Passive Seismic Monitoring: Listening to What The Reservoir Is Saying

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Introduction

Passive seismic monitoring of microearthquakes induced during oil field operations is a quickly growing technology for mapping fractures. Induced fractures or movements of existing fractures during hydraulic fracture stimulations and secondary injections result in microearthquakes that can be detected with sensitive downhole geophones. By passively "listening to the reservoir" the microseisms can be used to directly characterize the fractures themselves. In this paper, an overview of the technology and various case studies will be presented.

Significant seismic deformation is induced during hydraulic fracture stimulation to enhance permeability in tight gas reservoirs. These microseisms can be directly used to characterize the resulting fracture network and improve the stimulation design. Of particular interest in this application is that the completion engineers are the main clients, and directly utilize the geophysical data to improve the design. The microseismic image are used to investigate the effectiveness of the fracturing, image the geometry and growth, assess fracture complexity associated with interaction with pre-existing fractures or faults, and often test effectiveness of high tech well completions.

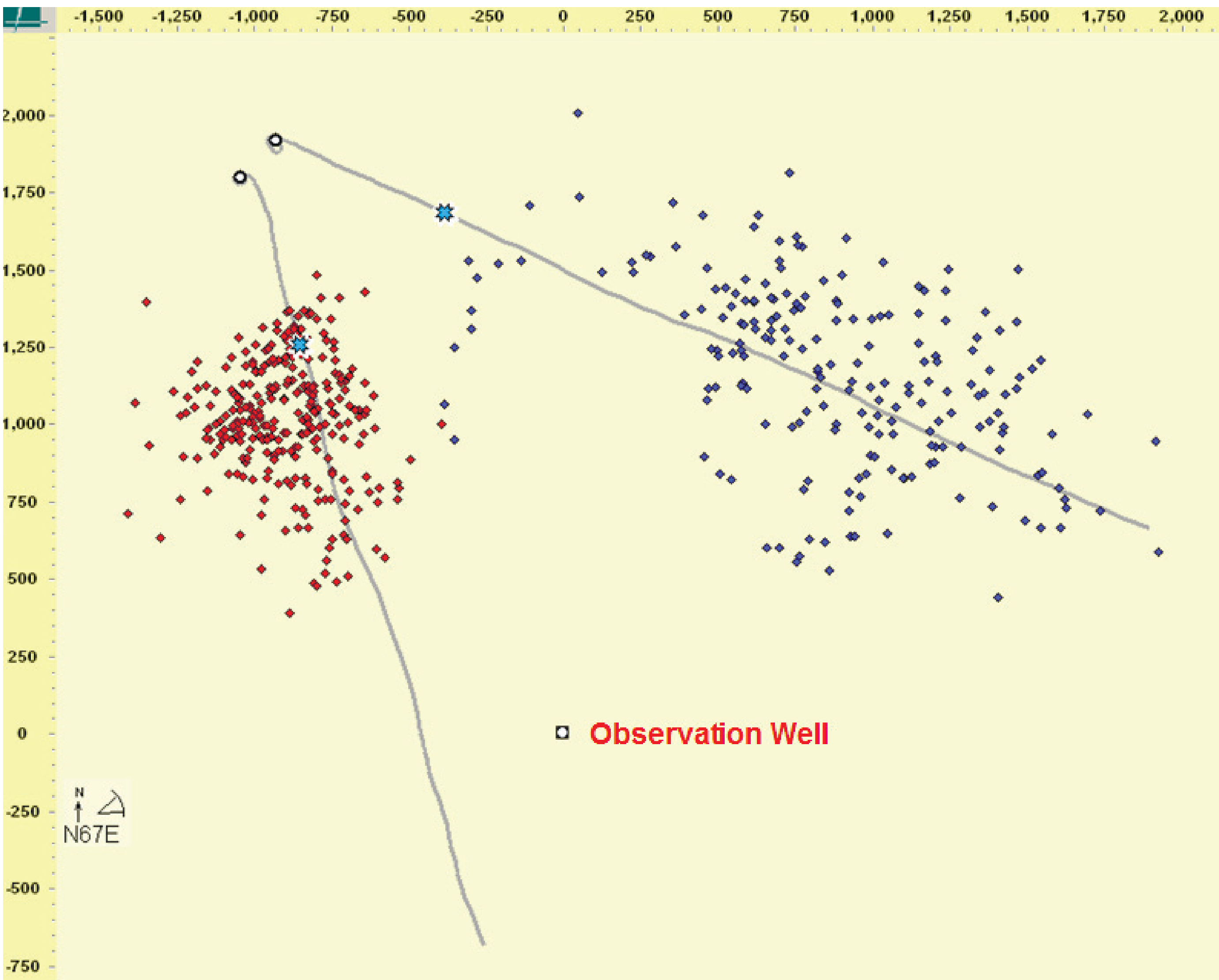
Microrseisms can also occur during injections for secondary recovery. In cases where injection pressures are below so-called frac pressure, pore pressure increases can induce shear failures. Of particular note in the WCSB is the application of microseisms to image steam injections. During steam injection, thermal stress changes and material property changes further enhance the probability of inducing shear failure. For example, in Cold Lake Imperial Oil extensively utilizes passive monitoring during routine operations in their cyclic steam operations.

