World's Largest Buried Microseismic Array

Sanish Field, Mountrail County, North Dakota

By Fred J. Anderson

Introduction

Managing the production of oil and gas from "tight" shale reservoirs is generating new technologies that help the petroleum geologist and reservoir engineer monitor the development and production of the oil and gas resource. One of these new technologies is "passive" microseismic monitoring. Whiting Petroleum Corp., recently selected Microseismic, Inc., to install and operate the largest microseismic monitoring array ever constructed to continually evaluate the ongoing development of oil and gas and reservoir conditions at Sanish Field just north of New Town (fig. 1) in the heart of Bakken production in North Dakota.

Traditional "active" seismic programs commonly set out sensors called geophones along a pre-determined survey line or grid. A seismic source such as a small explosion is initiated, which generates the seismic energy that travels through the ground and is recorded by the geophones as it is reflected and refracted by the different types of rocks and geologic units. The collected data provide a picture of the subsurface that helps to reveal the geologic structure of the underlying rock units. Passive seismic monitoring is similar, except that the source is generated within the ground by natural processes such as earthquakes or anthropogenic activities like hydraulic fracturing (hydrofracing) of reservoir rocks in oil and gas fields. Essentially we are simply listening to the ring of the bell, rather than ringing the bell and listening to the resulting sound.

The passive microseismic array in the Sanish Field consists of over 290 stations installed on an approximately three-fourths of a mile grid that covers an area of more than 150 square miles (just over four standard PLSS townships) (fig. 2). Like the much larger EarthScope Transportable Array (Anderson, 2009, 2010) the microseismic array is effectively a single, high resolution seismometer capable of detecting very small ground movements. In the Sanish Field these are principally the weak, high-frequency vibrations associated with reservoir rocks as they break and shift in response to pressure changes brought about by hydrofracing or the extraction of fluids, that is, oil, gas, and water. By recording these events, the array enables petroleum geologists to better monitor reservoir conditions as production and development of the oil and gas resource progresses.

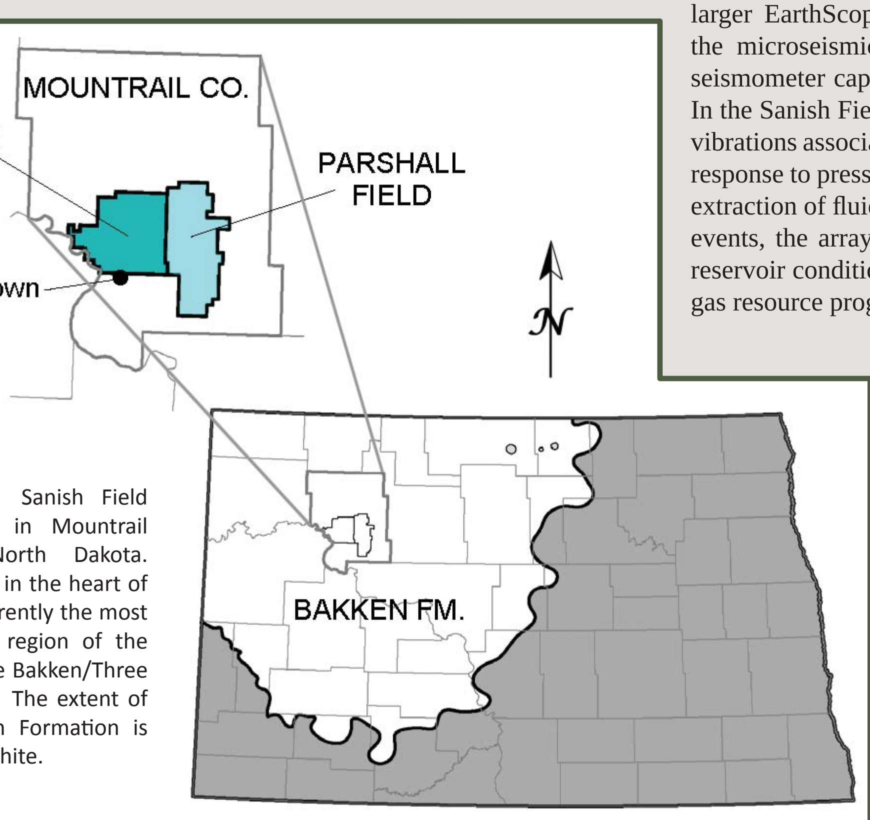

Figure 1. Sanish Field is located in Mountrail County, North Dakota. The field is in the heart of what is currently the most productive region of the basin in the Bakken/Three Forks play. The extent of the Bakken Formation is shown in white.

