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4-D, 9-C Delineates Key CBM Variables

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GOLDEN, CO.–The Rulison Field in the Piceance Basin in western Colorado is the site of the world's deepest coalbed natural gas production, with wells producing methane gas from coal beds at depths of 7,200-8,000 feet. CBNG is produced from tectonically-enhanced fracture zones in the coals. Time-lapse multicomponent 3-D seismic data have been used to identify the tectonically enhanced fracture zones in the coal interval.

The Rulison Field is a basin-centered gas accumulation with a production history dating to the 1960s. It is located along the Colorado River between the Mamm Creek Field to the east and the Parachute and Grand Valley fields to the west. The target reservoir is made up of fluvial deltaic sandstones and coals in the lower part of the Cretaceous Williams Fork formation, and alluvial-plain sandstones in the upper part.

Wells produce from the Cameo Coal interval and the overlying tight gas sand interval of the Williams Fork. The matrix permeability of the sandstones ranges between 5 and 80 microDarcies, and natural fractures in the tight sands significantly enhance relative permeability to gas. Permeability enhancement through hydraulic fracturing is greatest when the fracture stimulation connects the natural fracture network to the well bore.

The Cameo Coal constitutes reservoir as well as source rock. The coals contain natural fractures, but at the depth of production in Rulison Field, cleat permeability is in the microDarcy range. Well productivity depends substantially on enhanced permeability through tectonic fractures.

Multiple 9-C Surveys

Multicomponent 3-D seismic monitoring is being conducted at the Rulison Field under the direction of the Colorado School of Mines' Reservoir Characterization Project. Three multicomponent (9-C) seismic surveys have been acquired to date. The first survey was acquired in 2003, a repeat survey was shot in 2004, and then another in 2006 (Figure 1). The operator of the field, Williams Production Company, is conducting an ongoing infill drilling program to reduce development spacing to 10 acres (660 feet) between wells.

Most wells are completed in multiple stacked, lenticular tight sands and coals, starting with the upper low-permeability sandstone interval and extending into the Cameo Coal zone. The overpressured net pay interval averages 1,000-1,200 feet in thickness. Typically, multiple hydraulic fracture stages (generally between four and six) are completed in each well.

Conventional compressional (P) wave seismic data have done little to augment this reservoir. Multicomponent data give different images of the reservoir, and these images are of value for fault and fracture delineation, and for detecting gas-saturated intervals. Consequently, multicomponent seismic surveys were shot to determine if the data could detect the fracture zones that control the permeability structure in the reservoir.

Experience has shown that the seismic character in the reservoir interval is

FIGURE 1

Multicomponent Acquisition Grid

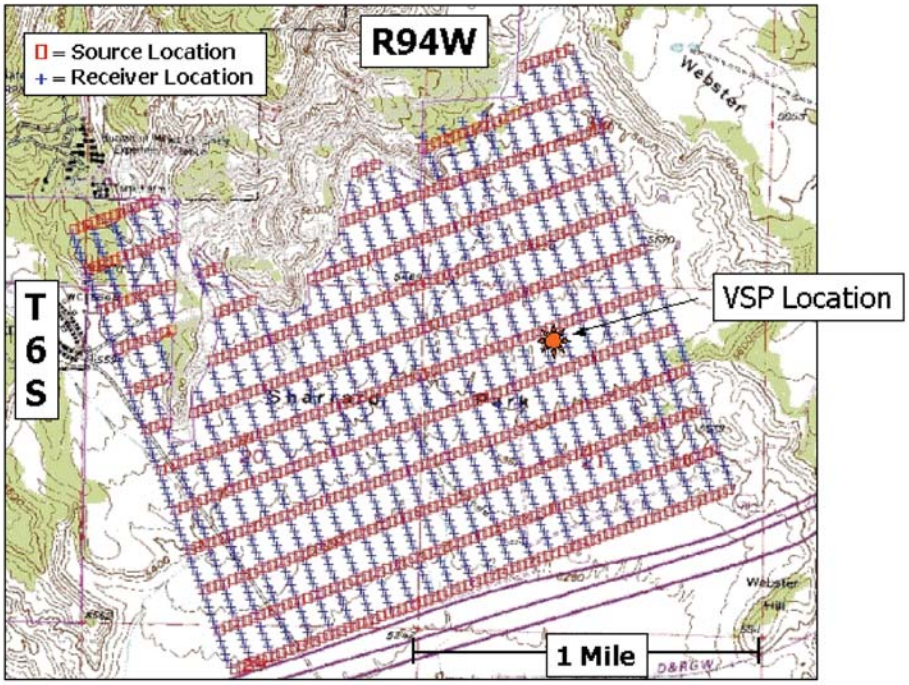
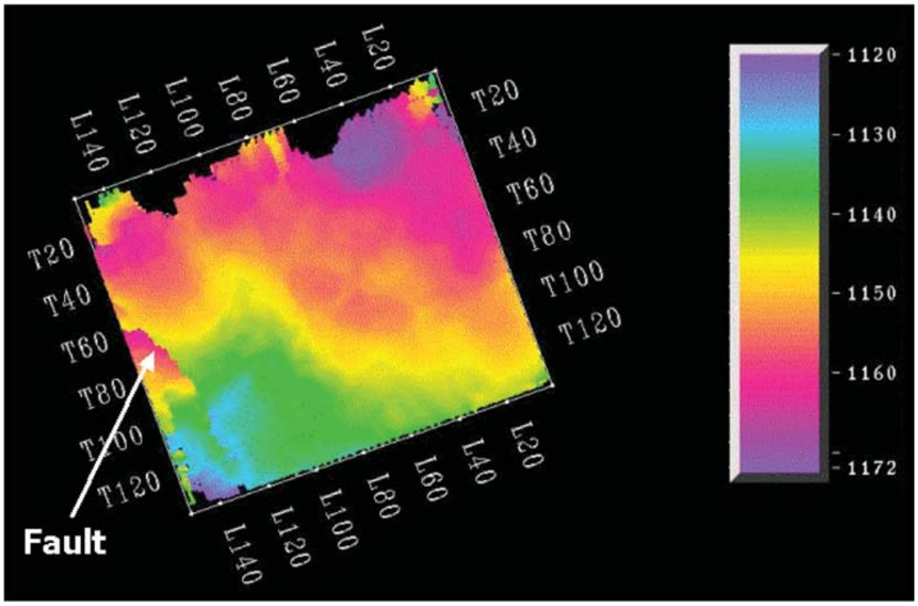


