This large, propped fracture is a sight rarely seen. *Source: Hydraulic Fracturing Research Site 1.*

A Look Into What Fractures Really Look Like

Stephen Rassenfoss, *JPT* Emerging Technology Senior Editor

Reports from the Hydraulic Fracturing Test Site offer a glimpse into what hydraulic fractures really look like.

The featured attraction in the 13 technical papers presented over two mornings at the Unconventional Resources Technology Conference (URTeC) was 600 ft of rock fractured in late 2015 near wells in the upper and middle Wolfcamp. Those core samples spawned a mind-boggling array of observations about the rock, proppant, and natural and hydraulic fractures, and how they all interact.

In the more than 2 years since the samples were gathered, the sections of core have been meticulously analyzed by teams of experts. More than 700 fractures were categorized based on whether each one was created by nature, hydraulic force, or the stress of drilling the slant well. And the majority of the 400 stages pumped were studied using tracers and/or monitored using advanced diagnostics.

The density and distribution of the fractures were measured as the scientists worked to understand how natural and hydraulic fractures interact. The bits of sand, calcite, and drilling mud found in and around the rock were collected and sorted. Automated imaging and painstaking manual examinations were used to measure the size, shape, and translucence of each grain in order to identify and quantify the grains.

The "incredible complexity" observed was "far beyond what current simulations can model and predict," said Jordan Ciezobka, manager for research and development for the Gas Technology Institute (GTI), which managed the federal grant supporting test site 1 and is planning Hydraulic Fracturing Test Site 2 (URTeC 2937168).

Ciezobka predicted that findings from the first Permian test site hosted by Laredo Petroleum in the Midland Basin would be studied for years to come. The public-private partnership is just beginning to deliver the delayed reports of what it learned from the $25-million research project. Federal funding for the project requires the partnership to ultimately disclose its results, with data releases beginning later this year. The lag time rewards companies that supported the project with a long first look.

Cause and Effect?

The completion engineers in the room those two mornings likely left wanting more. With one exception, the talks avoided mentions of the ultimate measure of what works—production. Instead, they challenged widely held mental images of fracturing.

For one, fracture height is overrated. While microseismic testing indicated that fractures grew up about a 1,000 ft, the height of the propped fractures—the fractures most likely to produce oil and gas—was about 30 ft.

Proppant distribution was sporadic. While there were thick fractures full of

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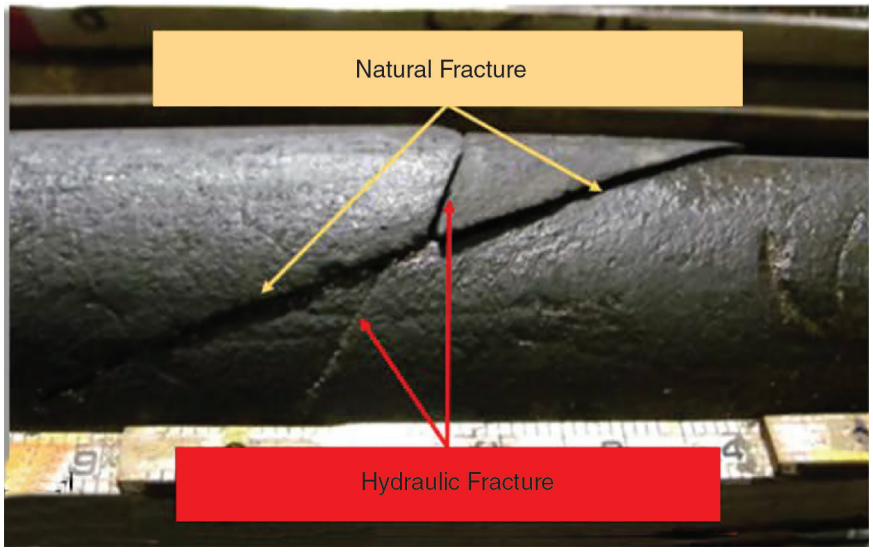

Scientists examining the rock found places where natural and hydraulic fractures intersected. *Source: URTeC 2937168.*

sand inside, a paper describing fracturing (URTeC 2902624) said that only three of them were found among hundreds of propped fractures. And all of those were found in the upper Wolfcamp.

While the fractured lateral in the middle Wolfcamp was further from the slant well—135 ft vs. 90 ft from the nearest stage—the middle Wolfcamp core has a lot more proppant than the upper Wolfcamp core (URTeC 2902364).

