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Software Delineates Stratigraphic Traps

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BOUNTIFUL, UT.–The search for gas in stratigraphic traps in the Green River Basin has been difficult over the basin's lengthy exploration history. The reservoir sandstones and their encasing rocks tend to be dense and of high velocity. Lithology changes that create stratigraphic traps commonly lack corresponding impedence changes, and therefore, do not generate mappable reflections. These reservoirs, even when gas-filled, do not lend themselves to direct hydrocarbon detection.

Numerous high-tech approaches, such as applying amplitude-versus-offset (AVO), azimuthal velocity analysis, and three-component seismic acquisition for shear data, have not proved to be significant risk reducers in exploring for gas. However, a breakthrough technology–event resolution imaging (ERI)–has been successfully applied to delineate Green River Basin stratigraphic traps.

In 2003, Tom Brown Inc. used the technology on a test case involving seismic data from the proprietary Lookout Wash 3-D data set, a 58 square-mile survey shot in July 1999 by Western Geophysical and reprocessed by Tricon Geophysics in 2002.

The Lookout Wash Gas Field is located in T14N-R93W in Carbon County, Wy., on the eastern flank of the Washakie Basin portion of the Greater Green River Basin. A handful of excellent gas wells produce from thick, porous Almond Sandstone on trend with prolific Almond production in Standard Draw-Echo Springs gas fields to the north.

This good Almond production has been interpreted to be from Almond bars deposited in a long linear north-to-south trend. The bar system has subsequently been tilted up to the east. In this system, dry holes are encountered east of the bar edge line, because the reservoir is missing. Poor wells (low rate and low recovery) are encountered in the bar system downdip to the west where Almond bar sandstone is present, but where gas saturation is too low to make for good production. Excellent wells are encountered in the updip edge of the bar system.

Learning Wells

In the test case, seismic traces relating to five wells representing three conditions were used for learning. The wells, and their corresponding conditions, were:

- Well Nos. 12 and 14, where no sand was penetrated (the wells are located too far updip and east of the bar edge line);
- Well No. 6 with a subeconomic sand volume (the well is located too far downdip and low in the bar with poor gas saturation); and
- Well Nos. 1 and 3 with economic sands (10 billion cubic-foot wells positioned high in the bar system).

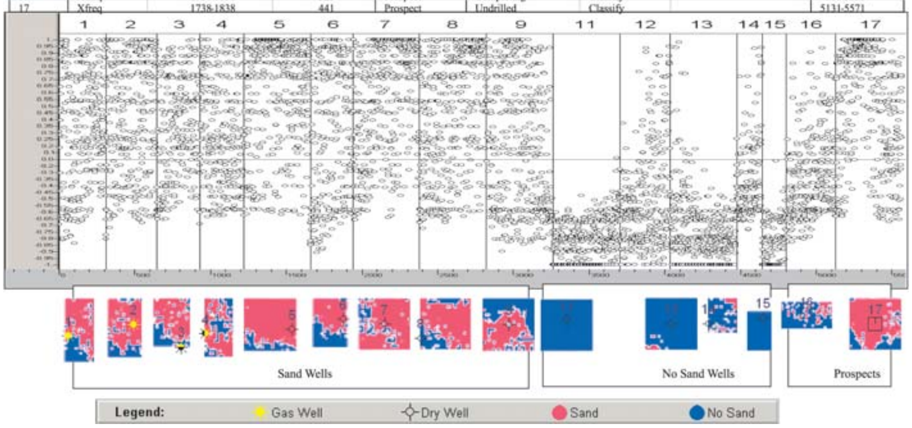
In addition, the locations for another 12 drill sites (four representing no sand, four with subeconomic sand, two with economic sand, and two locations not drilled at the time) were also made available for the Green River Basin study.

