Development of Diagnostic Techniques to Identify Bypassed Gas Reserves and Badly Damaged Productive Zones in Gas Stripper Wells in the Rocky Mountain Laramide Basins

during the Period 05/15/2001 to 03/14/2002

By

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March 14, 2002

Work Performed Under Prime Award No. DE-FC26-00NT41025
Subcontract No. 2039-IDT-DOE-1025

For
U.S. Department of Energy
National Energy Technology Laboratory
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Final Report

May 15, 2001 to March 15, 2002

Contract No. 2039-IDT-DOE-1025

Stripper Well Consortium

Prepared by:

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Overview

Many of the gas stripper wells in the Rocky Mountain Laramide Basins (RMLB) have resulted from a very poor understanding of subsurface fluid-flow systems and their impact on drilling, completion, and stimulation techniques. Without a clear understanding of how these systems affect drilling, gas wells characterized by highly damaged productive zones or considerable bypassed pay are common. It is clear that a process-oriented technology is needed to address the specific problems encountered when drilling in anomalously pressured rock-fluid systems.

The essential problem to be addressed in this work is how to identify bypassed gas and badly damaged productive zones in RMLB gas stripper wells. The development of new diagnostic techniques that will allow such identification of bypassed gas and badly damaged productive zones in these wells is imperative, for if these zones can be identified and remediation/recompletion strategies designed and executed, the life of many gas stripper wells will be extended substantially. The goal of using these techniques will be to effectively and efficiently expedite additional gas production from gas stripper wells.

Work Accomplished

Our study area consists of the Wind River and Greater Green River basins (Figure 1), which together contain 5,537 gas wells, of which we have access to complete log suites and production data for 375 wells. From the 375 wells, 45 test wells were chosen for the proposed work, including commercial gas wells, gas stripper wells, and abandoned gas wells. For each of the 45 wells, the following tasks were completed:

- Determination of the thickness of the underpressured zone beneath the pressure surface boundary from sonic and mud logs, and acqui-

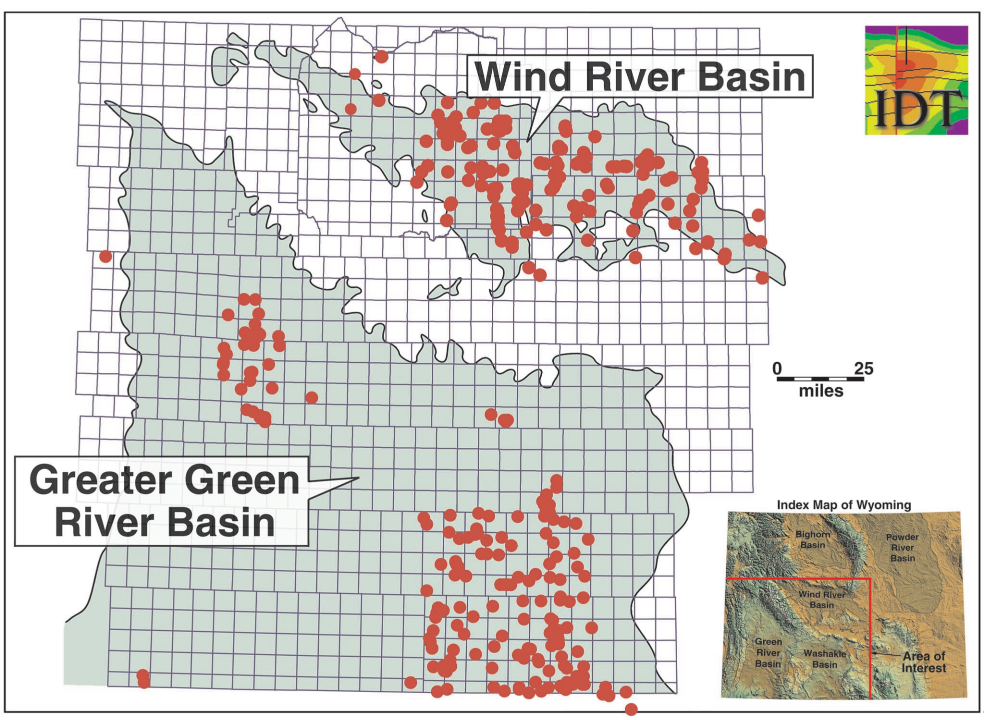

Figure 1. Index map of the study area, the Greater Green River and Wind River basins, WY.

sition of DST and RFT data where available.

- Evaluation of complete log suites for each well, with special emphasis on determining the relationships among the velocity inversion surface (i.e., sonic log), mud log, high resistivity, neutron and density porosity (i.e., gas crossover), gamma ray, and caliper logs.
- Compilation of production data patterns and trends for the 45 wells.
- Evaluation of each well type (stripper, abandoned, gas) using the compiled data:
  - Thickness of underpressured zone
  - Distribution of gas-charged sandstones and fractured shale
  - Production characteristics
  - Distribution of the rock-fluid system that has been exposed to overcompensated mud weight (e.g., potential damage zone)
- Integration of the data and determination of the potential for bypassed gas and damaged productive zones in each of these three types of wells and determination of the most effective, efficient routines for identifying bypassed gas and damaged pay in the gas stripper wells.