The sand grains collected tended to be extremely fine, many one-half to one-third the size of the grains that would just fit through a 100-mesh screen. Samples from the core tended to be mostly made up of those tiny particles. The three proppant packs were the exception, with a lot of bigger grains.

While crushing could turn large grains of sand into small ones, close examination showed that the tiny bits of sand were generally smooth and rounded, not the jagged shapes created by crushing. Nor did researchers find particles embedded in the fracture faces.

Fractures expose many different faces. Some are smooth, others rough. They did not appear to be the simple fractures growing out in opposite directions, known as bi-wings, which are widely assumed in modeling. After looking at hundreds of examples, Julia Gale, a senior research scientist for the Bureau of Economic Geology at the University of Texas at Austin, said, "we are not dealing with planar bi-wing things."

Payoff for Pulsations

The papers also suggested the industry consider pumping jobs differently. In his paper, Ciezobka offered some production results of the sessions in a short report on a test of a fracturing method that used sharp variations in the pumping rate to increase production. "The rapid changes in the fluid flow, or a rate pulse, temporarily produce a pressure pulse of hundreds of thousands of pounds per square inch."

A well fractured using the variable rate method delivered 20% gains on average over four other wells on the pad where a steady pump pressure was used, said Ciezobka, who is listed as the co-inventor on a patent held by GTI.

The variable rate well "clearly outperformed four adjacent wells with the same or higher proppant loading, in both initial production rate and cumulative production after 24 months," according to the paper.

Meanwhile, on the URTeC exhibit floor, there was a booth promoting Hydraulic Fracture Test Site 2, which is being hosted by Shell and Anadarko Petroleum. Work will begin later this year on Anadarko acreage in the Delaware Basin.

The reservoir there is significantly different from the Midland Basin, home of Test Site 1. Results from the first site "will establish the foundation for investigating EOR techniques, which we plan to investigate" in the second site, Ciezobka said. This second phase of the Delaware Basin project will inject natural gas into the wells in hopes of recovering an added 2–4% of the oil in place, according to the test site webpage.

Proppant Packed or Not

Large fractures packed full of sand do exist. In the cored rock from the fracturing test site there were fractures from 0.5–1 cm thick full of proppant. They were fine examples of the large breaks in the rock propped open with sand.

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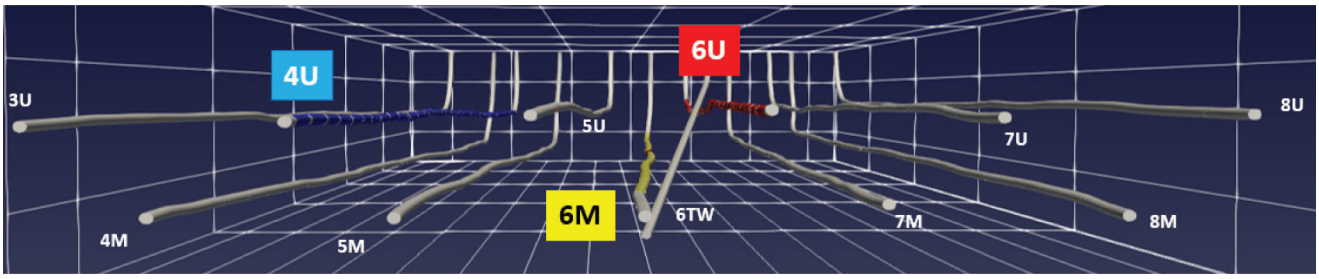

At the heart of the Hydraulic Fracturing Test Site was a test well (6TW) used to collect about 450 ft of fractured rock from near an upper Wolfcamp well (6U) and 150 ft of core from a middle Wolfcamp well (6M). Proppant tracer was pumped while the three highlighted wells were fractured. *Source: URTeC 2902960.*

