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Microseismic event locationing considering refraction and ambiguity of S-wave picking: Horn River case study

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Summary

Microseismic hypocenter distribution is a key to estimate fracture propagation and fault existence. In Horn River Basin, refracted waves are observed due to high velocity layer of carbonate which exists just below reservoir. Misplaced picks among direct wave and reflected wave could lead mislocation of hypocenter. There are a few studies discussing microseismic locationing considering refraction and ambiguity of S-wave pickng. To accurately estimate the hypocenter distribution, we constructed a velocity model and implemented microseismic event locationing with the following procedure. First, we carried out synthetic waveform simulation for direct and refracted arrivals with the assumed velocity model with high velocity layer below the reservoir. Direct arrivals shows much gentler moveout than refracted one. Based on this observation, manual direct wave arrival picking was carefully carried out. Secondly, a layered orthorhombic velocity model was constructed by sonic logs and perforation shot information using a traveltime inversion scheme. Thomsen parameters are iteratively updated to minimize the residuals between observed and calculated traveltime. Our Thomsen parameters of final velocity model show consistency with previous studies in Horn River Basin. Thirdly, a grid search method with the model and traveltime of P and S-wave was applied for microseismic event locationing. Also in the grid search, high weighting factor was applied on P-wave due to ambiguity of S-wave picking. The results show that most of our estimated microseismic events are distributed within the reservoir even if considering location residual. Since our Thomsen parameters and hypocenter location obtained by careful first direct arrival picking and the orthorhombic velocity model are consistent, this processing scheme provided improvement of velocity model accuracy and hypocenter location.

Introduction / Backgrounds / Objectives

One of the conventional and useful microseismic analysis is examination of microseismic hypocenter distribution to estimate fracture propagation and fault existence (Maxwell, 2014). Even if auto processings are used, accurate microseismic event locationing requires arrival time picking and velocity models.

In Horn River Basin located in Alberta State of Canada, where the target formation is the Middle Devonian shale, there is high velocity layer of carbonate, Keg River formation, just below the reservoir. This carbonate layer could cause refraction of microseismic wave propagation. In reality, our microseismic data show 2 arrival phases both in P-wave and SH-wave as indicated in Zimmer (2011). In addition, most of the direct arrivals and refracted arrivals of SH-wave are overlapped and they are sometimes masked over SV-wave. These mixed phases lead misinterpretation of arrival time picking. Furthermore ambiguity of S-wave picking sometime distort microseismic event locationing.

Since maximum stress is horizontal in this area, orthorhombic velocity models, which can represent fracture effect on P and S wave velocity, would be suitable. Orthorhombic velocity models for microseismic analysis were utilized in some previous studies. Yuan and Li (2017) constructed the model by S-wave splitting measurements and Belayouni et al. (2017) constructed the model by direct and reflection arrivals, and performed event locationing in Woodford play. Grechka and Yaskevich (2014) compared not only pure VTI and orthorhombic models in Bakken shale but also examined triclinic models. Yu and Shapiro (2014) created orthorhombic velocity model in Horn River Basin.

Though orthorhombic velocity model can improve accuracy of hypocenter distribution location, difficulty of S-wave picking should be considered. Zhang et al. (2015), Coffin et al. (2012), Fuller (2010) and Zimmer (2010) performed microseismic event locationing using head-waves. However, the number of studies which treat refraction phase is small. In addition, there are few studies constructing orthorhombic velocity models and performing microseismic locationing with a real field data where refraction occurs and direct arrival time picking of S-wave is difficult. Yuan and Li (2017) constructed layered orthorhombic model but they used blocked sonic log. In this research, we apply orthorhombic velocity model with factored sonic log. Additionally, considering the ambiguity of S-wave picking due to refraction phase overlapping, careful manual time picking of direct arrival are carried out and add large weight on P-wave results since P phase have less difficulty than S phase picking to estimate accurately microseismic hypocenter distribution.

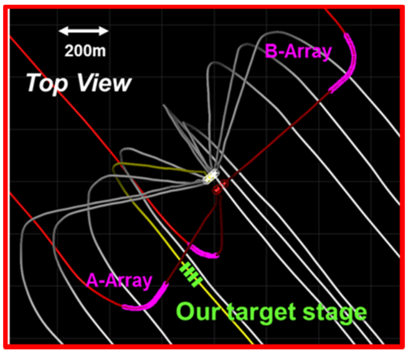

Figure 1. Location of target stage and receiver arrays for microseismic observation.