The objective of the study was to determine the feasibility of applying event resolution imaging software technology to use the Lookout Wash 3-D seismic data to separate drill sites into two categories:

FIGURE 1

Separation of Sand versus No Sand (Green River Basin, Wyoming)

Well #	Data Type	Time Window	Traces	Condition	Status	SI Use	SI Key Traces	KAP Traces
1	Xfreq	1784-1884	312	Drilled	Sand	Learn	1-312 (Even)	1-312
2	Xfreq	1803-1903	336	Drilled	Sand	Classify		313-648
3	Xfreq	1784-1884	285	Drilled	Sand	Classify		649-933
4	Xfreq	1809-1909	288	Drilled	Sand	Classify		934-1221
5	Xfreq	1836-1936	441	Drilled	Sand	Classify		1222-1662
6	Xfreq	1824-1924	280	Drilled	Sand	Classify		1663-1942
7	Xfreq	1877-1977	441	Drilled	Sand	Classify		1943-2383
8	Xfreq	1833-1933	441	Drilled	Sand	Classify		2384-2824
9	Xfreq	1746-1846	441	Drilled	Sand	Classify		2825-3265
11	Xfreq	1704-1804	441	Drilled	No Sand	Classify		3266-3706
12	Xfreq	1758-1858	330	Drilled	No Sand	Learn	1-300 3rd starting with trace 1	3707-4036
13	Xfreq	1603-1703	441	Drilled	No Sand	Classify		4037-4477
14	Xfreq	1602-1702	168	Drilled	No Sand	Learn	1-168 3rd starting with trace 2	4478-4645
15	Xfreq	1650-1750	160	Drilled	No Sand	Classify		4646-4805
16	Xfreq	1756-1856	325	Prospect	Completing	Classify		4806-5130
17	Xfreq	1738-1838	441	Prospect	Undrilled	Classify		5131-5571



"sand wells" and "no sand wells." A further aim was to determine whether ERI could be employed to separate economic gas wells from uneconomic gas wells by analyzing 3-D seismic data.

In event resolution imaging, the seismic traces in the vicinity of existing bore holes are analyzed to discover useful patterns in the seismic data that robustly discriminate between any two states (states A and B). State A might represent sand while State B represents no sand, or State A could represent an economic gas well while State B could represent an uneconomic gas well. As another example, State A could represent a high-production oil well and State B could represent a low-production oil well, or a dry hole. In this manner, event resolution imaging technology employs mathematical information found in 3-D seismic data to separate two distinct states based on the known characteristics and the known production levels of existing wells.

In some ways, ERI behaves like a neural network in that it learns from the seismic traces around existing wells. However, strictly speaking, ERI does not employ neural network technology to do its learning because it does not use back propagation or gradient descent. As a matter of fact, ERI does not use traditional discriminate analysis, linear regression, non-linear regression, or any type of algorithm that attempts to minimize a least squares equation in order to minimize the metric distance between target values and actual values.

Counting And Sorting

What event resolution imaging does do is rely on a computationally intensive method of simple counting and sorting, thereby employing the awesome power of the modern computer to simply step into, and sort through, a large number of separation landscapes, with each landscape being spanned by a number of features, characteristics or mathematical attributes of the 3-D seismic signal. Attributes such as amplitude, frequency and phase relationships are encoded in signal features that are composed utilizing appropriate feature weights to generate a composite attribute value or activation value that is plotted on a key activation plot (KAP), as shown in Figures 1 and 2.

The seismic traces in the vicinity of the good wells, such as sand-bearing wells or gas producing wells, are considered to be "sheep" and take on positive values between zero and positive infinity. The individual seismic traces in the vicinity of bad wells, such as nonsand wells or dry holes, are considered to be "goats" and take on negative values between zero and minus infinity.

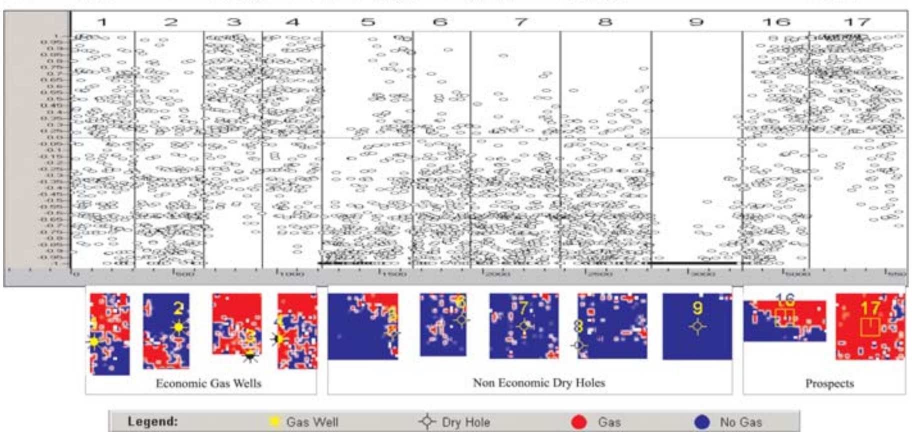
A threshold is determined by laying down a separation fence in each distinct attribute space to separate the sheep from the goats over the separation landscape. The software searches for a separation space or attribute landscape where most of the sheep are on the right side of the separation fence and most of the goats are on the left side of the separation fence. No preference is given to whether the sheep come right up close to the fence or are scattered out toward infinity. For the purposes of counting and sorting, all that is important is that the sheep are on the right side of the fence and the goats are on the left side. In this way, no artificial statistical mixing pressures are introduced into the separation problem.

