



UP FRONT WITH KEVIN FISHER

Many in the energy industry were happy to put 2009 in the rearview mirror. With the global economic crisis driving down demand for oil and gas, leading to a drop in the commodity pricing for these products, leading to a dramatic drop in drilling activity, it was a year to forget for many. By the end of last year, there were signs that the economic malaise was lifting and we witnessed some rebound in oil and gas prices which led to gains in drilling and completion activities. Parts of North America suffered through one of the coldest winters I can remember—Houston's winter was the sixth coldest on record and had 3 recordable snowfalls! Now we watch and wait to see if these recent increases in activity will be sustainable.

For Pinnacle, 2009 was a very significant year for other reasons. At the end of 2008, Pinnacle was acquired by Halliburton making 2009 our "year of transition". An old proverb states "may you live in interesting times" and



it was an interesting year indeed. On top of working through the aforementioned global economic crisis and the subsequent meltdown in the upstream energy industry, particularly in the western hemisphere, Pinnfolk were busy adapting to new processes, technologies and organizational structures with co-workers across Halliburton's 50,000+ person strong organization. Global opportunities abounded, new synergies with various HAL product lines were explored, relationships were forged and yes, a record number of fracs were mapped as well.

I am proud to say that our outstanding employees were up to the challenge and passed this year-long test with flying colors. Never during my time in this

industry have I witnessed an acquisition with less turnover in the employee base of the acquisition target, with less disruption to the primary processes driving the value of that organization, or with more support from executive management of the acquirer for a relatively small acquisition (in terms of revenue and number of employees). Thank you Pinnfolk and Halliburton for helping us remain the World's "Greatest Little Service Company" and we look forward to the new challenges that arise and the future before us as we "go viral" globally.

In this issue, you will find some history and editorial content about hydraulic fracturing that I hope you find interesting and thought provoking as well as a very good technical summary about the "State of the Union" in Microseismic Mapping from "The Frac Doctor", Norm Warpinski.

Hope you enjoy and see you on your next stage!

A handwritten signature in black ink that reads "Kevin".

Kevin Fisher
General Manager

CAN WE JUST AGREE ON ONE THING?

I've followed the news coming out of Washington regarding the now nationally famous "Frack Act" with a keen and vested interest. A year or two ago, no one outside of the upstream oil and gas industry even knew what a hydraulic fracture was and now we have the EPA, senators, congressmen and journalists all discussing fracturing as if they were frac experts!

Is there any doubt that natural gas is the cleanest fossil fuel available? Is it abundant in North America and many other parts of the world? Has the growth in the last decade of "unconventional" gas, primarily from shale, materially added to the recoverable gas (and sometimes oil) reserves in North America, virtually eliminating the need for natural gas imports? Does that improve our energy security? Does that create jobs in whatever country the gas is produced? Does it create new sources of tax revenues? Is there a more impacting service in low perm reservoirs than hydraulic fracturing? Does hydraulic fracturing imperil our groundwater supply? Whoa, let's park the pump trucks here for a moment.

On March 17, 1949, a team comprised of Stanolind Oil Company and Halliburton personnel converged on a well about 12 miles east of Duncan, OK, to perform the first commercial application of hydraulic fracturing. Later the same day, Halliburton and Stanolind personnel fractured another well near Holliday, TX. The technique had been developed and patented by Stanolind (later known as Pan American Oil Company) and an exclusive license issued to Halliburton to perform the process. In 1953, the license was extended to all qualified service companies. Since that fateful day in 1949, hydraulic fracturing has done more to increase recoverable reserves than any other technique, and Halliburton has led the industry in developing and applying fracturing technology. In the more than 60 years following those first treatments, more than 2 million frac treatments have been pumped with no documented case of any treatment pollut-



ing an aquifer—Not One.

Below are excerpts from speeches and memos from ranking EPA officials:

"There is no evidence that the hydraulic fracturing at issue has resulted in any contamination or endangerment of underground sources of drinking water," Carol M. Browner EPA Administrator, May 5, 1995 (now Energy Advisor to President Barack Obama).

"I have no information that states aren't doing a good job already," Steve Heare, director of EPA's Drinking Water Protection Division said on the sidelines of a state regulators conference here. He also said despite claims by environmental organizations, he hadn't seen any documented cases that the hydro-fracking process was contaminating water supplies.

