AAPG Search and Discovery Article #90187 © CSPG/CSEG/CWLS GeoConvention 2013, Integration: Geoscience Engineering Partnership, 6-12 May 2013, Calgary, AB, Canada

Microseismic event locations for deviated boreholes

Amna Feroz, University of Alberta, Canada
aferoz@ualberta.ca
and
Mirko van der Baan ,University of Alberta, Canada

Summary

Microseismic data processing is the first step towards fracture evaluation, generated in response to fluid/steam injection in the reservoir. Improvements in processing workflow leads to accurate event locations and alternatively to better interpretation. An integrated workflow is generated to accurately locate the microseismic events by using grid search algorithm and incorporating covariance and hodogram analysis to remove 180 degree ambiguity in back azimuth, this workflow uses S-P wave arrival time thus eliminating the source origin time error. This workflow results in accurately locating the microseismic events which will be analyzed in near future of shear wave splitting analysis.

Introduction

Several methods are used to enhance the production from shallow heavy oil reservoir in Canada, Including grids of vertical injector/ producers, horizontal injector/producers, Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS) [*McGillivray*, 2005]. Microseismic data for this study belongs to cyclic steam injection (CSS) experiment, several horizontal wells are drilled in the reservoir to bring the bitumen to the surface. Microseismic events are generated in response to the geomechanical changes occurring in the underground reservoir, which is sensitive to several quantities (e.g., stress, lithology, fracture density and orientations) and physical quantities (velocity, impedance and density).In order to understand the geomechanical changes occurring in the reservoir, first step is to find out about the fracture network/density and anisotropy of the reservoir which will be extracted from microseismic events recorded over time.

Multi-component microseismic data is mostly acquired during reservoir monitoring experiment [*Wikel et al.*, 2012], and basic principle of microseismic monitoring is the recording of these seismic waves to identify the locations where rock failure occurred. Ultimate goal of processing is to find the hypocenter of microseismic events recorded by the geophone array in a single or multiple boreholes. There are several aspects of microseismic data processing, including tool orientation, P and S wave picking and event location. And accuracy of the processing results not only depends on the signal to noise ratio but also on spatial distribution of the receivers [*Eisner et al.*, 2011]. Correctly orientating the tool and locating the events will also yield to better estimation of azimuthally dependent quantities required from splitting analysis [*Wikel et al.*, 2012]. Source location of microseismic event is the most fundamental measurement in microseismic monitoring experiment [*Usher et al.*, 2011]. Therefore the most important aspect of this study is to accurately locate the source.

Theory and/or Method

Most desired output from processing is source location. Taking into account the deviation of the borehole, an integrated approach is used for microseismic event location. Polarization analysis is based on the covariance method of three component data x, y and z. And covariance matrix C is evaluated as

$$C_{ij} = \frac{1}{N}\sum_{i=1}^{N} x_{ij}x_{ik} \tag{1}$$

Where j and k are the component indices and ith is the sample of component and N is total number of sample in covariance analysis window. At first, covariance method is used to find azimuth of the ray at each receiver point.

$$C = \begin{pmatrix} C_{xx} & C_{xy} & C_{xz} \\ C_{xy} & C_{yy} & C_{yz} \\ C_{xz} & C_{yz} & C_{zz} \end{pmatrix} \tag{2}$$

The covariance matrix C represents the polarization ellipsoid with the best fit to the real data. The three eigenvalues $\lambda 1 \geq \lambda 2 \geq \lambda 3$ and eigenvectors p1, p2 and p3 of the matrix C are associated to the principal axes of this particle motion ellipsoid. And principle axis of the ellipsoid fulfills the equation $(C - \lambda I)\, p = 0$ where I is the identity matrix. The directional cosine of the largest Eigen vector corresponding to the largest Eigen value defines the azimuth θ, defined counterclockwise from the positive x axis [*Bayer et al.*, 2012].

$$\theta = atan\left\{\frac{p_1(y)}{p_1(x)}\right\} \tag{3}$$

It is known that this method contains 180 degree ambiguity and gives two possible source directions. But hodogram analysis at every station can guide towards the correct source direction and azimuth. Calculated azimuth and recorded S-Pare input in the grid search method. Grid search algorithm is used to invert for the S-P travel time and azimuth. Look up table of theoretical S-P time and azimuth is generated. And event is located by minimizing the difference between the observed and actual S-P travel time and searching in the limited azimuth range, defined from previous step. Hence forward problem for event location is solved. One of the main advantages of using S-P travel time is evident from equation (4) and (5)

$$\Delta t = T_s - T_p \tag{4}$$

$$D = \Delta T\, V_p V_s / (V_p - V_s) \tag{5}$$

Hence source location coordinates are free from the origin time error, but accuracy will depend on the velocity model. Figure (1) shows the workflow of how events are located in this particular case, where only one deviated observation well is drilled in the field. Basic principle is first applying covariance analysis and then hodogram analysis at each receiver location. If the possible event location is between 0 to 90 or 180 to 270(estimated from covariance analysis), then NMO at each point will be different and event will be located by grid search but limiting the search within the above mentioned azimuth. But if the event lies perpendicular to well trajectory then NMO will be symmetrical along the trajectory. Then hodogram analysis at each station will resolve the possible direction of the source. And then grid search is done in the limited quadrant specified by the azimuth.