Once the best separation landscape (having the highest number of animals each positioned on their correct side of the fence) has been found, a separation key, which encodes those attributes and feature weightings necessary to effect the separation of the seismic traces (animals), is then recorded. A natural distribution function is composed of the learning data to map the sheep that naturally scatter from zero to positive infinity onto a 0.0 to +1.0 scale. Likewise, the goats, which naturally scatter from zero to minus infinity, are mapped onto a 0.0 to -1.0 scale. Following this approach, a KAP is generated with values ranging from -1.0 to +1.0, with a zero axis playing the role of the separation fence.

FIGURE 2

Separation of Economic versus Uneconomic Gas Wells (Green River Basin, Wyoming)

Well #	Data Type	Time Window	Traces	Condition	Status	SI Use	SI Key Traces	KAP Traces
1	Xfreq	1784-1884	312	Drilled	Gas	Classify		1-312
2	Xfreq	1803-1903	336	Drilled	Gas	Classify		313-648
3	Xfreq	1784-1884	285	Drilled	Gas	Learn	1-280 (Even)	649-933
4	Xfreq	1809-1909	288	Drilled	Gas	Classify		934-1221
5	Xfreq	1836-1936	441	Drilled	Not Economic	Classify		1222-1662
6	Xfreq	1824-1924	280	Drilled	Not Economic	Learn	1-280 (Even)	1663-1942
7	Xfreq	1877-1977	441	Drilled	Not Economic	Classify		1943-2383
8	Xfreq	1833-1933	441	Drilled	Not Economic	Classify		2384-2824
9	Xfreq	1746-1846	441	Drilled	Not Economic	Classify		2825-3265
16	Xfreq	1756-1856	325	Prospect	Completing	Classify		4806-5130
17	Xfreq	1738-1838	441	Prospect	Undrilled	Classify		5131-5571



Sand Analysis

Figure 1 shows a key activation plot for wells labeled Nos. 1-17. Each column contains a number of data points representing 160-441 seismic traces in the vicinity of each bore hole. Each data point represents a single seismic trace. A time window of 100 milliseconds, centered on the pay zone, was used to analyze each seismic trace.

Tom Brown provided cutouts around each well for analysis of two 3-D volumes: a dip moveout (DMO) migration volume and an XFREQ volume (XFREQ is a high-frequency analysis package proprietary to Tricon Geophysics). It was found that the wells separated more easily into their correct categories using the XFREQ data volume from Tricon, presumably because some of the features used in the separation key encoded frequencies in the higher ranges.

In the key activation plot of Figure 1, three wells were used for learning: the No. 1, 12 and 13 wells. Well No. 1 was used as an example sand well, with 156 of the traces in the vicinity of this well bore used for learning. Well Nos. 12 and 14 were used as examples of no sand wells, or wells drilled in locations where no sand was found. In the vicinity of Well No. 12, 100 traces were used for learning, while 56 traces were used from the vicinity of Well No. 14. A collection of features was found in the data, which accurately separated the nine wells containing sand (Well Nos. 1-9, with an average sand thickness of 17 feet) from the five wells that contain no sand (Well Nos. 11-15). Well Nos. 16 and 17 were undrilled prospects.

As can be seen in Figure 1, the first nine wells (the sand wells) have nearly all of their data points (traces) in the range from -0.7 to +1.0, with very few data points in the range between -0.7 and -1.0. In contrast, the wells that contain no sand (Nos. 11-15) have most of their data points at values less than 0.0, and only have a very small number of data points close to 1.0.