From our perspective, Pinnacle has mapped more than 15,000 fracturing treatments in the past decade and a half and can conclusively say from those results that hydraulic fractures are generally better confined vertically and are longer than conventional wisdom or models predict. In the areas with the largest measured vertical fracture growth (like the Marcellus), the tops of the hydraulic fractures are still thousands of feet below the deepest aquifers suitable for drinking water.

Can we just agree on just one thing? FRACKING is not spelled with a "K"! You only save 2 letters versus FRACTURING and it just looks goofy... Pull two more letters, Vanna and let's save the FRACK for fans of Starbuck in Battlestar Galactica!

NORM'S NOTES: CONTINUING EVOLUTION OF MICROSEISMIC MONITORING

Based upon recent activity levels and the number of papers and workshops dealing with the topic, it is clear that microseismic monitoring has become one of the top evaluation technologies for optimization of both stimulation and field development in most of today's unconventional reservoirs. Being a relatively new technology, at least as applied using downhole receiver arrays to map hydraulic fractures, many aspects of the hardware, sensors, telemetry, acquisition, processing, visualization, data formats, and interpretation continue to evolve as the technology matures. I would like to provide a brief update of some of the more recent developments and trends in fracture microseismology.

One major area of improvement is in data acquisition. We are continuing to see more use and more

advantages of both stacked and extended arrays wherever conditions are appropriate. Stacked arrays, which have several "nodes" where two or three receivers are immediately adjacent to each other and the data are stacked (added together), have helped improve data quality and viewing distances in many reservoirs where we may be at the limits of detection given the size of typical microseisms, formation attenuation and typical well spacing. Extended arrays have proved useful in reservoirs like the Marcellus where significant height growth may occur, but also in carbonate systems where the fast velocities of the carbonates can cause problems with both detection and accuracy (see the design plot in the paragraph below). It is self-evident that more receivers, faster sampling, and improved signal-to-noise characteristics are array modifications that improve our microseismic location accuracy and reliability.

Another area that has been very useful in maximizing our ability to accurately observe the fracture is experimental design. We have developed and implemented modeling tools to perform Monte Carlo studies of likely event accuracy for a given velocity structure and array characteristics. Figure 1 shows an example of the uncertainty contours that one would expect for an 18 level extended array that is straddling a reservoir zone, with the additional characteristic of having a fast carbonate zone below the reservoir interval (very typical of many gas shales). The uncertainty contours (blue is excellent) for many possible event locations

are shown from the side view, and most of them suggest that location accuracy will be quite good for this array design. Notice, however, the larger uncertainties of the lowest events and how fracture height will be less accurate if the fracture were to propagate downward. Knowing this behavior, we can customize the array length and positioning to improve downward resolution in cases where height is the important issue in a given reservoir.

One of the more difficult problems in microseismic monitoring is dealing with rock anisotropy when we have very little information about the anisotropic parameters for all of the individual layers. Rocks are notoriously anisotropic and non-homogeneous, yet we still need to model the wave propagation through the unknown rock mass between wells. We have typically accounted for all of these unknowns by using source shots such as perforations or string shots to give us sufficient information to build calibrated velocity models that incorporate all of the unknowns. This usually works quite well, but can result in cumulative errors when microseismic events are observed far from the calibration points. We have recently added the capability to extract vertical anisotropy information from the source-shot data so that we can directly perform anisotropy corrections in the cases where steep ray paths may result in errors. There are still many assumptions implicit in doing such an analysis (weak anisotropy, elliptic anisotropy, lateral heterogeneity, uniqueness of solution, etc.), but we can now provide this capability with

