RESERVOIR SOLUTIONS

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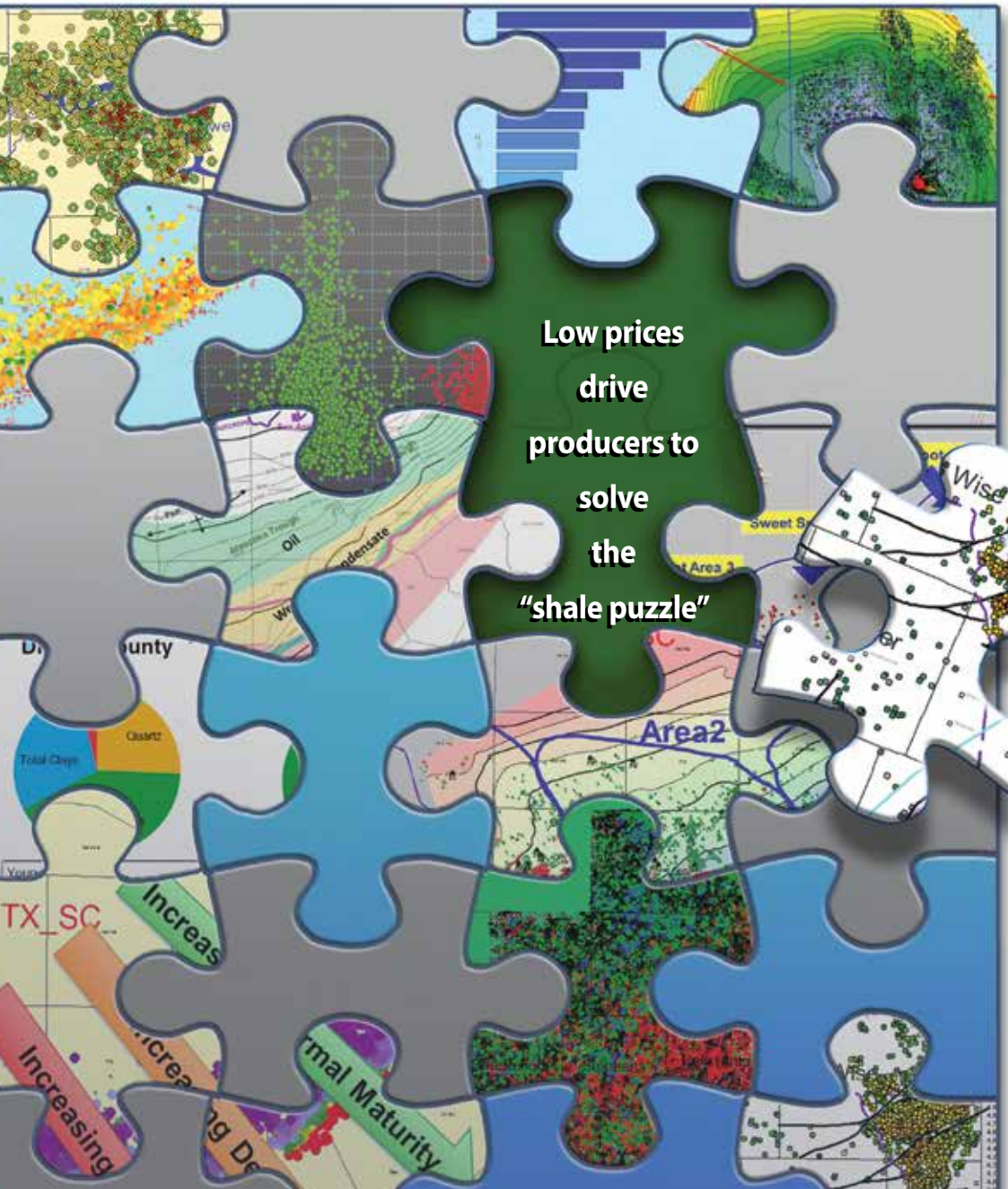
Data mining from shale plays critical in low-price environment

Oil prices dipped below $45 a barrel in January, driving producers of shale oil, with its high cost of extraction, to rethink their strategies. "You're not going to stop the shale revolution," **Fadel Gheit**, senior energy analyst at Oppenheimer, told CNBC in December. "Technology will accelerate this (production) rate even if we have lower oil prices. Usually companies become more creative with lower prices."

What has proved to be successful in these "technology plays" is a starting point for creativity. However, history, the greatest teacher, is in short supply. The venerable Barnett shale play that kicked off the shale revolution is about 30 years old compared to the 150-year-old modern oil industry.



Furthermore, knowing what has worked over the past three decades is not that simple. As many as 100 variables in geology, well architecture, completions, stimulations and production may apply to a single well location. Those parameters en masse generate an enormous number of combinations requiring iterative processes to detangle and analyze.

In a given unconventional reservoir, companies use predictive data-mining techniques to build statistical models to ascertain which geological and engineering parameters are most likely to affect production results. Not all statistical approaches are the same.