Examples

To better understand and gain confidence on the above mentioned workflow of event location. We generated synthetic waveforms with homogenous velocity model where event occurred perpendicular to the receiver array .Each receiver array consists of ten 3C geophones and is at equal distance from the source. This geometry is created so the NMO is same at both the receiver arrays. Results of covariance analysis shows the same source direction for both events but with prior knowledge of the source location confirms the fact that covariance analysis is unable to resolve the 180 degree ambiguity associated with source azimuth. And it also shows that azimuth varies up to 10° in this particular geometry. Therefore particle motion vector found at different receivers should converge back to the source location. So by plotting the particle motion at first and last receiver and extending it to find the potential convergence point/direction can possibly resolve the 180 degree ambiguity. To test this idea we plotted the particle motion for case 1 (receiver array 1) and case 2 (receiver array2).

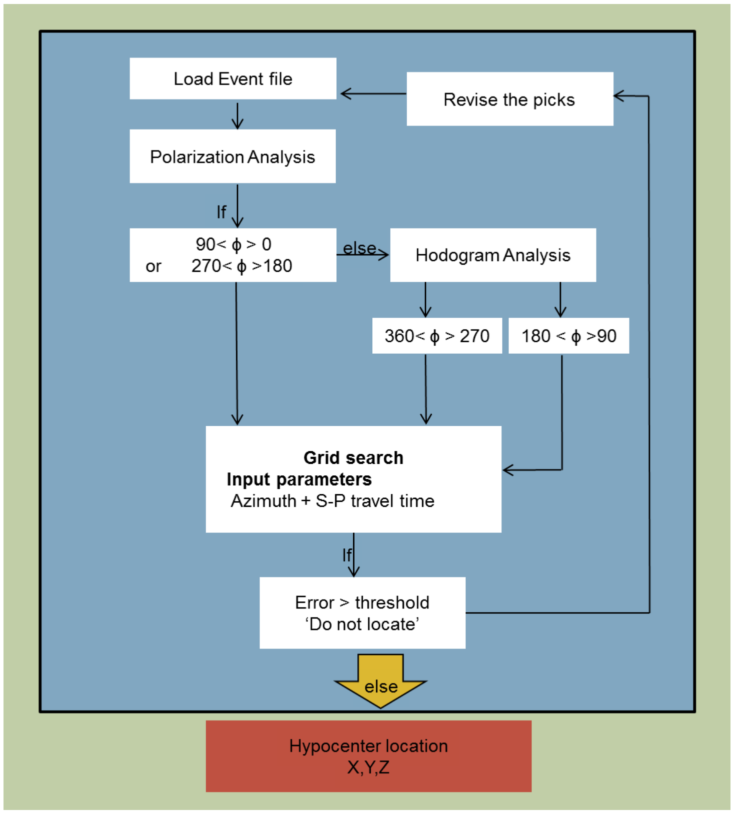

Figure 1. Flowchart showing the workflow followed to locate the microseimic event.

Particle motion vector at both receiver arrays tends to converge to southeast and northwest, indicating the correct source direction. After finding the correct direction of the source, grid search for hypocenter location was done but limiting the search to the quadrant indicated by the convergence direction. The hypocenter locations were recovered with good accuracy and removing 180 degree ambiguity.

After applying the workflow on synthetic data, we started processing the real data set. Data for this study was acquired during a monitoring experiment over a heavy oil reservoir. Acquisition geometry is shown in figure 2a. Raw microseismic data had to be filtered, picked and finally located.

When the tool in lowered into the borehole during acquisition, it rotates and results in an unknown orientation so first step was to orient the tool. This is done by using source azimuth (using perforation shot), inclination and azimuth of the well at each receiver point and then calculating 3×3 rotation matrix for each receiver. It rotates the data from z, h1 and h2 into Z, Y and X component.

Then data was filtered using two different band pass filter, events recorded in the beginning of the steam injection cycle were filtered between 20 to 450 Hz whereas events recorded after 1.5 to 2 years into the steam injection experiment were filtered between 20 to 200 Hz. Next step was to pick the P and S wave on all 3C data, autoregressive technique by [*Sleeman and Eck*, 1999] is used to pick P wave whereas S wave was picked manually. QC has been done to remove the false events or noise files before event locating.

A velocity model is required to locate the events. It was constructed by smoothing and blocking of sonic log, also calibrated with the available perforation shots. Once a satisfactory model has been obtained, a lookup table was created. Event location workflow was followed as shown in figure 1 to locate the events. Figure 2 b shows the events located map of the events recorded in June 2005. Work is still in progress to improve the velocity model to minimize the uncertainty in the event location.