FIGURE 2

P-Wave Time Structure Map (Top of Cameo Coal)



generally different between compressional and shear (S) waves. This difference is the result of the different impedances that are affecting the seismic response of these two wave modes.

Compressional waves are sensitive to the presence of gas, which affects bulk compressibility. Because S waves are unaffected by gas, shear energy is better for imaging this gas reservoir. Natural fracturing is another significant factor. S waves are much more sensitive to fractures than P waves. Shear waves are affected by rigidity, whereas P waves are affected by compressibility and rigidity. Therefore, changes in the reflectivity of shear waves can be attributed to changes in rigidity caused by fractures.

Project Objectives

In regard to the Williams Fork Sandstones, time-lapsing the multicomponent data assists in detecting "sweet spots" with high natural fracture permeability in the tight gas reservoir, as well as monitoring reservoir conformance as the field is developed. For the coals, the 9-C surveys were shot to characterize the tectonic fractures that control permeability in the Cameo reservoir. Once production commences, pore pressure declines, which leads to fracture closure and diminishing permeability. As a result, well production drops rapidly with an early flush of production from the fractures, followed by gas desorption from the matrix.

Solid State Geophysical Ltd. acquired the time-lapse multicomponent 3-D data for the Reservoir Characterization Project using the Input/Output (now ION Geophysical Corp.) Vectorseis™ radio telemetry system in 2003 and a cable telemetry system in both the 2004 and 2006 surveys. P- and S-wave vibrators were used to acquire a full-wave field (9-C) survey. Subsurface bin size was 55 X 55 feet, with 1,500 single Vectorseis sensor locations and 770 source locations, with three components of source located at each point. The grid was located as a single live patch throughout the survey area, with receiver line spacing of 330 feet and source line spacing of 660 feet. Data quality is excellent.

A time structure map on the top of the Cameo Coal interval is shown in Figure 2. Note the area of high curvature on the flank of the Rulison Field "nose" in the central portion of the study area. This is an area of natural fracturing associated with folding and extension related to a wrench fault zone.

Overpressure in the Rulison Field is a result of active gas generation in the coals. Pressure depletion from fractured coal beds creates time-lapse seismic anomalies that are observed on elapsed time surveys. As pressures are lowered, the fracture systems close and seismic impedance increases. This response can be seen with time-lapse seismology, since the fractures are dynamic and change in response to changes in effective stress.

In addition, as pressures are depleted in the reservoir interval above the coals, it creates the potential for methane gas to remigrate from the coals into the overlying reservoir rocks. Gas remigration through the fracture network is a possible explanation for abnormally high-productivity wells that are connected through the fracture system, and in fact, time-lapse difference mapping of the Cameo Coal interval supports this remigration hypothesis.

The coals are dry and devoid of free water. Pressure gradients up to 0.8 psi/foot have been observed in the coal interval. A high-permeability fairway, or sweet spot, related to tectonic fracturing associated with the wrench fault system is present in the central region of the survey area.