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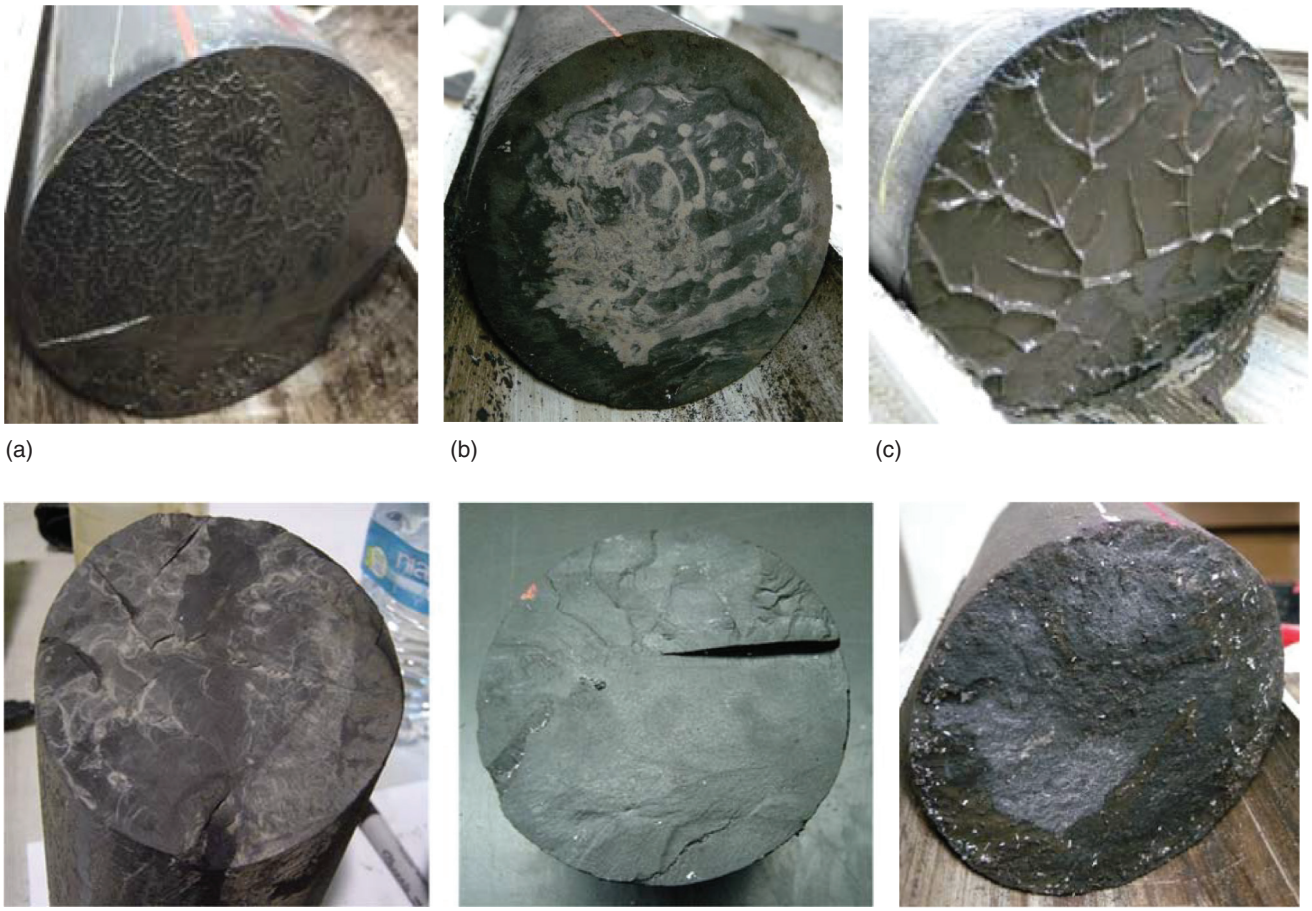

These six cores collected from a well drilled into fractured rock shows they vary from rough to smooth. The breaks in some (a, b, c, d) contained drilling mud inside. Sample c, which had no sand inside, was 3.3 ft below a fracture with a thick proppant pack. Sample f shows a carbonate layer. Source: URTeC 2902624.

In 600 ft of core, researchers found three big fractures packed with sand among hundreds of propped fractures, most of which were smaller. The breaks examined held from 1.3 pounds of particles to a fraction of an ounce of sand, drilling mud, and bits of calcite and pyrite from the formation, said Debotyam Maity, a senior engineer at GTI, whose presentation covered the analysis of the sludge of sand and other particles found around the depressurized core (URTeC 2902364).

What they observed resisted orderly categorization. Maity's paper also noted that "the proppant seems to show sudden jumps and drops with some core samples showing no proppant and some showing a lot." Differences were ascribed to "geology/fracture or stress-related variations." Hydraulic fracturing interacted with natural fractures in many ways.

"They are certainly reactivating natural fractures" and there is proppant down in there, said Sara Elliott, a research scientist associate from the Bureau of Economic Geology for the University of Texas. The paper (URTeC 2902629) covered the painstaking job of extracting and measuring particles found in fractures. To begin with, researchers had to develop a method to allow them to get all of the material, including particles that escaped the depressurized core, and then clean it, sort it, and record where samples were collected.