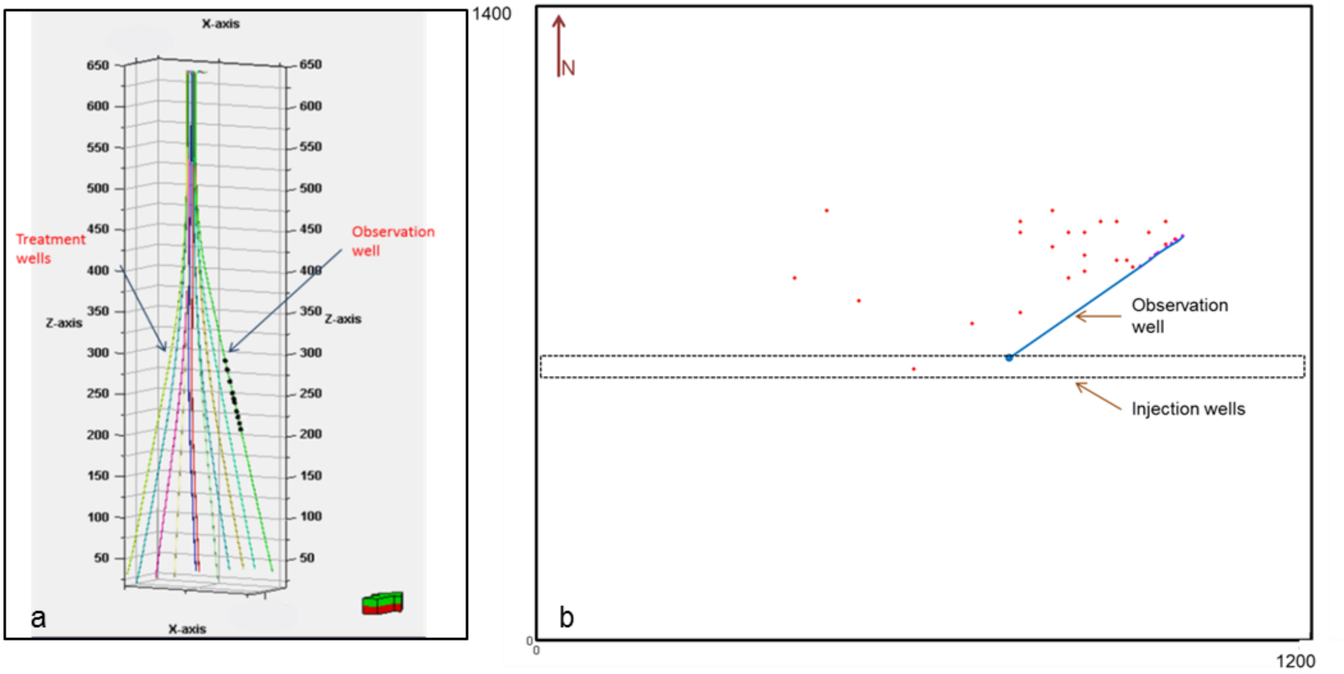

Figure 2. a) Acquisition geometry of treatment wells and observation well on pad X. b) Plain view of the Microseismic event location map of events recorded in June 2005 in a deviated borehole at Pad X.

Conclusions

Incorporating particle motion vectors helped to eliminate the 180 degree ambiguity in locating microseismic events for this particular case, where only 1 single deviated observation well is present in the field. And error in event location due to velocity model will be reduced by updating the velocity model with time using the perforation shots and sonic logs. This integrated approach in locating microcosmic event will significantly reduce the errors.

Acknowledgements

We sincerely thank the sponsors of the Microseismic Industry Consortium for supporting this research, and an anonymous company for providing the data and permission to show the results.

References

Bayer, B., R. Kind, M. Hoffmann, X. Yuan, and T. Meier (2012), Tracking unilateral earthquake rupture by P-wave polarization analysis, Geophysical Journal International, 188(3), 1141-1153,

Eisner, L., V. Grechka, and S. Williams-Stroud (2011), Future of Microseismic Analysis: Integration of Monitoring and Reservoir Simulation, AAPG., 2011 Annual Convention, 10-13 April, Houston, Texas

McGillivray, P. (2005), Microseismic and time-lapse seismic monitoring of a heavy oil extraction process at Peace River, Canada, CSEG Recorder, (January), 5-9.

Sleeman, R., and T. V. Eck (1999), Robust automatic P-phase picking: an on-line implementation in the analysis of broadband seismogram recordings, Physics of the Earth and Planetary Interiors. 113(1-4), 265-275.

Usher, P. J., D. A. Angus, and J. P. Verdon (2011), Influence of velocity model and source frequency on microseismic waveforms : some implications for microseismic locations, , 1-9.

Wikel, K., R. Kendall, and P. Energy (2012), Processing 3-C Heavy Oil Data for Shallow Shear-wave Splitting Properties, cseg.ca, 1-4.