Randy F. LaFollette, director-applied reservoir technology at Baker Hughes Inc., eschews univariate, two-dimensional cross plots and linear

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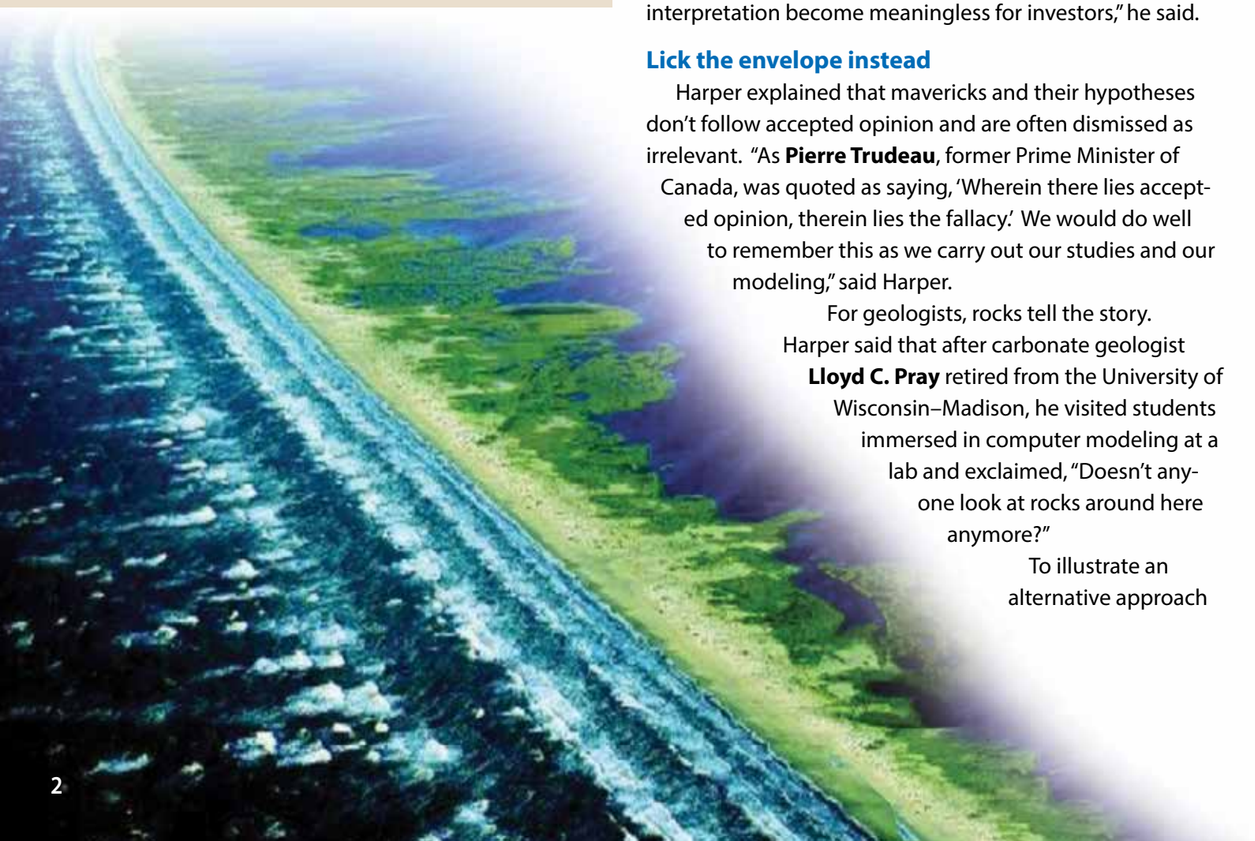
Publisher's Statement
Reservoir Solutions newsletter is published quarterly by Ryder Scott Co. LP. Established in 1937, the reservoir evaluation consulting firm performs hundreds of studies a year. Ryder Scott multidisciplinary studies incorporate geophysics, petrophysics, geology, petroleum engineering, reservoir simulation and economics. With 130 employees, including 90 engineers and geoscientists, Ryder Scott has the capability to complete the largest, most complex reservoir-evaluation projects in a timely manner.



Maverick hypotheses break mold, shift paradigms in reservoir characterization, says Harper

Mavericks with new approaches have debunked some depositional and facies models accepted by industry for decades, said **John Harper** at the Ryder Scott Canada reserves conference late last year. The technical advisor at Geo-Reservoir Solutions in Calgary remarked, "The old archetypes for the U.S. gulf coast barrier islands and for the Wembley field in Alberta have given way to fact-based geoscientific models."

He urged industry to do a better job documenting facts in the subsurface rather than forcing data to fit preconceived models. "Let's look at the rocks and the facts before committing to our models," Harper said.

> *"...to avoid licking the glue on a stamp, lick the envelope instead..."*
>
> – Lloyd C. Pray

Harper drew the distinction between data and models. "Modeling is not data. It's interpretation. Data and the wrong interpretation become meaningless for investors," he said.

Lick the envelope instead

Harper explained that mavericks and their hypotheses don't follow accepted opinion and are often dismissed as irrelevant. "As **Pierre Trudeau**, former Prime Minister of Canada, was quoted as saying, 'Wherein there lies accepted opinion, therein lies the fallacy.' We would do well to remember this as we carry out our studies and our modeling," said Harper.

For geologists, rocks tell the story. Harper said that after carbonate geologist **Lloyd C. Pray** retired from the University of Wisconsin–Madison, he visited students immersed in computer modeling at a lab and exclaimed, "Doesn't anyone look at rocks around here anymore?"