Located at each station is a buried seismometer (fig. 3) specifically designed to "hear" the acoustic signals emitted from reservoir rocks during hydrofracing and production. The recorded data are typically displayed as points (each point representing a single microseismic event) within a four-dimensional (volume & time) framework that is focused specifically on and at the reservoir scale (fig. 4).

Through the analysis of the locations and sizes of the recorded microseismic events (fig. 5), the effectiveness of reservoir production operations and hydraulic fracturing stimulations can be evaluated in near real-time.

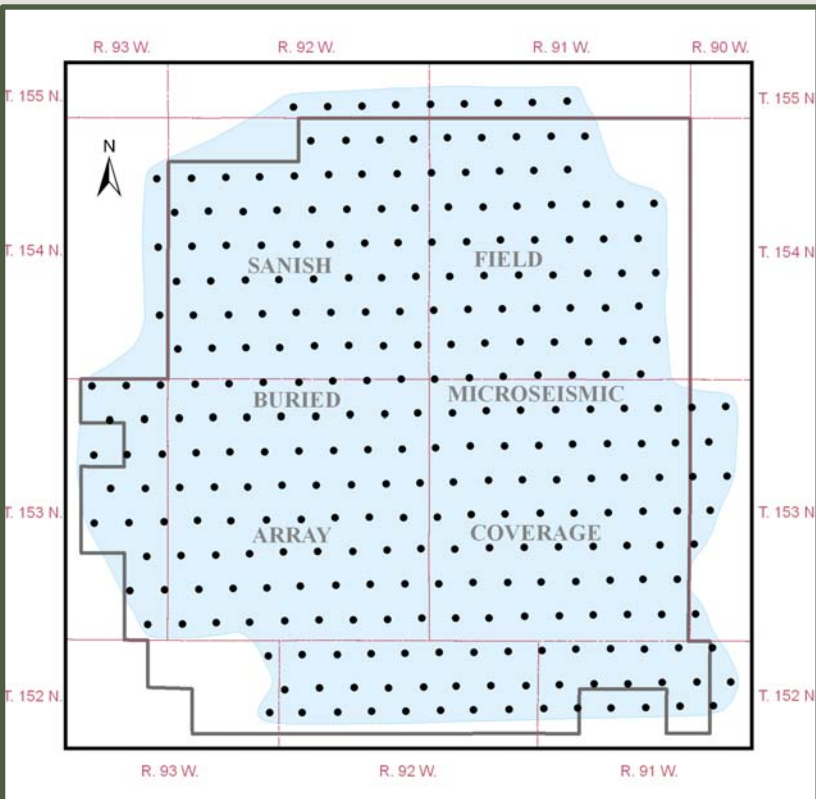

Figure 2. Approximate area of Sanish Field covered by the Sanish Buried Microseismic Array (shown in shaded blue). Approximately 150 square miles are covered by this surface array of seismometers designed to monitor reservoir conditions within the field in southwestern Mountrail County.

According to Stanford University geophysicist Mark Zoback, the amount of energy released by a microseismic event is roughly equivalent to the amount of energy released by a can of soda when it is dropped to the floor from about waist height.

Instrumentation

Most modern seismometers are broadband instruments capable of recording ground movements over a wide range of frequencies. Typically, they are designed to capture signals within a specified range but some, like the Guralp CMG-3T (fig. 7), are capable of recording across the full seismic spectrum (120 s* to 50 Hz). The Guralp CMG-3T is also an example of a "weak motion" seismometer. These highly sensitive instruments are used in

Size of a Seismic Array

The size of a particular seismic array is dependent on the spacing of individual geophones and the depths of interest. It is also dependent on the signal frequency of the source being monitored (for example, earthquakes, microseismic, etc.) such that, generally speaking, the higher the signal frequency, the smaller the overall geophone spacing needed to "resolve" it.

