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Microseismic Deformation Rate Monitoring

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Abstract

Microseismic monitoring of hydraulic fractures is an important tool for imaging fracture networks and optimizing the reservoir engineering of the stimulation. The range of magnitudes of the recorded microseisms depends at the lower limit on the array sensitivity; while the upper limit varies significantly from site to site. In this paper the variation in the microseismic magnitude range is examined and compared with the injection and site characteristics. Although there are numerous potential factors effecting the seismic deformation, the energy of the pumping and state of stress appear to be the two dominant factors. However, interaction with pre-existing faults also results in increased deformation. Ultimately, this can potentially be used to design the stimulation to maximize the deformation. Characterization of the seismogenic potential is also important for seismic hazard assessment, as well as the design of passive monitoring.

Introduction

Over the last few years, microseismic imaging of hydraulic fracture stimulations[1] has become a widespread diagnostic technology. Microseismicity is used to image fracture geometry dynamics and optimize stimulations in a wide variety of settings. The resulting images are useful in both simple and complex fracture networks and able to detect fracture complexity resulting from injections in naturally fractured reservoirs. Particularly in North America, microseismic imaging has become a standard in development of both conventional and unconventional resource plays.

Generally, the temporal locations of microseisms detected in an offset observation well are used to monitor the growth of the hydraulic fracture geometry. In most cases the hydraulic fracture is being created by tensile failure of the rock resulting from injection of fluids at pressures exceeding the minimum principal stress level, although the deformation mechanism associated with the recorded microseisms appears to be shear dominated deformations. Microseisms typically contain significant shear wave energy suggesting substantial shear deformation in the source of the microseismic energy, although fracture opening could occur simultaneous with the shear deformation and play a role in the permeability enhancement. One model to explain the shearing is stress changes or pore pressure increases associated with the primary hydraulic fracture[2], leading to induced shear failure. However, dog legs, offsets or other complexities along the hydraulic fracture could also result in localized shear deformations along a conventional tensile fracture. Intersections of a hydraulic fracture with oblique angle pre-existing fractures could also lead to localized shear deformation. Microseism signal analysis can be used to investigate aspects of the source characteristics of the shear deformation, although this may or may not provide insight into the stimulation objective of creating a permeable fracture possibly containing a fluid conductive proppant pack.

An important microseism source attribute is the source strength or magnitude[3]. Source strength is best quantified by seismic moment (product of shear modulus, shear displacement and area) which can be expressed with a moment magnitude scale, analogous to the well known Richter Magnitude scale. Investigating source strength has proven valuable in determining the effective detection range, by simply plotting magnitude versus distance between the microseisms and seismometers. However, the spatial extent of the seismic deformation has been postulated to image the extent and density of a stimulated fracture network in the Barnett Shale, and appears to provide a useful attribute that correlates with gas production in a case study examining several wells[4].

Generally, the strength of microseisms recording during a hydraulic fracture is highly variable. For example, magnitudes spanning from magnitude -3 to -1 have been reported[4], although the range is likely even larger. Geothermal stimulations have reportedly resulted in significantly larger microseisms, up to +3 on the magnitude scale[5]. There are a number of factors that likely influence the strength of microseisms recorded during a treatment, although since the mechanism relating the