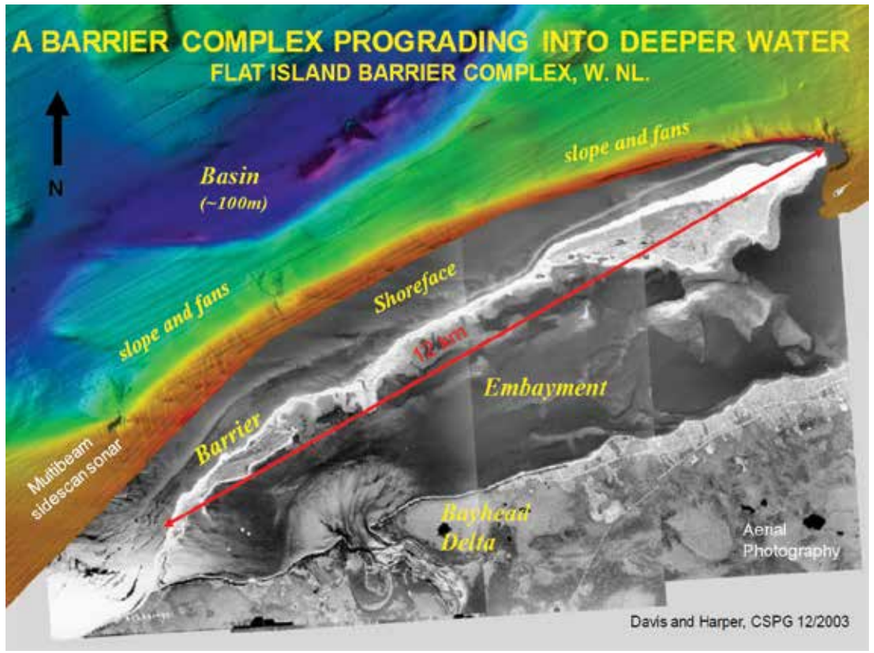
To illustrate an alternative approach not considered by most, Pray offered a simple solution to avoid licking the glue on a stamp—lick the envelope instead, remarked Harper.

Other mavericks

The theory of continental drift, forerunner to the plate tectonics theory, was introduced by mavericks, said Harper, but it took almost four centuries for it to be accepted. **Abraham Ortelius**, a Flemish cartographer and geographer, presented the idea in 1596 and it was lightly dismissed. **Alfred Wegener**, German geophysicist, advanced the theory in 1912 but it was rejected by the scientific community. American scientist **John Oliver** provided seismic evidence supporting plate tectonics in 1968 and the theory became universally recognized, said Harper. (Others argue that the theory was formulated by American, Canadian and British geophysicists in a cooperative effort over decades rather than by the effort of a lone maverick who went against the grain.)

Harper also cited **George Mitchell**, former CEO at Mitchell Energy & Development Corp., as a maverick in the 1980s and 1990s, as he pushed his company to experiment with hydraulic fracturing of the Barnett shale to extract gas.

Oil industry historian **Daniel Yergin** said Mitchell's fracing technique is so far "the most important and the biggest energy innovation of this century."



Above graphic: Basin-floor fans in deeper waters of St. George's Bay

Barrier island facies model

The classical theory of barrier-island formation is based on the U.S. gulf coast barrier-island facies model and is the one used by most reservoir modelers, said Harper. The U.S. east coast model is essentially the same.

"It should come as no surprise however that not all barrier islands fit these models," said Harper. "Go back to sedimentological basics when looking at core, logs and seismic. Look at the depositional process models, and recognize the scale at which they operate."

The classical model—which changes significantly as the rate of sedimentation increases, commensurate with increased coastal energy of combined winds, waves and topography—applies only in generalities, said Harper.

It was challenged by **L. Davis**, a colleague of Harper's, in a PhD thesis in 2002. Contrary to the accepted model, Davis' hypothesis concluded that deeper water sediment fans occur off a barrier island/spit.

Harper showed a series of basin-floor fans on the Flat

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Left image: East coast barrier island

Data mining – Continued from Page 1

regression techniques for making predictions. At the Ryder Scott reserves conference, he said, "Traditional linear regression methods are problematic because of the impacts of missing and erroneous data, non-linear data and subtle interrelationships among variables that may be hidden."

LaFollette's answer is to use multivariate analysis combined with pattern recognition from geographical information systems to work toward better answers. He and his colleagues have written several technical papers for the Society of Petroleum Engineers that focus on the use of that approach and address questions of well optimization in unconventional reservoirs in the Barnett, Bakken and Eagle Ford shale plays.

With even more relevancy now in a low-price environment, LaFollette's presentation, "Well productivity drivers in unconventional reservoirs: What the data can tell us?," is posted at ryderscott.com/presentations. The combo approach has not been documented in technical literature previously, the authors' research indicates.

Data for statistical analysis

LaFollette et al made use of public and private data in amassing the available variables for the three plays. For the Barnett, they used directional surveys, all of which were in the public domain, from 3,300 wells to interpret the effect of lateral length, drilling azimuth, drift angle and degree of undulation (porpoising) on productivity.

"University professors would tell me, 'you can't do anything with public data,' until they saw what can be done with it. The next thing I knew was grad students were working on public data-mining projects," said LaFollette.

He said that as of November 2014, his team had parsed about 4,000 Barnett vertical wells and about 62,000 horizontal wells onshore the United States for all formations, including shales. LaFollette used public data collected by IHS Inc.

Randy F. LaFollette, director-applied reservoir technology at Baker Hughes Inc.

Barnett model

LaFollette showed inherent problems of cross-plotting peak gas rates vs. stimulated fluid volumes in the Barnett shale play. While the plot was built to show the relationship between bigger frac jobs and increased production, it failed to account for the influence of independent variables, such as reservoir-quality differences, while the broadly scattered data points had numerous outliers.