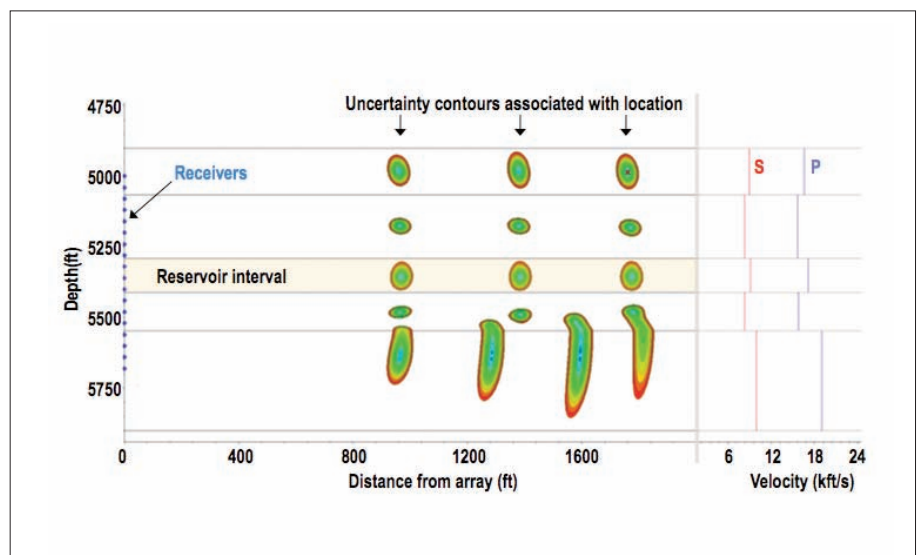


Figure 1. Example uncertainty plot for a design analysis.

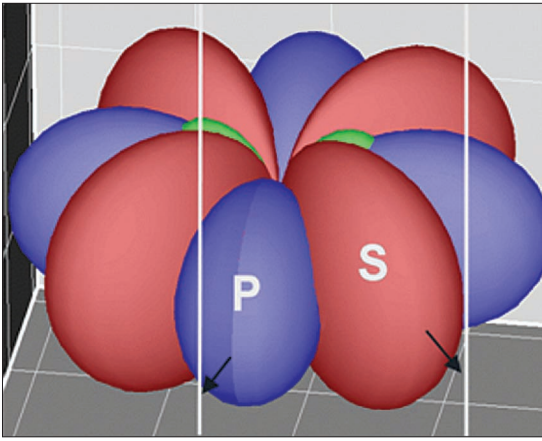


Figure 2. Example radiation pattern (wave amplitudes) from a strike-slip shear microseism. P & S are compressional and shear waves.

error sensitivities noted. When good anisotropy parameters are available, then microseismic event locations using anisotropic wave propagation can be readily provided.

Real-time processing is a necessity for many projects where continuous control of fracturing operations can help improve stimulation results. We have always provided “real-time” processing in which the delay is only that needed for a geophysicist to examine and modify wave arrivals if necessary – usually a minute or two at most. While this method is very accurate (assuming the velocity structure is well known) and works quite well for getting useful information quickly, it is clear that machine-driven processing could analyze and locate more events faster in a given time period than humans can. For reasons of speed and efficiency, automatic processing is a useful tool and we have been working with a new automated technique for a number of months in order to provide this capability. Full disclosure; we believe that it needs to be correct as well as being quick. Fast and wrong is the worst possible answer, as it enables a wrong response to be made at the worst possible time. As a result, we plan to offer automatic processing, but only with a “Pinnacle-standard” level of QC provided by a geophysicist who can reject (and correct) any events that are mislocated by the automatic processing. Our proprietary software is geared so that we will calculate numerous attributes of the microseism that will allow us to select events for auto-processing only when they are sufficiently qualified.

Everyone knows by now that microseisms are micro-earthquakes and, like all earthquakes, the characteristics of the compressional and shear waves tell us something about the source (strength, orientation, slip direction, etc.). We call these characteristics the radiation pattern, and an

example is shown in Figure 2. Unfortunately, for a single vertical array, the changes observed across the array are usually very small, which makes it extremely difficult to extract accurate information about the source. Nevertheless, there are cases where it can be done (more than one monitor well, nearby events, other constraints) and we have implemented both a moment-tensor inversion and a double-couple inversion to extract these parameters. The difference in the two is that the double-couple inversion assumes that the source behaves as a pure shear event, whereas the moment-tensor inversion allows for any general type of movement along a fault surface. With these tools we are able to provide information that can help characterize the reservoir and the fracture.

There are also many specialized types of analyses that we have been developing to deal with the

uncertainties faced when monitoring near carbonates, for example. The very fast velocities in the carbonates compared to the slow velocities of the shales create issues that need to be handled in order to ensure accurate results. Another analysis we employ occasionally is a relative location technique using double differencing, as well as other similar techniques for clustering. These are not generally needed or recommended, but have applications in certain situations.