Microseismic events typically fall below the conventional earthquake magnitude scale of 0 to 10 and so are measured and reported on a negative scale from, say, 0 to -4 (fig. 6).

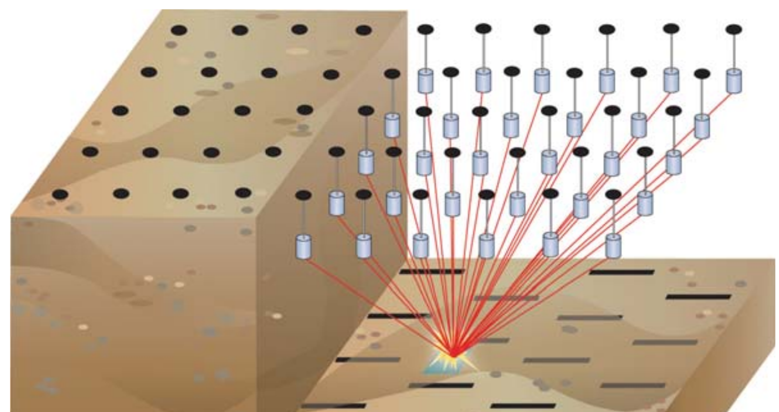

Figure 4. Schematic illustration of seismometers buried in the shallow subsurface in a dense array in order to effectively "resolve" a microseismic event at the oil & gas reservoir scale. (Modified from Microseismic, Inc., 2010)

* seconds per cycle (Hz^{-1})

Figure 3. Buried microseismic monitoring station in the Sanish Field. The stations were installed during the winter of 2009. Each location contains a buried seismometer, solar panel power supply, along with data recording and transmitting equipment. A well pump-jack and tank battery can be seen above in the background. (Image courtesy of MicroSeismic, Inc.).

earthquake studies to detect minute vibrations from small local, moderate regional, and teleseismic events. The seismometers that are currently installed in North Dakota as part of the Transportable Array (TA) are of this type.

In microseismic monitoring, specially designed geo-phones, which are simply scaled-down versions of traditional three-component (3C) instruments, act as individual seismometers (fig. 8). They are designed to record the low-energy signals from very small localized events, such as the fracturing of rocks in an oil and gas reservoir during stimulation (hydro-fracturing) and pro-duction of the fluids.

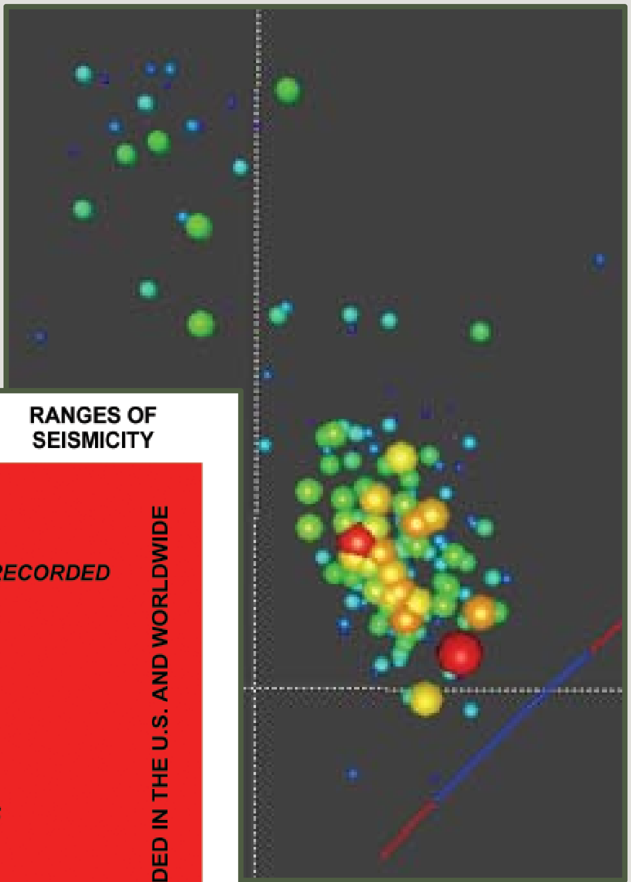

Figure 5. Example of microseismic events recorded around a well during a hydraulic fracture. Fractures are displayed in their four-dimensional context (Modified from Microseismic, Inc., 2010).