Conversely, using boosted-tree, multivariate analysis, LaFollette's team captured the influence of injection rates and fluid volumes in the absence of all other variables. The method enables modeling the effect of specific well architecture, completion and stimulation parameters on the production outcome by integrating out the impact of the other variables in the system.

"The tree models are better because first of all, there is no assumption of an error distribution. You're not trying to fit something that may or may not fit," he said.

Comprised of thousands of decision trees, the boosted-tree model better predicts dependent variables based on observed values even in cases where relationships are complex and non-linear.

GIS data was also integrated into the model of the Barnett. Pattern recognition is an important tool in the analysis of the large, multivariate data set where geological, geomechanical, and geochemical factors are strong predictors of well production.

A geochemical map with thermal maturity data points was generated and overlaid with a bubble map of production and subsurface map. **The best 10 percent** of the wells were in two sweet spots in two fault blocks. "You can see that the best wells are drilled away from the faults. There is a strong tendency for poor wells to be drilled right along the Barnett faults," said LaFollette.

After starting with up to 100 variables and using a "backwards-stepping" feature elimination, **10 key parameters** reached the top of the importance plot with the No. 1 factor being north-south location. "It's location, location, location. That's the main predictor for production. If your reservoir quality is poor, you can't frac your way out of that," said LaFollette.

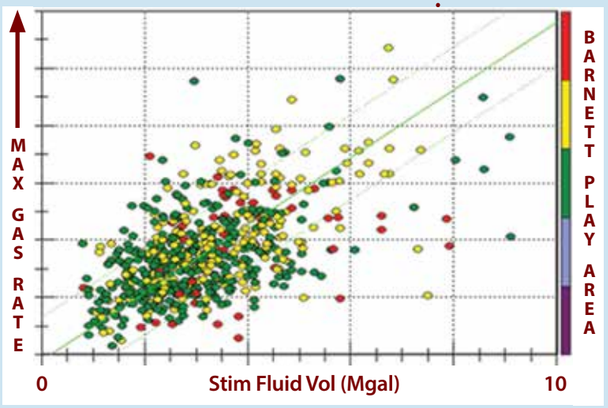
After north-south location, the following parameters ranked by influence were as follows: Completed length of the lateral, treatment volumes, 40-70 mesh-size proppant, 20-40 mesh-size proppant, true vertical depth, frac fluid injection rate, east-west location, surface treating pressure and proppant concentration.

Higher-volume and higher-injection-rate frac treatments were associated with better wells. Horizontal drilling azimuth, lateral length and drift angle matter, said LaFollette. In this and the

Continued on the next page

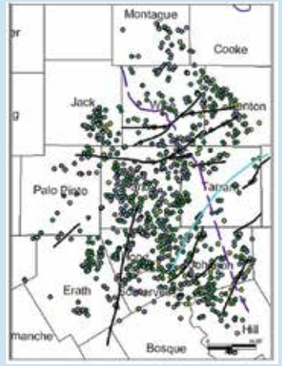
History: Spreadsheets and Cross Plots

Do Larger Treatments Yield Increased Production?

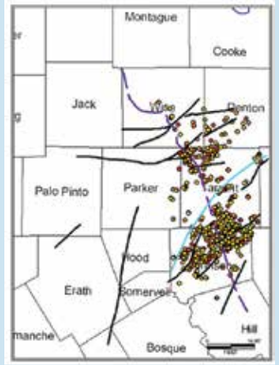


Source: SPE Paper No. 140524

Lowest 10% vs. Best 10% of Barnett Horizontal Producers



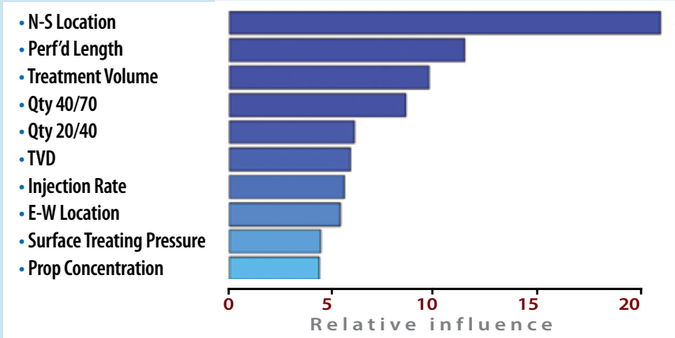
Location of lowest 10% of peak producers



Location of top 10% of peak producers

Source: SPE Paper No. 140524

Boosted Trees Importance Plot: Top 10 Parameters Influencing Decline in Barnett



Data mining – Continued from Page 5

other two studies, it was important to use well location as a proxy for reservoir quality when working with data sets that lacked such measurements.

Bakken model

Screening the data set with a scatter plot matrix before plugging variables into the model is a preliminary step in this type of study. "The plots are used to screen the data to try to find out close relationships among variables. What you're trying to do, if you have two variables with a close relationship, is take one out of the analysis. Otherwise you're diluting the impact of both of them," LaFollette said.

He presented a graph of variables in the Middle Bakken that were most and least influential to the barrels-of-oil-per-completed-foot-of-lateral-efficiency metric. The most influential in order were completed lateral lengths, well location, prop quantity, fluid volume and prop concentration.