It was "one of first attempts at physical collecting and quantifying injected proppant from a parted fracture break from a stimulated reservoir," said Elliott.

The total volume of proppant found in middle Wolfcamp fractures was a lot higher than in the upper Wolfcamp, where researchers observed five times more fractures including natural fractures. "The upper Wolfcamp hydraulic fracture should show a lot more interaction with natural fractures, providing more opportunities for the proppant to screen out locally due to a reduction of fluid momentum/carrying capacity of the fracturing fluid," Maity wrote.

Other concentrations of proppant were found at fractures in seams between layers of rock with contrasting properties. "We find that almost all of the high-proppant-concentration zones appear close to carbonate bed boundaries or where there is a significant change in stress/brittleness," Maity said. These included complex fractures at the intersection of beds of carbonate with contrasting rock properties.

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Imagine Fracture Modeling

Based on Actual Fractures

Depending on one's perspective, the 600 ft of core is either a really big sample, or not really significant.

It is huge considering how rarely anyone goes to the expense of mining back fractured rock from a well drilled nearby. It is also the first reported in the Permian Basin. The only technical paper reporting on fractured rock that was mined back in a liquids-rich basin was written by ConocoPhillips in the Eagle Ford in 2014 (URTeC 2670034).

But that 4-in. diameter angled well in the middle of an 11-well pad amounted to a pin prick in a formation prone to abrupt, unexpected changes that affect fracturing. Jordan Ciezobka, manager of research and development at the Gas Technology Institute, pointed out the formation is "under-sampled." The institute managed the federal grant supporting test site 1 and is planning Hydraulic Fracturing Test Site 2 (URTeC 2937168).

For those doing modeling, the data present a quandary. They offer physical evidence of what fracturing looks like in the ground. But the range of observations in the upper and middle Wolfcamp suggest the same fracturing design will perform differently in a zone 325 ft deeper.

Instead, Laredo Petroleum used the test results to identify what widely available formation evaluation methods can be used to reliably predict critical variables, such as the presence of natural fractures.

That information "is essential for understanding the economic impact that complex fracture networks have on well performance," according to a paper on using fracturing data for better modeling presented by Whitney Campbell, a geologist at Laredo Petroleum (URTeC 2934611).

Analysis of hundreds of fractures was used to narrow down a long list of test methods to the ones most likely to accurately predict changes in fracture density.

Fractured shale samples present an obvious challenge—the most interesting features are likely to crumble.

Teams of experts brought in to measure the size and origins of hundreds of these breaks had to figure out how to preserve these rare samples gathered at great cost. CT scans were done to record the rock in its original condition. Then it was placed in aluminum tubes that had been milled in half, forming a clamshell core barrel.

Epoxy was used to stabilize a short section of core. That idea was quickly dropped because the glue changed the dimensions of the thin fractures and interfered with their opening, said Julia Gale, a senior research scientist for the Bureau of Economic Geology at the University of Texas at Austin (BEG).

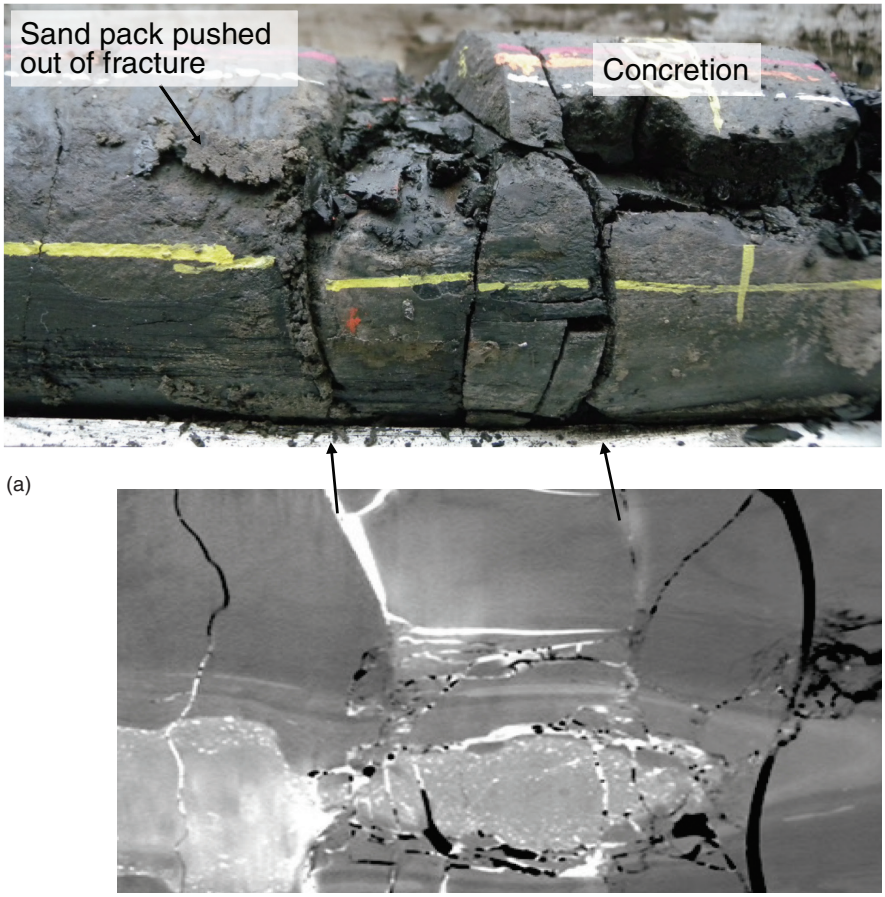
Despite the core's frail appearance, Gale said it "was much more intact than I thought and pieces were bounded by fractures that were mostly meaningful."