Microseismic signals are typically recorded with downhole sensors. Monitoring with surface sensors is problematic due to increased noise levels and signal attenuation particularly in the near surface. Often using an array of 3C geophones in a single borehole close to the target, hypocentral locations of the source position of the microseisms are computed by inverting relative arrival times of the compressional and shear waves and also using polarization or hodogram analysis to determine a unique 3D location. A velocity model is also required which is typically generated from dipole sonic logs and used to forward model expected arrival times to match the observed times. In addition to location, other source attributes such as the magnitude of the event can also be computed. This information is then typically used to produce a 4D image of the fracture dynamics. Quality control of the image is critical during interpretation to understand the data quality, sensitivity and resolution. The microseisms are generally very small magnitude and the signal strength is attenuated with travel path. This generally limits the effective detection range from a monitoring well, although two or more simultaneous monitoring wells can effectively extend the monitoring range and offer more accurate event locations if signals are recorded on sensors in more than one well. The actual detection distance depends on background noise conditions, seismic attenuation and the microseismic source strength, although targets out to 1 km have been imaged in western Canada.

Hydraulic Fracture Stimulations

The Barnett Shale is one of the main areas where microseismic monitoring is extensively used. Barnett stimulations utilize injections of large volumes of water to stimulate shear slip on pre-existing fractures, resulting in high quality microseismic images of the fracture complexity resulting from the interaction with the pre-existing fracture networks. The technology is also extensively used in other fields, including growing application in various fields in Canada. In addition to tight gas, CBM and other unconventional gas plays offer applications where the technology can be used to understand the mechanics of the stimulations.

Figure 1 shows a recent Canadian example where the stimulation design of horizontal laterals was optimized to ensure the stimulation of the complete lateral length.



Integration of the microseismic data with other reservoir information including seismic reflection volumes also offers the possibility to understand the impact of reservoir structure on the hydraulic fracture geometry.

Reservoir Monitoring

Microseismic imaging for reservoir monitoring provides details of the dynamics of stress changes during reservoir operations. Although the technology is similar to mapping hydraulic fractures, the main challenge is related to how the reservoir engineer will use the data. In order to uniquely interpret the microseismic data caused by most reservoir processes, it is important to consider the geomechanical conditions of the reservoir. In the case of steam injection for example, thermal expansion results in significant surface uplifts. These surface heaves can be detected using a number of technologies, although tiltmeters offers the highest sensitivity to measure small deformations. The observed surface deformation can be inverted for the the underlying reservoir strain causing the surface heave. Integrating this reservoir strain with the microseismic deformation associated with stress changes offers the opportunity to characterize two critical aspects of the geomechanical response of the reservoir. Together with temperature and pressure, strain can be directly compared with, and used to calibrate and validate a geomechanically coupled reservoir simulation. In the case of steam injections, commercial geomechanical reservoir simulators are commonplace due to the important role of the geomechanical state to the steaming of the reservoir. Calibrating these simulations with direct geophysical observation is critical for reservoir engineers to calibrate the long term performance of the thermal operations, and also to provide ongoing monitoring to avoid unwanted steam breaches.