The study found that shorter laterals were more efficient in the Bakken. LaFollette also pointed out that unless there is sufficient experimentation, data mining will not be useful. "If all your wells are drilled in the same direction, if all your fracture treatments are at 100,000 pounds per stage, you can't data mine and learn anything," said LaFollette. "Years ago, we saw that shorter laterals can be more efficient and we published information on that. We had operators tell us the same things."

Stage count was on the least-influential list ranking 13th out of 15 total variables. "Beware of people telling you stage count dominates over treatment volumes," said LaFollette. However, he added that experimentation with stages in the studied Bakken data set was not sufficient to warrant any judgements.

"High-stage-count wells tend to have only high proppant masses pumped. You don't have the combination of a high stage count with a very low proppant mass that will tell you which one is more important," LaFollette said. Stage count was shown to be "significant" in the northwest and southeast areas of the Middle Bakken.

Eagle Ford model

The results of this study were presented at the SPE Hydraulic Fracturing Technology Conference last year. Despite the drilling of 5,000 horizontal wells at the time of the study, geologists and engineers were questioning whether their companies were using the most appropriate operating practices, LaFollette said.

The study limited its focus to oil wells with gas-oil ratios less than 15,000 scf/bbl. Multivariate analysis of larger data sets, scaled to local conditions, helped solve the challenge of a small sample size and hidden influences on outcome.

LaFollette showed three sweet-spot areas—two of which lined up along a southwest-to-northeast trend—and increasing API gravities, depth, thermal maturity and pore pressure from northwest to southeast on the map. Pie charts of mineralogy and rock properties for four counties segmented out carbonates, quartz and clay, a key variable.

"Mechanical properties change as you get into the 30- to 40-percent range of clay. What you are trying to figure out is whether hard or soft particles in the rock are bearing the load and whether mechanical rock properties are going to change radically if the rock is made wet and those fractures stay wet for a long period of time," said LaFollette. "The more clay you have, the more susceptible you are to softening and proppant embedment."

A scatter-plot matrix graphed each variable to every other variable to remove ones that were closely related. In Karnes and Gonzalez counties, the most productive region, lower GORs resulted in better performing wells and were a function of location. Generally, higher proppant quantities and longer lateral lengths increased production with stage count appearing to be less significant than treatment size.

"Larger treatments and more proppant are important in boosting productivity in the Eagle Ford, but that does not hold true for all reservoirs. Recent industry work in the Midcontinent showed that larger treatments were not generating higher production metrics. So it's not just play dependent. It's also reservoir dependent and dependent on your specific well location," said LaFollette.

Google Earth: A virtual helicopter flyover

Visually monitoring well operations across the Eagle Ford and other shale plays to mine for data is as easy now as looking at a computer screen thanks to Google Earth overlaid with well maps. LaFollette showed that zooming into the visible well pads, a user can see image dates and whether artificial lift has been installed.

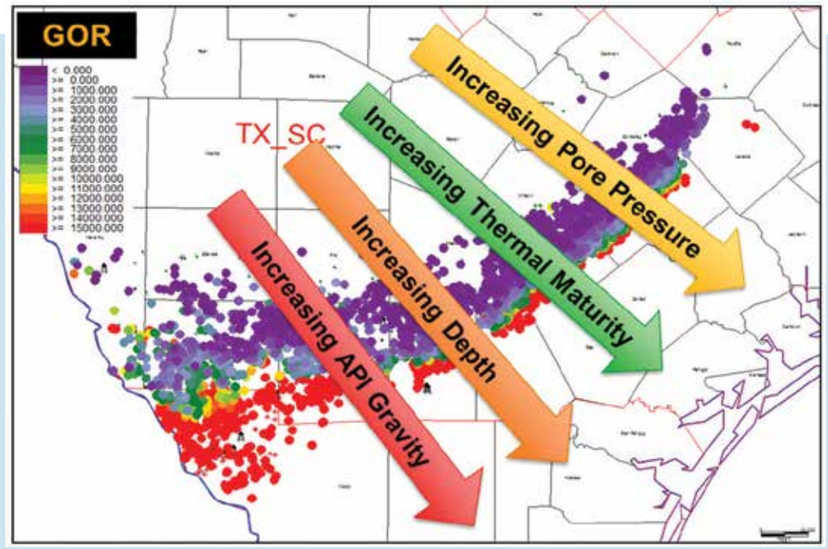
Hyperbolic decline rates in the Eagle Ford and other low-permeability shale plays require installation of artificial lift earlier in the life of the well. Timing is key.

"You can look at the best wells and see image dates indicating when the pump jacks were installed, which in this case, were a very short time after the wells were completed," said LaFollette. "This operator has a reputation for being one of the best and for bringing in among the best production results."