Gale led one of two teams—one from the BEG and the other led by ConocoPhillips—that developed methods for classifying the origins of each fracture.

Their judgment had to reflect interactions, such as hydraulic pressure intersecting with natural fractures and breaking open fractures long cemented shut by calcite.

Like art critics asked to judge if a master actually painted a picture, researchers assigned various degrees of certainty to their assessments. "We see only a small snapshot of each fracture," Gale said.

Armed with real-world data on the number of fractures per foot and more



Fractured shale samples present an obvious challenge—the most interesting features are likely to crumble. *Source: URTeC 2902624.*

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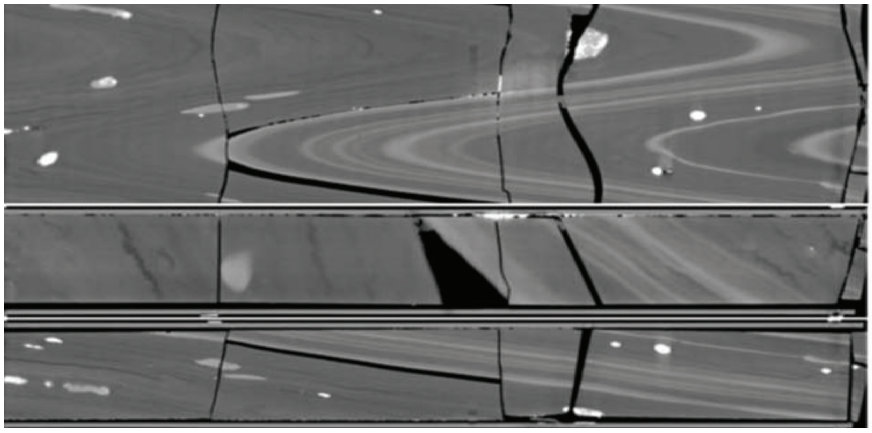
than 30 inputs on the reservoir rock, Campbell said the company created a "facture intensity log" to reliably answer the question "do we see a fracture at this interval or not?"

The paper described a two-stage project. First it narrowed the list of markers for predicting natural fracture intensity to the ones most likely to get it right. Then they used that result as an input along with the best set of markers to predict hydraulic fracturing results.

While natural fracture data from seismic testing are often used, the paper questions the "over-reliance on seismic attributes that are commonly influenced by noise."



A cross section of a core with multiple fractures. *Source: URTeC 2902624.*

At the top of the list of the best predictors of natural fractures are gamma ray logs, shallow resistivity, and bulk density measures, plus a measure of brittleness, which Campbell said was based on an output from their logging software.

Most significant on the hydraulic fracture inputs list was the gamma ray log, followed by Young's modulus, shallow resistivity, and a model used to identify weak interfaces between rock layers with differing properties. They help "identify the rock type, brittleness, stress, and the presence of weak interfaces."

The paper said the "results imply that hydraulic fractures have increased intensity in organic-rich shale sequences."

A significant input in the hydraulic fracturing model is an output from the natural fracture model used to indicate where fractures are prevalent. Campbell said that is significant because "there seems to be an inverse relation between natural and hydraulic fractures."