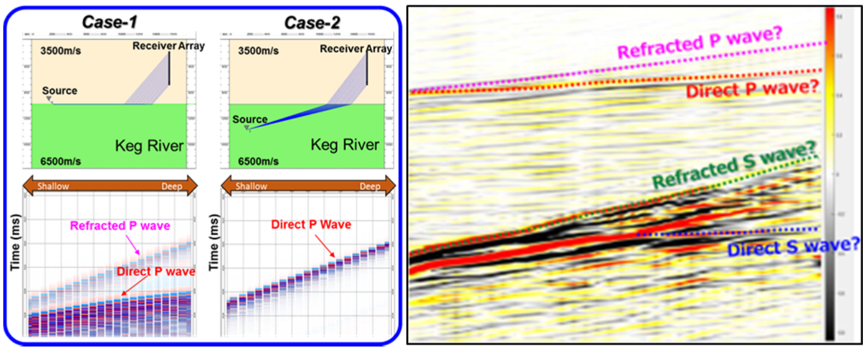

Figure 2. Comparison between waveform modeling of microseismic in 2 cases (left) and observed microseismic data (right). In the first case of the left figure, microseismic hypocenter locates at very close to Keg River carbonate, while in case 2, within Keg River. The observed data looks similar to the case-1, which implies that a faster arrival is refraction phase.

Method / Workflow

We chose 1 hydrofracturing stage of a certain well for the analysis where microseismic events are located below reservoir according to the vendor's analysis. This is one of the multi-pad drilling wells and the pad is constituted of 20 wells. In this well, hydrofracturing was carried out in 24 stages in 2013. The hydrofracturing in the stage was carried out around 8 hours. Microseismic was recorded in 2 deviated wells, A-array and B-array. Each array has 36 receivers (figure 1). Microseismic was recorded from the start of pumping to the end of pumping. The stage is located between A and B array.

From continuous recorded data, microseismic events were detected by short-time average and long-time average (LTA/STA) method. We confirmed 2 types of events which indicate direct arrivals and refracted arrivals by waveform modeling of microseismic for a synthetic subsurface model with constant velocity. We found that when microseismic source is located much close to the top of Keg River formation, refraction are mixed with direct arrivals and in that case gentler events would be direct arrivals (figure 2). Also, when microseismic source is located within Keg River formation, only direct arrivals whose slope is the same as the refraction in case 1 of figure 2 are observed. Similarly, these results are observed in the previous studies such as Zimmer (2010). Therefore, we did not use automatic picking to avoid mispicking (Shapiro, 2015) and manually picked gentler moveout phase as direct arrivals referring forward modeling results even if it arrived later than refraction on the basis of the observation in the forward modeling. For direct wave arrival time picking, we utilized array seismogram volumes (Shimoda et al., 2015) which are consisted of high correlation coefficient event pairs in order to increase confidence of the picking.

We constructed a tilted layered orthorhombic velocity model by sonic log and microseismic data of perforation shots. P-wave velocity (Vp) and S-wave velocity (Vs) from sonic log of a reference vertical well 3 km away from our target area were used. We confirmed that lateral change of geology is not significant between the reference well and the target area by gamma ray log (figure 3). From the well log, we divided zones in 8 layers. Traveltime inversion scheme was applied to optimize the velocity model using the perforation shots. The perforation shots in 5 stages are chosen for the inversion, the target stage and next to the target stage of 4 directions. Vp and Vs of the model were obtained by multiplication of a sonic log factor to the log which compensate log frequency and microseismic frequency. The sonic log factor is applied sequentially from 0.85 to 1.05 with 0.05 increment. In each sonic log factor, Thomsen parameters, δ1, δ2, δ3, ε1, ε2, γ1, γ2 are optimized in each layer iteratively minimizing residuals between observed and calculated traveltime. The Thomsen parameters are constant in each layer. Tilted angle of the layers were estimated from interpreted horizons with 3D seismic and direction of symmetry planes of the model are estimated from maximum horizontal stress of the field in advance. Due to ambiguity of S-wave picking caused by overlapping of direct arrivals and refracted arrivals of S-wave, 20 times weighting factor was applied on P-wave against S-wave. The final optimized results were determined by considering the residual of the inversion.

A grid search method using the velocity model and traveltime of P and S wave picked was applied for hypocenter locationing. Also, 20 times weighting factor on P-wave was applied in the grid search. A location with minimum residual of traveltime was chosen as a hypocenter. Grid size was set as x: 5m, y: 5m z: 2.5m.