As this example illustrates, using only three wells it is possible to learn to accurately separate a significantly larger number of wells into their correct categories of sand verses no sand.

The colored images below each column of Figure 1 indicate a map view of the SEGY data corresponding to the data points in the KAP, with the value of each data point, or trace, being recorded in SEGY format according to its X-Y location in the survey. Also, the location of each well bore is indicated in the colored map view plot.

Gas Analysis

In applying the ERI method to separate economic from uneconomic gas wells, only two wells were used for learning: Nos. 3 and 6. In the vicinity of both wells, 140 seismic traces were used as State A (economic gas, Well No. 3), and State B (uneconomic, Well No. 6). In this economic-verses-uneconomic gas well study, the XFREQ data set from Tricon Geophysics again separated better than the standard DMO migration data.

The separation key used to generate the KAP shown in Figure 2 encoded features in the data that separated the four good gas wells (Nos. 1-4, averaging an estimated 5 billion cubic feet in ultimate recovery from the Almond bar) from the five uneconomic wells (Nos. 5-9, averaging less than 1 Bcf in estimated ultimate recovery from the Almond bar). All nine of these wells contained sand, but only the first four contained economic quantities of gas. Well No. 17 was an undrilled prospect, and Well No. 16 was a prospect in the process of being completed during the study (No. 16 turned out to be a good well, producing economic quantities of gas).

The No. 1 and 2 wells were partially depleted prior to shooting the 3-D seismic data. This may account for the reason the data points for these two wells seem to be evenly distributed between -1.0 and +1.0, whereas the majority of the data points for Well Nos. 3 and 4 are between 0.0 and +1.0.

Notice that the dry holes (Nos. 5-9) contain very few data points close to +1.0. All of the uneconomic wells have the majority of their data points between 0.0 and -1.0. Therefore, even though this separation is by no means perfect, it does show that it is possible to separate a number of wells–in this case, four good gas producing wells from five uneconomic wells–by learning on only two example wells.

In the colored map view cutouts below each well at the bottom of Figures 1 and 2, the data points with positive activation values between 0.0 and +1.0 are shown in red, and the negative activation values are shown in blue. The location of each bore hole is also indicated in the map view cutouts.

3-D Contrast Volume

Separation keys, like the ones used to generate the key activation plots in Figures 1 and 2, can also be applied to a picked pay horizon to generate a map view of an entire 3-D seismic survey following a particular pay horizon to generate a 3-D contrast volume. Such 3-D contrast volumes, which separate between a State A and a State B, can be generated and viewed on 3-D visualization workstations to identify new prospects. Therefore, event resolution imaging is often called a contrast volume method, in that it can be used to generate a 3-D volume comprising contrast information between any two states. The pair of states can be sand versus no sand, gas versus no gas, oil versus no oil, high porosity versus low porosity, etc. One particularly useful application of this method may be to separate high producing wells (State A) from low producing wells (State B) over

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a given 3-D seismic survey.

For the Green River Basin test case, ERI would have been a significant risk reducer had the technology had been applied before a large number of wells had been drilled. The "no sand" wells may not have ever been drilled. Many of the uneconomic wells may not have been drilled either. Two of the economic wells would probably have been relocated (with unknown results). Certainly, the rate of return would have been significantly higher for a program involving these locations.

It appears possible to use seismic trace separation techniques, such as ERI, to learn on a few wells and then to separate a large number of wells in a given survey, into one of two binary states, A or B (i.e., separating sand from no sand wells, or economic from uneconomic gas wells).

This technology has been applied to a wide variety of other 3-D seismic surveys recorded from various locations around the world to separate gas from no gas, sand from no sand, high porosity from low porosity, oil from dry holes, and high production from low production wells. The binary separation method of ERI has been used for both onshore and offshore data and can be applied to substacks, such as near-stacks, mid-stacks and far stacks, as well as specialty stacks corresponding to particular attribute volumes.

With the emergence of this technology, a new tool can be placed in the explorationist's toolbox to aid in the delineation of stratigraphic traps. The ERI tool has the potential to significantly reduce risk and greatly enhance return on investment in plays and prospects where 3-D seismic data exist or where their acquisition is being considered. ❐

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