The work described in the paper is now being used to create what Campbell described as a "high-confidence variable" for reservoir modeling for other Laredo developments in the Permian. When asked if this has improved production, she said the company is "working closely with some of our engineering groups to get a handle on that."

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Fracturing Wells in Pairs
Creates Strong Links

The 11 wells at the Hydraulic Fracturing Test Site were fractured in 2015 using what was then a fairly new method, zipper fracturing. Rather than pumping one well at a time, wells were fractured in groups—four pairs, plus three wells together in the middle of the pattern.

Zipper fracturing speeds work by allowing continuous pumping and it reduces the risk of frac hits because the method only fractures rock where pressure has not been depleted by production. Now zipper fracturing is used to fracture even more wells at once.

What researchers found at the fracturing test site was that zipper fractures create strong connections. By tracking the pressure responses in nearby wells during fracturing, and the chemical tracers in the fluids pumped during fracturing, they measured the higher degree of connection among those wells.

While fluids injected during fracturing were later observed at other wells on the pad, the ones that were zipper fractured showed more communication, said Ashish Kumar, a graduate research assistant in petroleum engineering at the University of Texas at Austin, who presented a paper on tracer and pressure data analysis at the recent Unconventional Resources Technology Conference (URTeC 2901827).

Connections matter because they can provide a pathway for well interference. The strongest connections were wells in which proppant tracers traveled from well to well, suggesting the passageway has been propped open. The paper said that "proppant exchange is very likely to happen between zipper fractured wells."

Simultaneous fracturing is likely to create stronger connections because the time between stages is relatively short, allowing fluid pumped in one stage to stimulate "induced un-propped fractures that have not closed over this short time" from the previous stage, he said.

Most of the well pairs were on the same bench, spaced 660 ft apart. The five lower wells were 325 ft deeper and spaced in between the six upper wells.

Fractures connected end-to-end can run 1,000 ft or more, but they generally do not have a lasting impact unless the pathway was propped—radioactive tracer tests showed some propped connections among well pairs.

Connected fractures without proppant closed after production began, as did all connections between the middle and upper Wolfcamp. Pumping more sand increased the probability of interaction among multiple wells.

A related study by Core Laboratories found that the same fracturing treatment performed differently in different benches. "Interwell communication within the middle Wolfcamp wells was significantly higher than communication within the upper Wolfcamp wells," according to a technical paper by the company (URTeC 2902960).

It also reported that a high percentage of proppant had traveled into the reservoir. The proppant was treated to give off a low-level radioactive signal, and the paper concluded more than 90% of the clusters were treated. The signal was detected using a gamma ray log whose range is limited to an area within a couple feet of the wellbore.

The paper reported that proppant injected at clusters 50 ft apart were as effective as those spaced 90 ft apart, and the wider spacing left more rock unstimulated. This did not vary between wells in the upper and middle Wolfcamp. **JPT**

For Further Reading

URTeC 2937168 Hydraulic Fracturing Test Site (HFTS)—Project Overview and Summary of Results *by Jordan Ciezobka, Gas Technology Institute; James Courtier, and Joe Wicker, Laredo Petroleum.*

URTeC 2902624 Hydraulic Fractures in Core From Stimulated Reservoirs: Core Fracture Description of HFTS Slant Core, Midland Basin, West Texas *by Julia F. W. Gale, Sara J. Elliott, and Stephen E. Laubach, University of Texas at Austin.*

URTeC 2902364 Assessment of In-Situ Proppant Placement in SRV Using Through-Fracture Core Sampling at HFTS *by Debotyam Maity, Jordan Ciezobka, and Sarah Eisenlord, Gas Technology Institute.*

URTeC 2902629 Analysis and Distribution of Proppant Recovered from Fracture Faces in the HFTS Slant Core Drilled Through a Stimulated Reservoir *by Sara J. Elliott and Julia F.W. Gale, University of Texas at Austin.*

URTeC 2934611 Natural and Hydraulic Fracture Density Prediction and Identification of Controllers *by Whitney Campbell, Joe Wicker, and James Courtier, Laredo Petroleum.*

URTeC 2901827 Well Interference Diagnosis Through Integrated Analysis of Tracer and Pressure Interference Tests *by Ashish Kumar, Puneet Seth, and Kaustubh Shrivastava, et al., University of Texas at Austin.*

URTeC 2902960 Interwell Communication Study of UWC and MWC Wells in the HFTS *by Tanner Wood, Richard Leonard, and Chad Senters, et al., ProTechnics Division of Core Laboratories.*

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