Results / Discussions

Figure 4 shows our velocity model results. All of the Thomsen parameters within the reservoir are plotted between 0.2 and 0.4. Yu and Shapiro (2014) constructed orthorhombic velocity model in Horn River Basin by simultaneous inversion with rock physics constraint and δ, ε, γ of Yu and Shapiro's study are all plotted within 0.2 to 0.4 at reservoir zone. Geometric average of our orthorhombic Thomsen parameters are 0.2 to 0.25 which are consistent with their results. Residual of P-wave traveltime is around 2 millisecond although residual SH-wave traveltime is 28 millisecond.

Figure 5 shows that our hypocenter results and the previous vendor's results. There is no large discrepancies of horizontal distribution of hypocenters between ours and vendor's. However, vertical distribution is completely different. Most of residual of our hypocenter locationing is lower than 10 millisecond. This indicates that each hypocenter includes locationing error of around 40 m in maximum if assumed P-wave velocity is 4000 m/s. Even if we consider the locationing error, most of the hypocenter of our results will be plotted within the reservoir. Therefore, our improved shallower relocated hypocenters were obtained by both the new layered orthorhombic velocity model with sonic log and careful direct arrival picking.

Qualitatively, vertical location of hypocenter is deeper if using refracted arrivals, not direct arrival events (Zimmer, 2010) and in his paper, the improved events are distributed within reservoir. Zimmer (2018) indicated that microseismic hypocenter distribution close to heel tends to be broader vertically and the distribution includes erroneous results in the view of probabilistic. Although our study does not apply probabilistic approach and not utilize refraction on velocity modeling contrary to Zimmer (2010), moreover high weighting factor is applied on P-wave both in the traveltme inversion and the event locationing, the results are consistent with previous papers performed in Horn River basin (e.g. Zimmer, 2011). On the other hand, we did not examine which factor was more contributed to the hypocenter improvement. In the next step, we will evaluate quantitatively location change and understand how the direct arrival picking and velocity modeling contribute on the event locationing separately.

Conclusion

In Horn River Basin, picking direct arrivals of P-wave is ambiguous and that of S-wave is difficult due to refracted arrivals overlapping on the direct arrivals. However, by picking gentler moveout events of P-wave and S-wave as direct arrivals referring the forward waveform modeling and accurate traveltime estimation via construction of the tilted layered orthorhombic velocity model using sonic log with high weighting factor on P-wave, microseismic event distribution was located within the reservoir even considering the location residuals. Our Thomsen parameters have similar trends with the previous papers reported. This indicates that this processing scheme was carried out successfully at the target area in Horn River basin for accuracy improvement of microseismic locationing.

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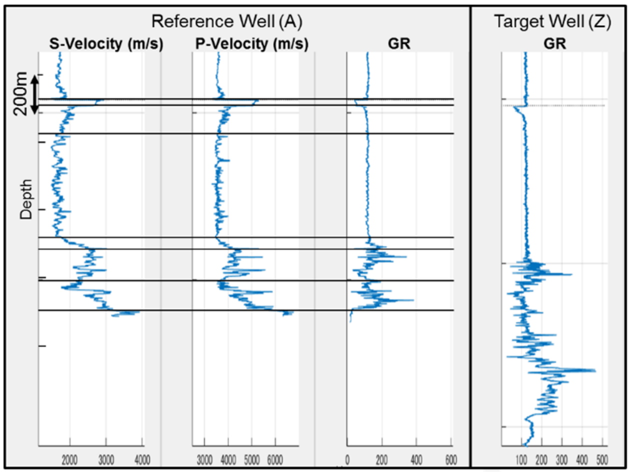

Figure 3. Comparison of gamma ray (GR) log between a reference well and a target well. The GR log is quite similar among them. Layers for our velocity model S-wave velocity and P-wave velocity used for the model are also shown.

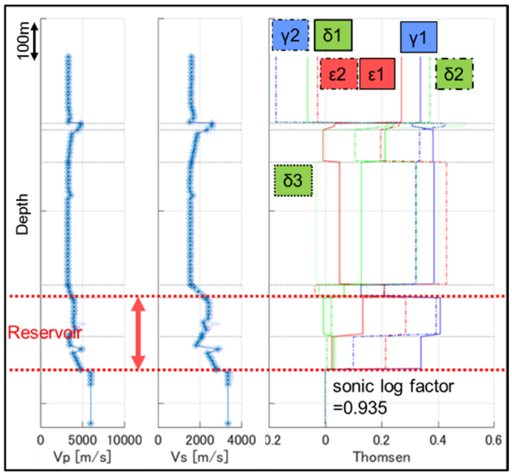

Figure 4. Results of our velocity model constructed. Most of Thomsen parameters are from 0.2 to 0.4 within a reservoir.