FIGURE 3

P-Wave Time-Lapse Data (RMS Amplitude Difference Anomalies)

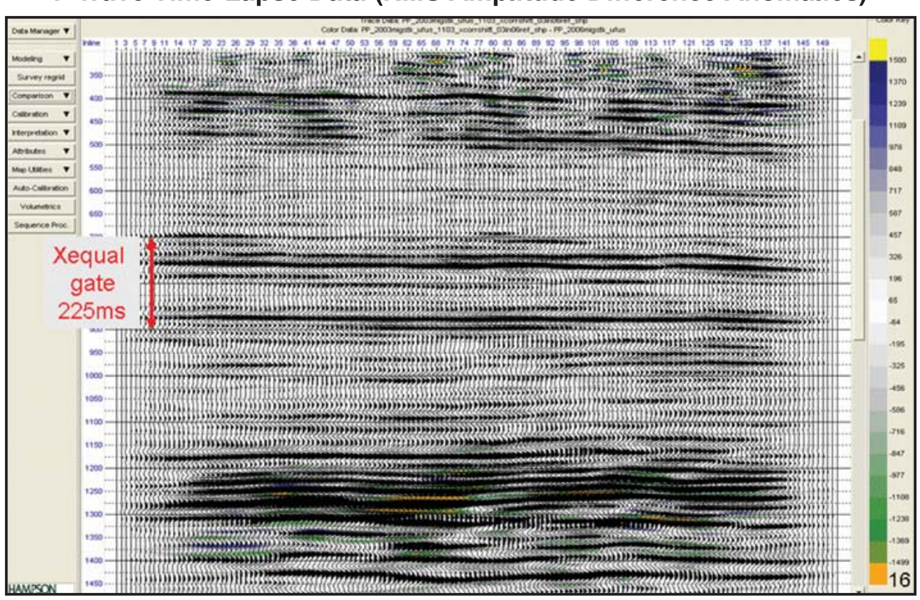


FIGURE 4A

P-Wave RMS Amplitude Difference (20-Millisecond Window at Top of Cameo)

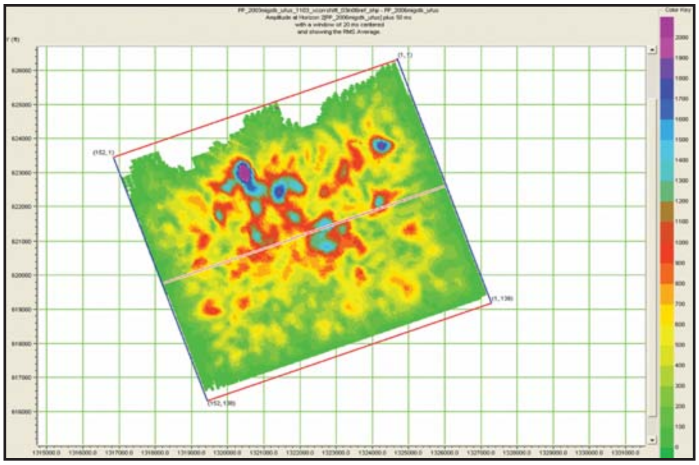
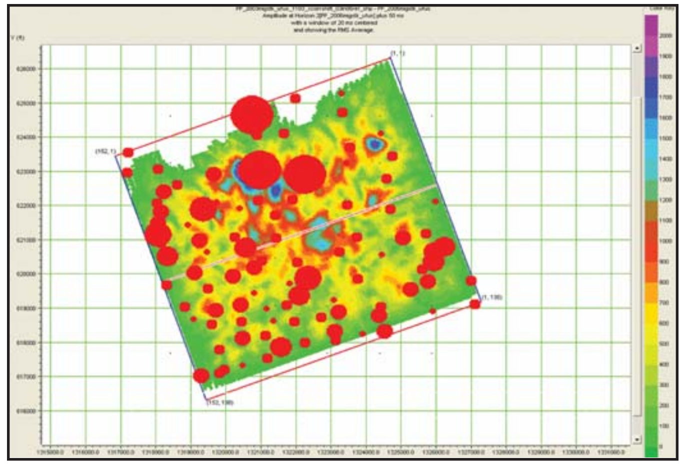


FIGURE 4B

2003-06 Production (Wells Scaled to Bubble Size)



Critical Component

Time-lapse seismic data demonstrate that the coal beds are a critical component of the tight gas resource at the Rulison Field. Lowering pore pressure in the coal interval causes an increase in effective stress and an increase in velocity and density, or acoustic impedance in the coals as a result of a decrease in pore pressure and crack closure. Monitoring this change in effective stress enables the establishment of connectivity in the coalbed methane reservoir.

Comparing the 2006 survey results to the 2003 9-C data reveals areas of change within both the upper and lower sections of Cameo Coal interval. For example, the P-wave time-lapse data in Figure 3 show root mean square (RMS) amplitude difference anomalies between 2006 and 2003 in the coal interval, superimposed on a line from the 2003 survey. An RMS amplitude extraction from a 20-millisecond window hung off the top of the Cameo on the P-wave time-lapse difference volume shows anomalies in the coal interval in the northern part of the study area (Figure 4A).