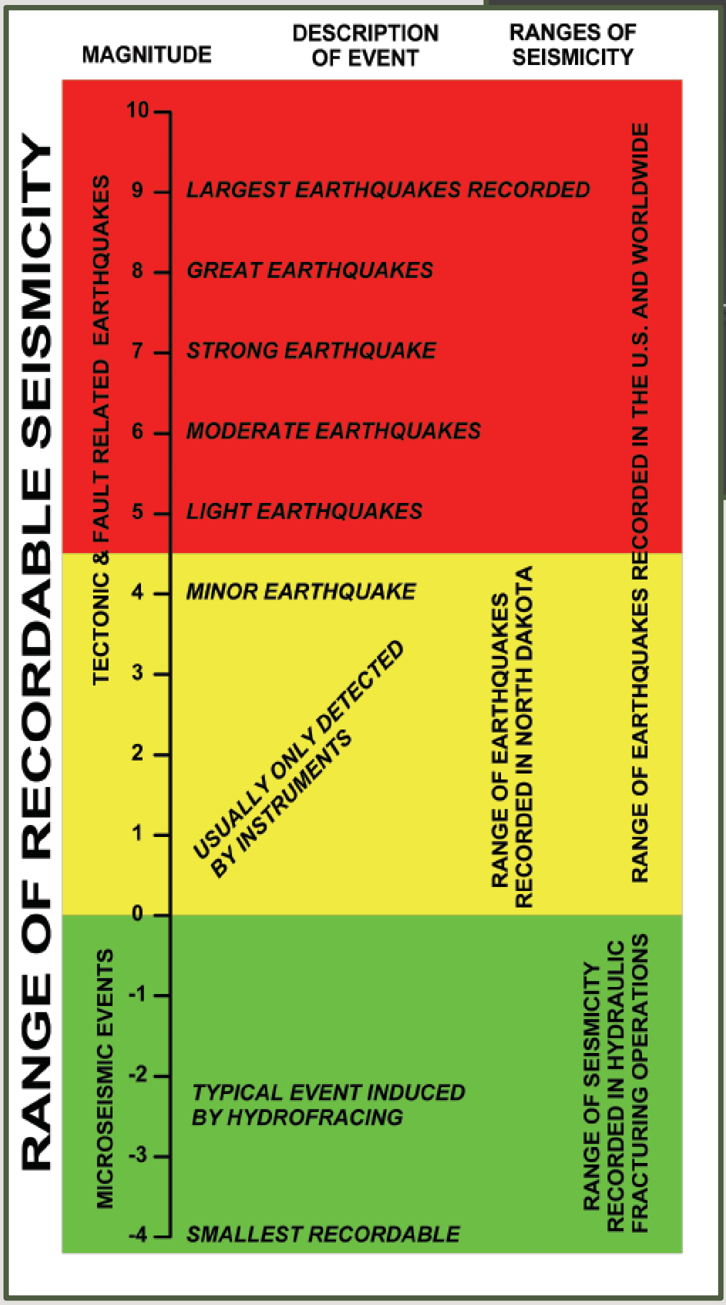

Figure 6. Comparison of the ranges in magnitude of conventional earthquakes and microseismic events. The range of microseismicity can be measured from magnitudes of 0 to -4. Conventional earthquakes that have occurred and been recorded in North Dakota have been measured from 0 to a magnitude of 4.5.

Other Uses of Passive Seismic Arrays (Volcanoes, Moonquakes, and the Oceans)

Microseismicity is one component of a multi-instrument program for monitoring active volcanoes throughout the world. Since the majority of earthquakes associated with volcanic processes occur at depths of less than 6.2 miles (10 km) and are commonly less than magnitude 3 (often occurring as swarms), an array of seismometers can listen to the pulse of a volcano's plumbing network as magma rises beneath it and puts stress on the overlying rocks. These rocks eventually

Figure 7. The Guralp CMG-3T broadband seismometer is used for recording and measuring earthquakes that occur around the world. This type of seismometer is rugged in design and can be quickly installed and removed for use as temporary stations (IRIS, 2010).

