THE AMERICAN OIL & GAS REPORTER®

JULY 2009

The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Permanent Arrays Provide Critical Data

By Jose E. Nevarez and Chris Neale

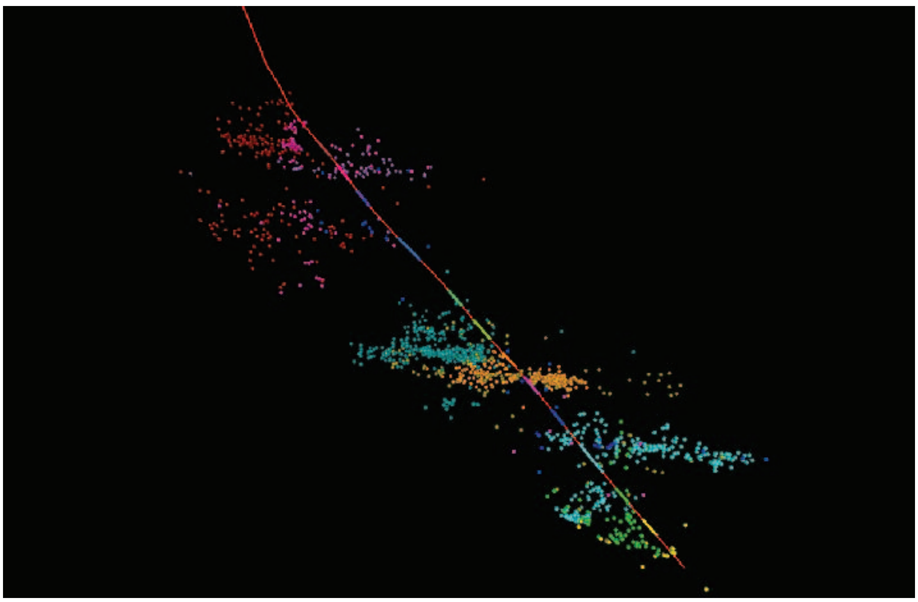
HOUSTON–The monitoring of induced microseismicity during the hydraulic stimulation of unconventional resource wells has become critical to understanding the complex interaction of forces at play during fracture operations. Traditional acquisition techniques using either downhole or surface-located geophone arrays have proven cost effective when used on a limited number of wells in a development area, but they cannot be economically utilized for high-density, front-loaded monitoring in a focused development area where hundreds of wells are drilled over a number of years.

Recent work in the Haynesville gas shale play of northern Louisiana and eastern Texas shows that it is commercially and technically feasible to perform high-resolution microseismic monitoring over areas of more than 25 square miles using a single sparse array of geophones buried to relatively shallow depths. These successes were made possible by ongoing advances in the beam forming technology used to process the data.

One such beam forming technique was developed for use with surface acquisition arrays, and has been adapted for use with the sparse near-surface arrays. Using a near-surface array and beam-forming processing allows the operator to rapidly develop the optimum completions strategy for the local geological conditions, and apply this knowledge early in the development cycle to maximize hydrocarbon recovery and minimize completions cost.

FIGURE 1

Surface Monitoring of Caney Shale Hydraulic Stimulation



The primary commercial driver for installing near-surface arrays currently is to optimize the completion of wells across a large area early in the development cycle. However, operators also are interested in using the arrays to investigate if depletion of an ultralow-permeability gas shale generates enough microseismicity to directly map individual well drainage areas and identify large fault/fracture systems that form pressure conduits over large distances.

Early development of microseismic monitoring focused on mapping geothermal resources to help locate wells in the highest-quality portions of the reservoir. Further research and development over the past decade, focused initially in the Barnett Shale, developed tools for mapping frac-induced microseismic activity. The observed frac patterns allowed the determination of several key geological attributes that must be understood to optimize unconventional resource development. Microseismic monitoring is now a valued tool for understanding local in-situ stresses, natural fracture properties, mechanical rock properties, and a host of other important geological, geomechanical and engineering factors.

Microseismic Monitoring

Figure 1 shows the results from monitoring the stimulation of a gas shale with a surface array. The east-to-west trend in induced fracturing indicates the local orientation of the maximum horizontal stress. In many cases, local stresses can vary significantly from regional trends as a result of local structure, faulting and fracturing, lithology, and offset production. The local trend in induced fracturing will be used to optimize the azimuth

FIGURE 2

Bore Hole Monitoring Geophones

of subsequent wells drilled in the immediate area. The monitoring of this well also provided feedback on the efficacy of variations in stage spacing, fluid types, proppant load and size, and pump rates to optimize the completion design.

Two commercial methods exist for monitoring microseismicity associated with hydraulic fracturing: downhole (well bore) data acquisition with "first-break" data processing, and surface monitoring with beam-forming processing.

