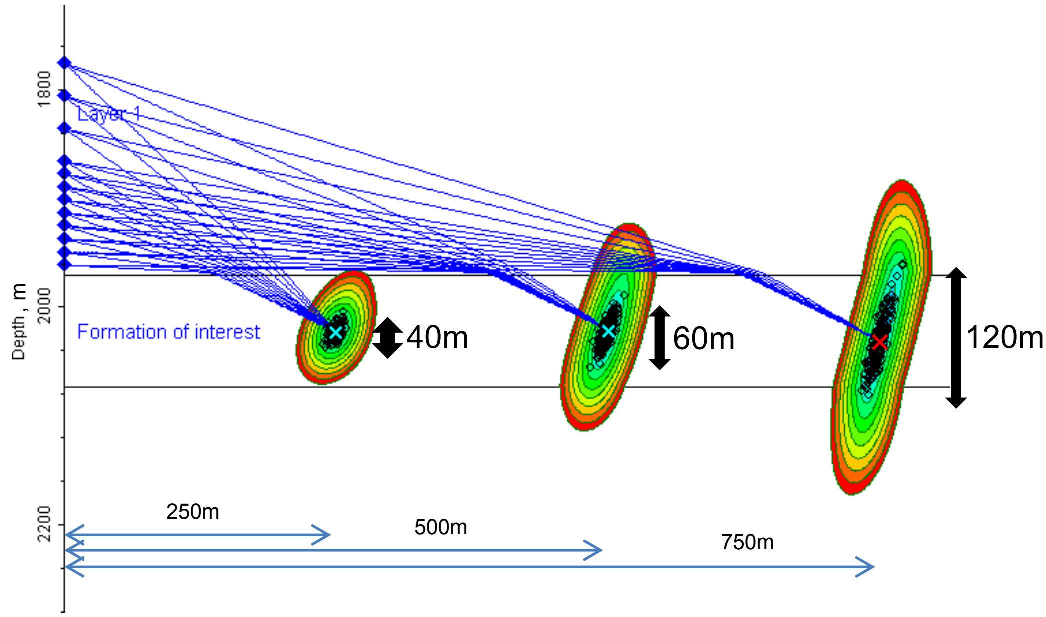

Figure 2: Monte Carlo solutions for each of the theoretical events (X's) (200 trials with Traveltime Error of 2ms) placed in 250m increments away from the extended 12 level toolstring placed above the zone of interest

Using longer toolstrings can also lead to a more complex velocity model analysis when it is harder to achieve small traveltime residuals on all levels. Good calibration data with P- and S-waves visible on all sensors is required in order to obtain the most accurate velocity model and achieve better location accuracy.

In some geological formations with lower microseismic activity signal will not reach all the tools for an extended shallow toolstring. While increasing operational cost, there will be no advantage of using the longer toolstring in terms of location accuracy. Figure 3 shows statistics on number of picks for both P- and S-arrivals on a toolstring consisting of 40 geophones and the array aperture of 585m. Only 21 out of 40 geophones had more than 10% arrival times picked while other 19 geophones had less than 10% or no arrival times picked at all. This case clearly indicates that a toolstring with a reduced aperture would be the most suitable for the formation and the available toolstring placement for this project.

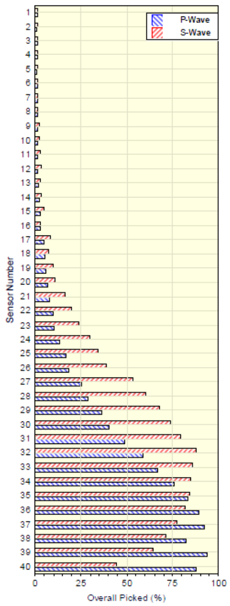

Figure 3: Number of picks on a 40 level toolstring

Conclusions

In cases where a straddling toolstring position is not achievable, placing geophones above the zone of interest is the only option for the downhole microseismic monitoring. Location errors are higher when using a shallow toolstring but they can be minimized by using an extended one. Detailed design studies should be conducted in order to predict waveforms and raypaths based on the velocity structure in the area in order to choose the most optimal toolstring placement. Formation of interest should also be considered when designing a toolstring as not all of them have high microseismic activity that can create signal visible on all the sensors.

References

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