Figure 8. A three-component (3C) seismic geophone used for the recording and measuring of microseismic events that occur at the reservoir scale during reservoir production and stimulation operations. Each recording coil is oriented in a different primary direction (up-down, front-back, left-right), enabling the instrument to record ground motion in both the horizontal and vertical orientations. This type of geophone/seismometer has an operating frequency range of around 0.5 to 40 Hz.

fracture, creating mini-earthquakes that are detectable with these sensitive seismometers. The USGS currently uses passive seismic monitoring arrays at five volcano observatories (Guffanti et al., 2009) located in Alaska, Hawaii, Washington, California and Yellowstone National Park (fig. 9).

Collections of seismometers formed into passive seismic "arrays" were used on the moon during the manned lunar landings phase (1969-1972) of the Apollo space program to investigate potential seismicity on Earth's nearest neighbor (fig. 10). Seismometers placed near the landing sites of the Apollo 11, 12, 14, 15, and 16 lunar modules continued to transmit seismological data back to Earth until September 1977 (although the Apollo 11 seismometer broke down after only three weeks). It was from these studies that "moonquakes" were detected and the internal structure of the moon was determined.

Ocean Bottom Seismometers (OBS) are multiple-sensor passive/active seismic instruments designed specifically for deployment on the ocean bottom (fig. 11). These instruments support various seismic research programs throughout the world's oceans, including studies on mid-ocean ridge volcanism, ocean basin tectonics, and the structure of continental margins. Funded by the National Science Foundation, a fleet of OBSs is maintained and operated by the Lamont-Doherty Earth Observatory at Columbia University, the Institute of Geophysics and Planetary Physics at Scripps Institution of Oceanography and Woods Hole Oceanographic Institution.

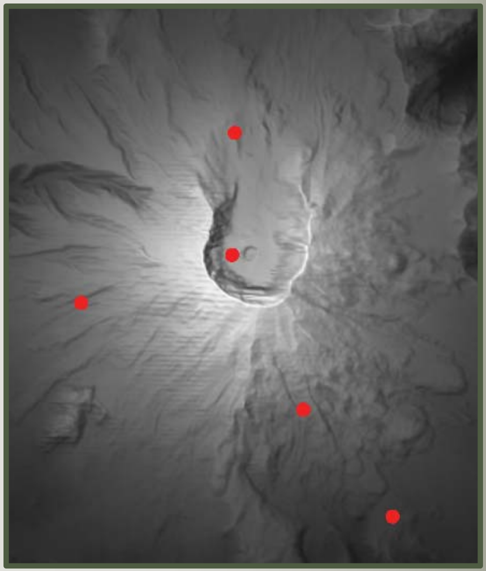

Figure 9. Example of a passive seismic array (red dots) currently monitoring seismic activity at Mt. St. Helens in southwestern Washington (PNSN, 2010).

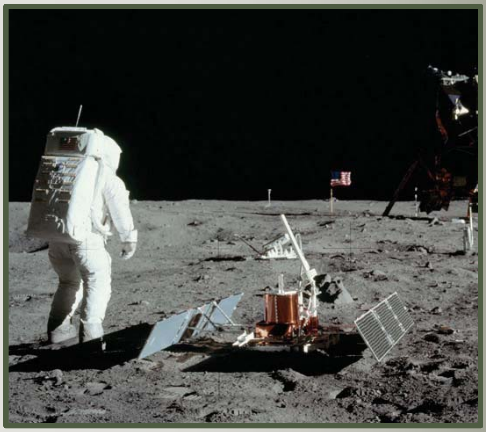

Figure 10. Astronaut Buzz Aldrin next to the Apollo II passive seismic experiment package deployment (Image from Lindsay, H., 2008).

Figure 11. An Ocean Bottom Seismometer (OBS) being readied for deployment by the USGS from the Woods Hole Science Center in Woods Hole, Massachusetts (USGS, 2007).

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