The final area I want to mention is the one that occurs at the end of processing; the very important issue of visualization. We recognize that microseismic results have the most value when they are viewed in the context of the geological environment, the well(s) intersection with the reservoir, and the particulars of the treatment. We have been working with Landmark to get microseismic data and treatment pumping data available in real-time within Landmark product families. In particular, Landmark’s DecisionSpace® Desktop Software now has the capability to display all of this information within the earth model environment in real-time, as seen below in the example multi-stage, horizontal-well stimulation.

Pinnacle remains dedicated to providing the highest quality service to our clients, to remaining industry leaders in hydraulic fracture optimization and mapping, and to making every effort to meet your needs and requirements. Please let us know about any areas that you think we should investigate!

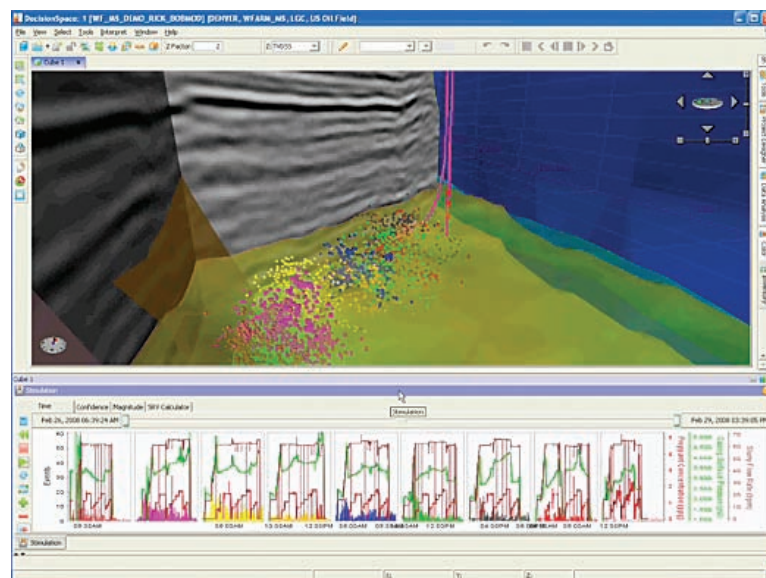


Figure 3. Example earth model visualization with treatment data and microseismic activity for a multi-stage, horizontal-well stimulation.

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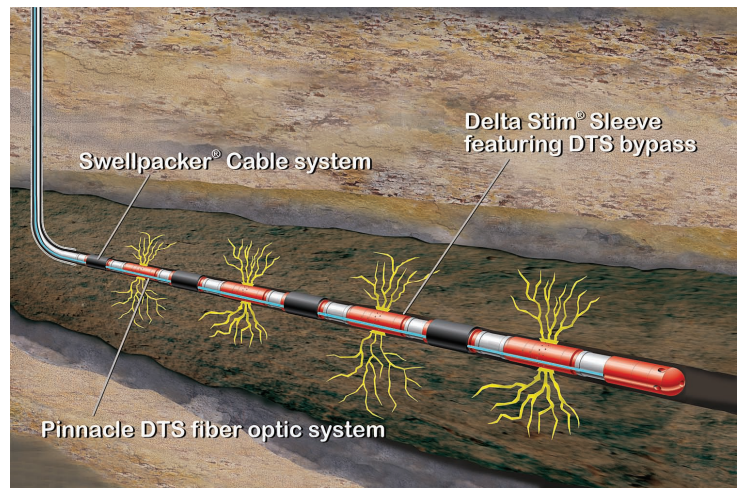
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PINNPOINT FIBER OPTIC MONITORING

Halliburton recently announced the consolidation of all fiber optic monitoring formerly performed by Pinnacle and Well Dynamics under Pinnacle. Pinnacle is now your "one-stop" shopping destination for any fiber optic monitoring services provided by Halliburton. From Distributed Temperature Sensors (DTS) for profiling a wellbore in a permanent or retrievable installation to a purely fiber optic pressure gauge solution, call Pinnacle first for your fiber optic monitoring needs.

To complement fiber optic monitoring for carbon capture and storage, waste disposal, subsidence monitoring, heavy oil (steam injection) projects and other reservoir surveillance monitoring, Pinnacle offers integrated surface deformation monitoring with tiltmeters, InSAR and high resolution GPS surveys along with downhole Tiltmeter and Microseismic services. Please contact Pinnacle at 281.876.2323 or via email at monitoring-solutions@pinntech.com.



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