Downhole/well bore monitoring consists of entering a cased hole and positioning a string of 10-40 three-component (3-C) geophones close to the events to be observed (Figure 2). The 3-C phones record both compressional (p) and shear (s) wave arrivals associated with nearby microseismic events, and first-break processing is used to locate the hypocenter of the events. Downhole monitoring can be very accurate when the observation string is within 500-1,000 feet of the microseismic events, but the limited aperture 1-D array causes event location accuracy to deteriorate rapidly with distance, depending on geological complexity and event magnitude.

Surface monitoring consists of deploying 1,000-plus channels of conventional 3-D seismic equipment in a radial array consisting of eight to 10 arms centered on the wellhead (Figure 3). Data processing from the surface array is similar to conventional 3-D reflection seismic processing where a large number of geophone channels are stacked or summed to amplify the highly attenuated signal from the microseismic events. The large 2-D aperture of the surface monitoring provides consistent and highly accurate lateral locations of the microseismic events, while vertical resolution is dependent on event magnitude and surface noise conditions.

Ideally, an operator would like to monitor most or all the wells drilled early in the development cycle to reap the financial benefits of rapidly optimizing well design based on knowledge of how the local geology and well completions interact. However, the cost to implement such a program with the established techniques is not commercially feasible. Downhole monitoring suffers from a relatively small volume of investigation, necessitating an impossibly large number of observation wells to monitor a typical 25-50 square mile development area. Surface monitoring requires centering the array on the pad with the stimulation equipment, requiring movement of the spread for each new well monitored.

Near-Surface Array

Ongoing development of microseismic monitoring-specific beam steering processing technology has led to an acquisition and processing system that combines many of the best attributes of downhole and surface monitoring, while overcoming the commercial limitations of both to provide commercially viable, high-resolution microseismic monitoring over very large areas at very low unit costs.

FIGURE 3

Surface Monitoring Array

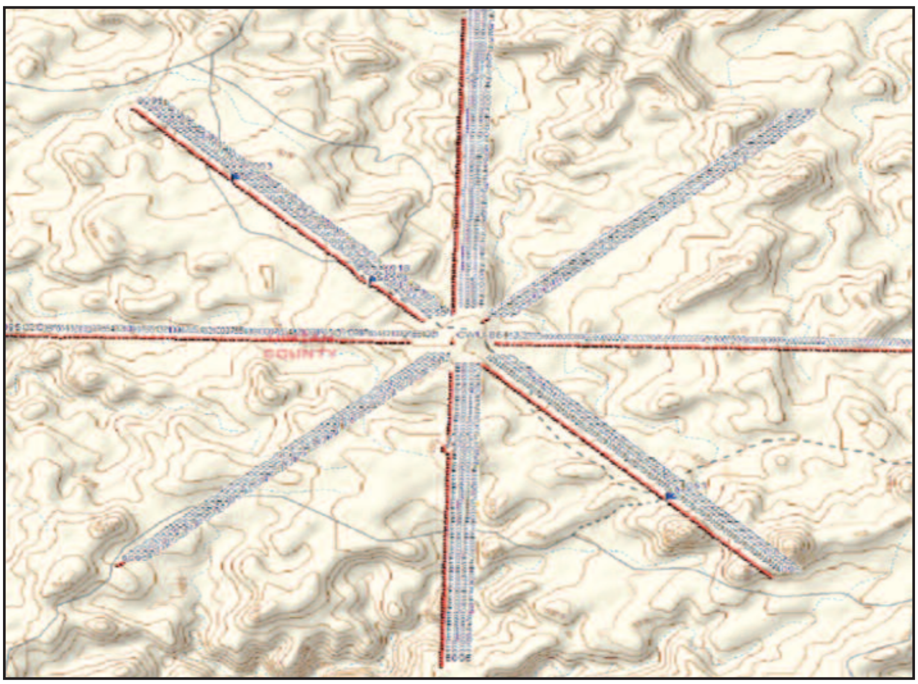


FIGURE 4

Typical Near-Surface Array Layout in Haynesville Shale (25 Square Mile Monitoring Area)