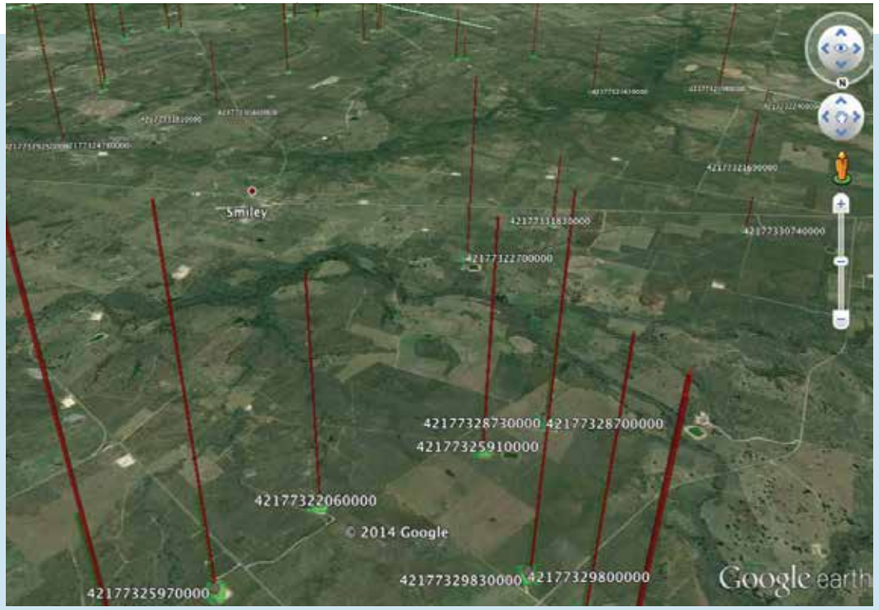
By hovering the mouse cursor over a wellsite, the map used by LaFollette shows details such as play and county identifications, API numbers, cumulative oil production, spud dates and current operator and lessee names. Vertical bars of various heights in the overlay represent productivity for wells in the Eagle Ford.

"Well operations are hardly being monitored at all today using this particular data-mining technique. I think we are going to use Google Earth a lot more in our work to try and really understand well operations from the surface, how they factor into production results and why a particular operator is doing what they are doing," said LaFollette.

For more information on multivariate statistical analysis paired with pattern recognition for shale plays, please contact randy.lafollette@bakerhughes.com.



Increasing Reservoir Parameters in Eagle Ford Shale



The following referenced SPE technical papers are available for purchase at onepetro.com:

- "Practical Data Mining: Lessons-Learned From the Barnett Shale of North Texas," Randy F. LaFollette and William David Holcomb, SPE-140524-MS, 2011
- "Application of Multivariate Analysis and Geographic Information Systems Pattern-Recognition Analysis to Production Results in the Bakken Light Tight Oil Play," Ghazal Izadi, Ming Zhong and Randy F LaFollette; SPE-163852-MS, 2013
- "Application of Multivariate Statistical Modeling and Geo graphic Information Systems Pattern-Recognition Analysis to Production Results in the Eagle Ford Formation of South Texas," Randy F. LaFollette, Ghazal Izadi and Ming Zhong; SPE-168628-MS, 2014

Left: Vertical bars of various heights representing productivity for wells in the Eagle Ford can be seen in this Google Earth map with a custom overlay.

RS Canada is 20 years old

Ryder Scott Canada is 20 years old this year. In 1995, Ryder Scott opened an office in Calgary to better serve an expanding Canadian clientele and to position the firm to be more active in this dynamic oil and gas province. Before that, Ryder Scott had evaluated Canadian reservoirs for many years from the Houston and Denver offices.

The firm's expansion into Calgary was dictated by the logistical advantages of being better able to meet client needs in a timely manner and being close to the 800 oil and gas companies. Ryder Scott also realized that Calgary was home to a talented group of Canadian engineers and geologists.

Initially, Ryder Scott hired a small staff of engineers and geoscientists. Some two decades later, the office has grown to 15 staff members who conduct studies for year-end evaluations, acquisitions and divestitures. Ryder Scott Calgary has also expanded its core services, providing reservoir simulation to complement its classical earth-science and engineering expertise.

"Our Ryder Scott staff in Calgary is looking forward to continued growth in the Canadian market," said **Lynn Kis**, senior vice president and head of the Calgary office.

Grey Cup MVP Mitchell wins another championship

Bo Levi Mitchell, son of Ryder Scott analyst **Susan Mitchell**, was named the Grey Cup most valuable player in quarterbacking the Calgary Stampeders to the Canadian Football League championship on Nov. 30. Mitchell completed 25-of-34 for 334 yards and the Stampeders outscored the Hamilton Tiger Cats 20 to 16.

"I can't even describe it right now," said the 24-year-old quarterback. "Just to get that cup, to get that ring—when it finally happens, it's an indescribable feeling."

The Globe and Mail reported that "his main miscue was an interception early in the fourth quarter, which kept Hamilton in it. Asked about what happened after the game, when it didn't matter anymore, Mitchell said, 'INT. That's what happened. Threw it to the wrong team.' The smile did not leave his face."

Mitchell set the best record for a starting quarterback in CFL history with 12 wins and 1 loss in 2014, stated Wikipedia.

He guided Katy High School in the Houston area to an undefeated season and 5A Division II Texas state championship in 2007.

He started at quarterback for two seasons for Southern Methodist University and passed for 4,590 yards with 36 touchdowns. In 2010, he transferred to Eastern Washington University where he led the Eagles to a championship in the National Collegiate Athletic Association Division 1 Football Championship Subdivision (FCS). Mitchell won the Walter Payton award as the best offensive player in the FCS.

He presented two autographed footballs to Ryder Scott earlier this year.

Photo reprinted with permission of the Calgary Herald newspaper.

Bo Mitchell, second from left, presented autographed footballs to (from left) Larry Connor, managing senior vice president; Fred Richoux, president; and Don Roesle, CEO. Mitchell, son of Ryder Scott analyst Susan Mitchell, was the quarterback for the Calgary Stampeders last year. He led the team to a Grey Cup victory Nov. 30.