Interestingly, these anomalies coincide with the best wells in the field that have been drilled since 2003 (more than 100 wells have been drilled in the study area, with roughly one-fifth of them since 2003, when the Reservoir Characterization Project became involved in the Rulison Field). In short, high production occurs because of high pore pressures and tectonic fracturing.

These wells were stimulated by hydraulically fracturing the Cameo interval in a single frac stage. The hydraulic fracture effectively hooks up the natural plumbing network of tectonic fractures in the coal. The fractures preferentially form in the sandstone beds in proximity to the coals, and serve to drain the coals through the interaction of the natural fractures with the induced hydraulic fracture(s).

Cameo Coal Correlations

When well production is compared to the difference map, the larger-volume wells correlate with the areas of greatest change in the upper Cameo interval (Figure 4B). High production relates to high fracture connectivity. Figure 5A contains a line from the difference of the inversion volumes that shows vertical connectivity through the coal interval. The lower Cameo Coal interval contains the thicker, more continuous coals, which are connected through tectonic fractures and hydraulic fractures to the upper coals.

However, the largest differences occur in the lower coal interval. Figure 5B shows an interval difference anomaly in

FIGURE 5A

Inversion Volumes Difference (Vertical Connectivity Through Cameo Coal)

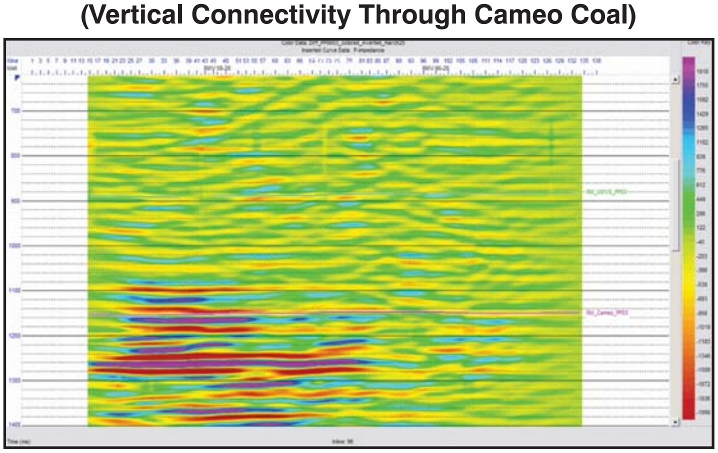
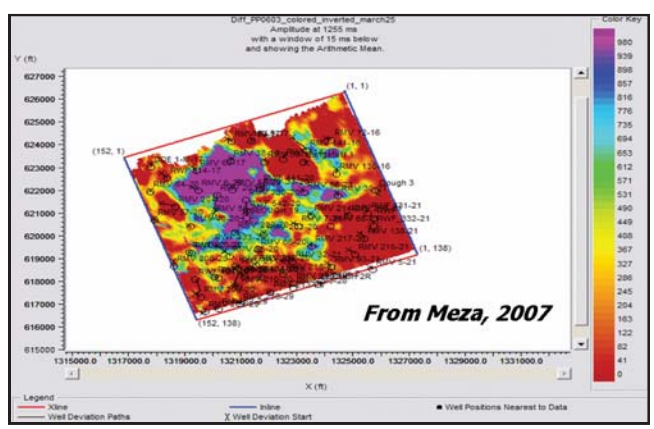


FIGURE 5B

Interval Difference Anomaly in Lower Cameo Coal-D



the lower Cameo Coal-D interval, which corresponds to 15-millisecond window hung from the Coal-D marker at 1,255 milliseconds on Figure 5A.

A key interpretative tool with multicomponent seismic data is calculating the ratio between the velocity of the P wave versus the velocity of the S wave (Vp/Vs). Previous work at Rulison Field has indicated that low Vp/Vs is an indication of gas saturation, making it a potential tool in future exploration and production work. A second key measurement is seismic S-wave azimuthal anisotropy. Areas of high anisotropy tend to correspond to areas of high fracture density in this field.

Sweet spots in unconventional plays are those zones with the greatest storage capacity and the highest fracture density/connectivity for high-productivity wells. Time-lapse seismic data show that sweet spots in the Rulison Field are related to tectonic fracturing in the Cameo Coal interval, as well as overlying zones of natural fracturing connected to the Cameo source beds.

For the field's exploration and production strategy, the key is to find the faults using multicomponent seismology and then high grade the better reservoir through a combination of Vp/Vs measurements and S-wave azimuthal anisotropy. A development strategy is to monitor the reservoir during the early phases of development with time-lapse multicomponent to accelerate production from the better quality reservoir first. ❒

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