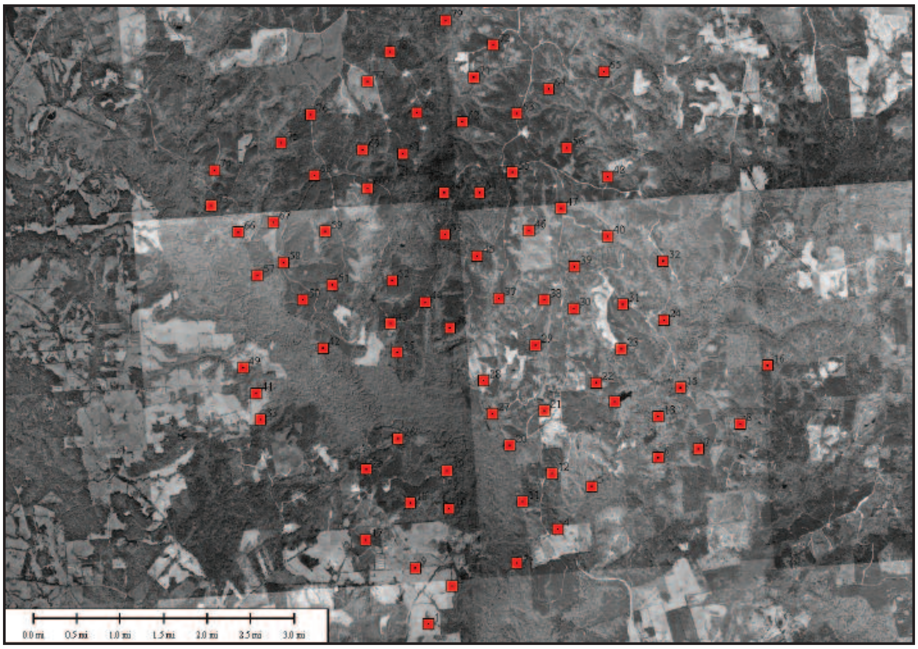


Figure 4 shows a typical near-surface array layout over a 25-square-mile monitoring area in the Haynesville gas shale play. To date, three such systems have been installed in the Haynesville Shale. The acquisition arrays consist of approximately 100 specially designed 3-C phones, each permanently cemented into the bottom of individual 300-foot deep holes. The geophones are installed on 3,000-foot spacing in X and Y coordinates, creating a grid over the 25 square mile area.

High-resolution monitoring is possible over the entire 25 square-mile footprint of the array, which can be expanded as required with the installation of additional receivers. The low installation cost of the buried geophone array (±$6,000 a location), allows this method to become cost competitive with the traditional microseismic techniques after monitoring only two or three wells within a development area. Additional monitoring beyond this initial base of two or three wells provides a growing economy of scale, with the installation cost amortized over more wells, while providing improved and more consistent microseismic event detection and location resolution over the conventional methods.

The installation of a near-surface array provides the operator with a microseismic monitoring system that is technically as well as commercially superior to both bore hole and surface monitoring, overcoming the principle limitations of both techniques. The large aperture of the near-surface array provides three principle benefits over bore hole monitoring; a monitoring area roughly equal to the footprint of the array, accurate and consistent event location accuracy of the entire monitoring volume, and an improved understanding of the geological and tectonic context of the induced seismic events through source mechanism inversion volume.

Permanently installing the geophone array at depths of 300 feet or more provides several benefits over surface monitoring including improved event detection thresholds and location accuracies because background noise is reduced by several orders of magnitude, a significant reduction in field effort to install the acquisition system prior to monitoring, and economically feasible long-term continuous monitoring because of the reduced acquisition system channel count.

Monitoring Results

The use of near-surface arrays in gas provinces that are early in their development cycle, such as the Haynesville Shale, is providing operators with critical information to optimize gas recovery and completion costs. Results from monitoring more than 50 frac stages have proven that the concept of near-surface geophone array monitoring is technically and commercially viable, providing high-resolution microseismic mapping that is being relied on to guide subsequent well locations, well bore azimuths, well spacing, stage spacing and fluid/proppant/rate optimization.

Field operators are gathering this detailed geological and engineering much earlier in the field development cycle and over a much broader area than possible with conventional monitoring techniques, which helps accelerate the maximization of gas recovery and the optimization of drilling and completion costs.

For most unconventional resource plays, drilling the well bore perpendicular to maximum horizontal stress to ensure propagation of induced fractures normal to the well bore azimuth is generally regarded as critical to maximizing recovery efficiency. Near-surface arrays are being employed in the Haynesville to provide detailed mapping of these stresses on a local level, and have already shown that the orientation of the stresses can vary considerably over relatively small distances. This is critical knowledge for developmental drilling, since the optimum well bore azimuth now can be tailored to specific portions of the field.