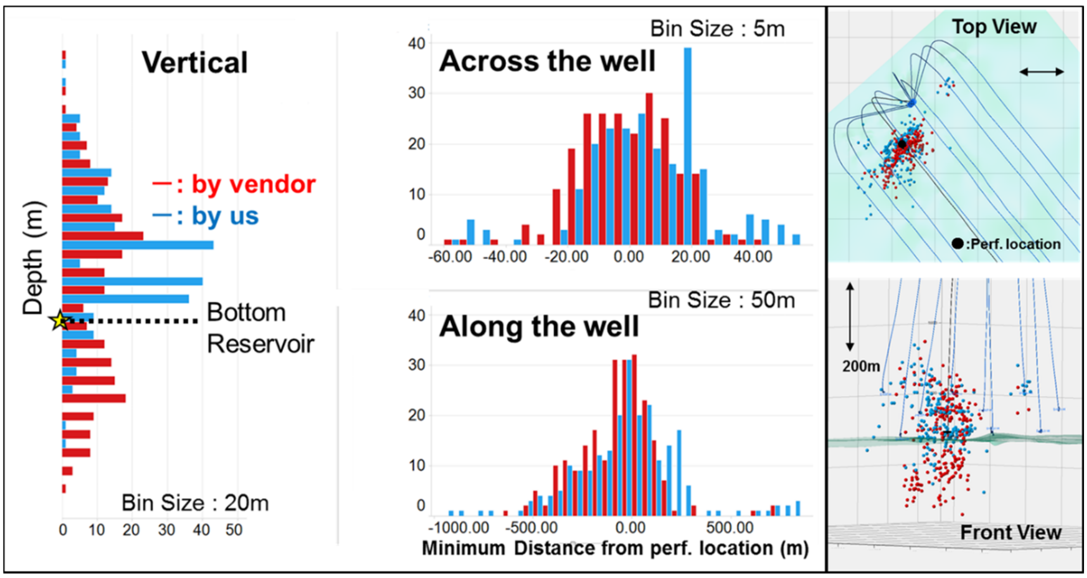

Figure 5. Comparison of microseismic location between our results and the vendor's results. On the left side a histogram of vertical location, on the middle, histograms of spatial location, across the target well (upper) and along the well (lower), on the right 3D view of the location from top view (upper), from front view of the well (lower).

References

Belayouni, N., Katz, D., A., Grechka, V., and Christianson, P., 2017. Microseismic event location with direct and reflected waves: A Woodford case study, 87th Annual International Meeting, SEG, Expanded Abstracts

Coffin, S., Hur, Y., Abel., J., S., Cuvler, B., Augsten, R., and Westlake, A., 2012. Beyond first arrivals: improved microseismic event localization using both direct-path and head-wave arrivals, 82th Annual International Meeting, SEG, Expanded Abstracts

Grechka, V., and Yaskevich, S., 2014. Azimuthal anisotropy in microseismic monitoring: A Bakken case study, Geophysics 79(1) KS1–KS12.

Fuller, B., L. Engelbrecht, R. V. Dok, M. Sterling, M. Kniffin, and L. Walter, 2010. Seismic wave phenomena and implications for accuracy of microseismic results: Recorder, 35, 36–37

Maxwell, S., C., 2014. Microseismic Imaging of Hydraulic Fracturing: Improved Engineering of Unconventional Shale Reservoirs, SEG Distinguished Instructor Series, No. 17 p197.

Shapiro, S., 2015. Fluid-Induced Seismicity, Cambridge University Press, p289

Shimoda, N., Reshetnikov, A., and Shapiro, S., A., 2015. Arrival time picking on common receiver gather for borehole array datasets, 85th Annual International Meeting, SEG, Expanded Abstracts

Yu, C., and Shapiro, S., 2014. Seismic anisotropy of shale: Inversion of microseismic data, 84th Annual International Meeting, SEG, Expanded Abstracts

Yuan, D., and Li, A., 2017. Joint inversion for effective anisotropic velocity model and event locations using S-wave splitting measurements from downhole microseismic data, Geophysics 82(3) C133–C143.

Zhang, Z., Rector, J., W., and Nava, M., J., 2015. Improving microseismic event location accuracy with head wave arrival time: Case study using Marcellus shale, 85th Annual International Meeting, SEG, Expanded Abstracts

Zimmer, U., 2010, Localization of microseismic events using head waves and direct waves, 80th Annual International Meeting, SEG, Expanded Abstracts

Zimmer, U., 2011, Challenges and solutions in locating and interpreting microseismic events from surveys in the Horn River Basin: CSPG, CSEG, & CWLS Convention.

Zimmer, U., 2018. Probabilistic estimation of fracture dimensions from microseismic and other data, 88th Annual International Meeting, SEG, Expanded Abstracts