SPE short course in reservoir simulation to be held Feb. 26-27

A Society of Petroleum Engineers short course, "Reservoir Simulation for Practical Decision Making," will be presented by **Dean Rietz** and **Miles Palke**, Ryder Scott executive vice president and managing senior vice president, respectively, Feb. 26 and 27. The class at the Royal Sonesta hotel in Houston will begin a day after the society's Reservoir Simulation Symposium concludes.

The two-day course covers all important facets of reservoir modeling with a considerable amount of class time reserved for case studies. Previous models constructed by the instructors will also be discussed.

Topics Include planning a simulation study, acquiring and analyzing data, fluid properties and rock-fluid interaction, developing geologic models, constructing grids and history matching and prediction.

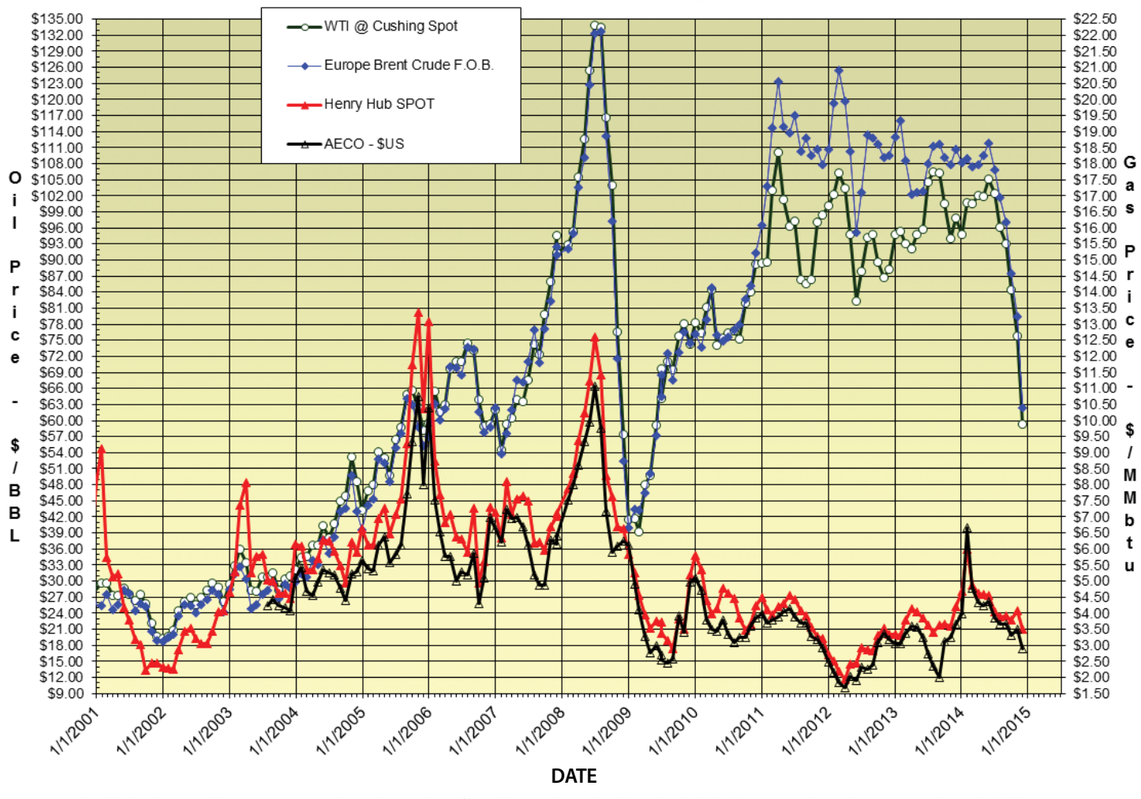
The aim of the course is to enable attendees upon completion to better understand how to plan and conduct reservoir studies and how to review studies conducted by others. This intermediate course is for those who want to progress beyond the SPE Fundamentals of Reservoir Simulation course.

"Those involved in conducting, reviewing, or overseeing reservoir simulation studies will benefit," said SPE.

Participants are encouraged to bring materials and non-confidential data relating to potential projects. The class, guided by Rietz and Palke, will brainstorm and discuss approaches to achieve desired objectives.

Attendees will receive 1.6 Continuing Education Units. To register, go to http://www.spe.org/events/rss/2015/pages/general/registration.php.

Price history of benchmark oil and gas in U.S. dollars



Published, monthly-average, cash market prices for WTI crude at Cushing (NYMEX), Brent crude and Henry Hub and AECO gas.

Reserves writedowns, impairment charges inevitable in 2015

With oil prices below $45 a barrel in January, public companies were bracing for first quarter reserves writedowns. "Impairments are unavoidable," said **Mark Sadeghian**, an energy-industry analyst at Fitch Ratings Ltd. in Chicago as reported by Bloomberg news agency Jan. 6.

Just how are reserves writedowns and impairment charges in petroleum accounting related? If the reserves report's values—typically, discounted future cash flows as a standardized measure—are less than the net book value of the assets, which is an accounting metric, then the property is impaired.

"One of the basic tenets of accounting is that the book value is the lesser of either the actual capitalized costs minus deductions or of the current value," said **Dan Olds**, managing senior vice president. He is author of technical paper, "Basic Petroleum Accounting for Petroleum Engineers," Society of Petroleum Engineers No. 162907-MS, 2012.

Book value

Book values are adjusted to account for capital spending for field development and production of associated reserves through an annual DD&A (depreciation, depletion and amortization) process. Typically, an accountant uses the net book value and a reserves report to calculate a depletion rate and then applies it to annual production to determine book value that was lost because of production.