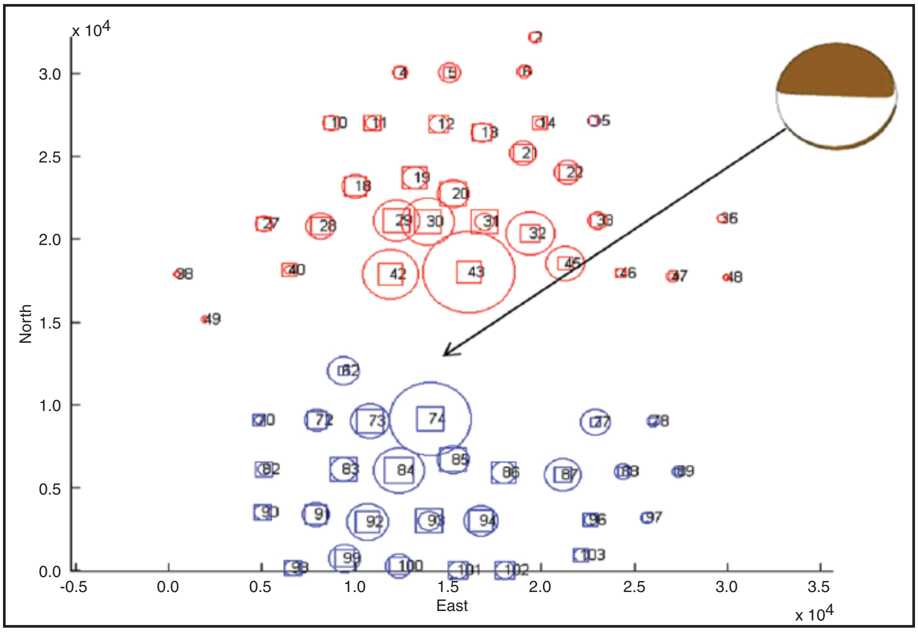
The low unit cost of individual well monitoring is allowing operators using near-surface arrays to optimize completions quickly by providing rapid and detailed feedback during the experimentation of various fluid types, pump rates and stage spacing. Microseismic mapping allows the operator to effectively separate the effects of local geological variations from the changes in pumping parameters.

Near-surface arrays provide the ability to determine the fault plane mechanism for a large number of individual frac events, enabling the subsurface team to understand the mode of failure, the plane of failure and their relation to principle stresses. Several failure mechanisms are observed on a single frac stage using the near-surface array.

Figure 5 shows a map of polarity for the first p-wave arrival from an event located in the center of a near-surface array (as indicated by the arrow), with the positive and negative polarity shown in red or blue, respectively. This event has been interpreted as a dip-slip failure as shown by the "beach ball" representation, with the plane of the fracture running east-to-west. This knowledge, combined with the orientation of the overall

FIGURE 5

P-Wave First Arrival Polarity Amplitude and Polarization Across Near-Surface Array



fracture propagation during stimulation, provides critical information on the interaction of horizontal and vertical compressive stresses in the immediate vicinity of the treatment well.

Ongoing Work

Ongoing work is investigating the likely hydraulic connection of wells being stimulated and offset wells through the possible reactivation of existing fault and fracture networks. Output from all 100-plus receivers is recorded during a monitoring of each stimulation job, so any volume within the array's footprint can be investigated if interesting activity is detected in offset wells during the recording period.

The low-channel count, near-surface arrays make long-term, continuous, real-time, fieldwide reservoir monitoring commercially viable. Work now is progressing to determine whether gas production from the Haynesville Shale generates significant levels of microseismic activity associated with stress changes in the contributing fracture network, especially during the first two or three months of production.

If production does generate detectable and usable levels of microseismicity, the near-surface arrays will have the capability to directly measure the drainage area of any well within the array's footprint. Knowledge of individual well drainage areas would allow for true optimization of development economics by providing the ability to eliminate unneeded wells and completion activity while maximizing overall hydrocarbon recovery.

Microseismic monitoring has evolved over the past decade to become an integral part of unconventional resource development. Near-surface permanent arrays almost certainly will play a vital role in the future of unconventional resources development as they are installed over an ever-growing number of fields worldwide. The information provided by these installations will significantly advance the science of unconventional resource development and will prove to be very satisfactory investments through the overall improved recovery and completion efficiency they enable. ❐

JOSE E. NEVAREZ *is vice president of exploration at Common Resources in Houston. The start-up company is a $500-million partnership between industry executives and private equity firms EnCap Investments and Pine Brook Road Partners, with operations onshore the Gulf Coast, West Texas and the Mid-Continent. Nevarez has 28 years of industry experience, starting his career with Cities Service/Oxy as a geophysicist. He subsequently worked as a geophysicist for Arco, Vastar and Spinnaker Exploration, and was vice president of exploration at Hydro before joining Common Resources.*

CHRIS NEALE *is vice president of business development at Houston-based MicroSeismic Inc., responsible for the adoption of the company's new technologies into the market. Neale spent 18 years with Texaco in Saudi Arabia, China, Scotland, Indonesia and Australia, initially as a reservoir engineer, and subsequently moving into engineering and operations management. Prior to joining MicroSeismic in 2003, he served for two years as the director of energy business development for the Houston Technology Center and as director of business development for Cogos Software Inc. Neale holds an undergraduate degree in mechanical engineering from Texas A&M University and an M.B.A. from Rice University. He is a past chairman of the Saudi Arabia section of the Society of Petroleum Engineers.*