Olds cited the formula for adjusting book values through a depletion rate calculated as follows: Depletion rate = book value/reserves; Annual DD&A = depletion rate x annual production. He also examined how DD&A is treated under both full-cost (FC) and successful-efforts (SE) accounting methods.

Under FC, all exploration and drilling costs are capitalized into a single, full-cost pool for each country. That approach dilutes the financial impact of a discovery or dry hole during the reporting period and results in more stable financial results.

SE companies capitalize drilling costs for discoveries or development wells, but expense exploration dry holes. The pool concept is limited to a single well, reservoir or field. Under SE, a significant discovery or dry hole is more immediately reflected in the financial reporting period.

FC companies factor in all categories of proved reserves in the depletion-rate calculation. SE companies adjust the book value of producing properties using proved developed reserves only, but consider the total proved reserves for amortizing acquisition costs, such as bonus payments or lease acquisitions.

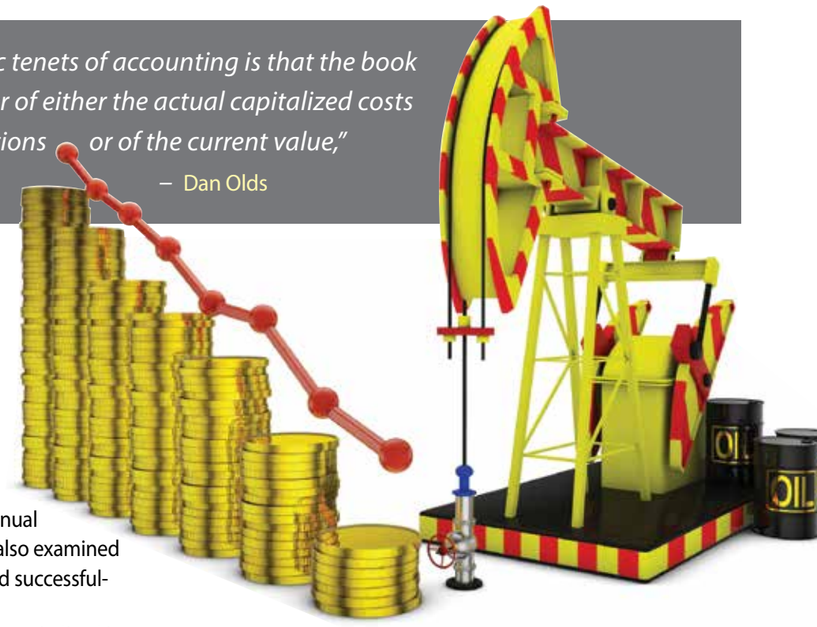
Impairment

The impairment process is different between FC and SE accounting as follows:

FC impairment—Discounted net present values in the reserves report are compared to the net book value (full-cost pool). If the ceiling test finds that the net book value is higher, then it is written down to the discounted NPV. Impairment is more likely for FC companies, because the FC pool may include unsuccessful wells that would be expensed under SE accounting.

SE impairment—Net book value is compared to the reserve report as in full cost, but adjustments can be made. A public issuer

> *"One of the basic tenets of accounting is that the book value is the lesser of either the actual capitalized costs minus deductions or of the current value,"*
>
> – Dan Olds



can consider changes to expected future prices and costs. An appropriate discount rate can be used. Companies also make adjustments for income taxes.

For a detailed analysis of petroleum accounting, reserves and impairments, please reference Olds' SPE paper for purchase at onepetro.com. For more information on book values and reserves, please see presentation by Olds at http://www.ryderscott.com/WP/wordpress/wp-content/uploads/2014/03/RSC-2012-Reserves-Conference_4BookValue_Olds.pdf.

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Maverick hypotheses – Continued from Page 3

Island Barrier Complex, which progrades along shore into the deeper waters of St. George's Bay in western Newfoundland, Canada. The fans in the aerial photographs were delineated with side-scan sonar.

"Believe it or not, some deny the side-scan data because it does not fit the accepted model," said Harper. "They refuse to accept it because it's not in the (classical) barrier model."

He showed the results of seismic and core data indicating the presence of submarine fans and fan toes 25- to 30-meters deep close to a 35-meter-deep basin floor.

Wembley field, Doig formation

Harper and colleague **Jessica Beal** proposed an alternative barrier-island depositional model of the Wembley field and its Triassic Doig formation in 2007. The newer theory states that the "anomalously thick sand bodies" formed from a barrier bar prograding off an antecedent shelf into deepening water and not from estuarine channel facies, abandoned channels cut into a lower shoreface margin or fault-related sand bodies.

Progradation involves growth of a river delta farther out into the sea over time.

Harper said that geoscientists were so busy looking at the Wembley Doig sands that they didn't look at the other facies in the sequence. He and Beal found that the field extended southward as spit lobes shingled the previous spit and shale lenses separated each lobe.

"The formation has the same mechanics as deepwater fields in Brazil, Africa and the Gulf of Mexico," said Harper. "Under the (classical) barrier model, geologists could not correlate one fan in Wembley Doig from another, but that can be done with log analysis."

The study found that random fan distribution resulted in log variability along the western margin of the sand body.

John Harper

"Reservoir modeling must begin with the rocks and not the accepted opinion," said Harper. "Consider the very significant facts of sediment supply, bathymetry, coastal morphology, spit-growth partitioning and coastal sorting to optimize production."

Harper's presentation is posted at ryderscott.com/presentations.

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