Data Collection

In order to create a comprehensive database for this study, 45 wells were chosen from the Greater Green River and Wind River basins (Table 1). Wellhead information was assembled and sonic and mud logs digitized for each of the 45 wells; we are currently analyzing the log data. Gamma ray, neutron porosity, density porosity, resistivity, and caliper logs were acquired and currently are being digitized. Available initial production, production zone, DST, and RFT data also are being acquired.

Determination and Delineation of the Fluid-Flow System

The fluid-flow systems in the RMLB are known to be compartmentalized, both on a regional and local scale. Regionally, these basins are divided into at least three large compartments; locally, these large compartments are subdivided into several smaller compartments (Figure 2). The boundary between the normally pressured, water-saturated fluid system and the underlying anomalously pressured, gas-charged fluid system is characterized by a significant sonic/seismic velocity inversion, which corresponds to the regional pressure surface boundary. Below this boundary, the velocity can be up to 2200 m/s slower than that predicted by the normal regional velocity/depth gradient. The regional pressure surface boundary is especially important because in the RMLB, a huge portion of the cumulative gas production, including most gas stripper wells, is from reservoirs spatially located below, but within 2000 feet of the boundary.

Sonic logs from 45 wells (Table 1), combined with DST, RFT, and mud data, were used to determine the fluid-flow regime (i.e., the pressure surface boundary and the underpressured zone below this boundary). Anomalous velocity profiles were generated for all 45 wells (Figures 3 through 5). The anomalous velocity was calculated by systematically removing the regional velocity-depth gradient from the sonic velocity profiles. Rocks with normal velocity are characterized by normal pressure and a water-dominated, single-phase fluid-flow system, whereas rocks with anomalous velocity are characterized by anomalous pressure (overpressure or underpressure) and a multiphase fluid-flow system (Surdam et al., 1997).

These anomalous velocity profiles are used to determine the: (1) pressure surface boundary, (2) interval with anomalous pressure, and (3) gas-charged, anomalously pressured section

Table 1. List of wells using in this project.

Greater Green River Basin

Well Name	API #	Township	Range	Section	Status
Canyon Creek Unit 32	4903722827	T12N	101W	9	SI
Cherokee Ridge Federal 1	4903720518	T12N	R96W	15	A
New Moon Unit 1	4903722317	T13N	R95W	13	SI
Federal 3-5	4903722029	T14N	R100W	5	A
CEPO Lewis 21-18	4903724185	T14N	R95W	18	Gas
Windmill Draw Unit 1	4903721071	T15N	R94W	14	SI
Lario Federal 33-14	4903724076	T15N	R94W	15	SI
Mull Federal 44-18	4903724124	T15N	R94W	18	Gas
Wester Federal 33-6	4903724352	T15N	R94W	6	Gas
Mulligan Draw Unit 6	4903722912	T15N	R95W	25	Gas
Coal Gulch Unit H 1	4900720662	T17N	R93W	2	Gas
Champlin 256	4903720763	T17N	R96W	3	A
C. G. Road Unit 26-3	4903723919	T21N	R94W	26	Gas
Beaver mesa 1-7	4903720416	T24N	R102W	7	A
Federal 21-1	4903722021	T24N	R103W	21	Gas
Freighter Gap Unit 1	4903721904	T24N	R12W	13	SI
Freighter Gap Unit 2	4903721982	T24N	R12W	12	A
Federal 1-1	4903722261	T24N	R14W	1	A
Packsaddle Unit 1	4903721425	T25N	R103W	24	A
Federal Q 1	4903721096	T25N	R96W	28	Gas
Musketeer Unit 1	4903721966	T26N	R101W	8	A
Golden Rod Unit 1	4903520601	T27N	R109W	30	A
Wardell Federal 1	4903520342	T28N	R108W	9	SI
Tot Unit 31-22	4903521652	T28N	R109W	22	Gas
Yellow Point Federal 11-13	4903521887	T28N	R109W	13	Gas
Stud Horse Butte 13-27	4903521359	T29N	R108W	27	Gas
Stud Horse Butte 5-26	4903521374	T29N	R108W	26	Gas
Wagon Wheele 1	4903520124	T30N	R108W	5	SI
West Pinedale 1	4903520348	T30N	R109W	33	SI

Wind River Basin

Shoshone Arapahole Tribal 534	4901320612	T1S	R2E	2	SI
Ocean Lake Tribal	4901321430	T2N	R4E	8	SI
Tribal 24-11	4901320748	T3N	R3E	11	A
Ocean Lake Tribal 1-15	4901321312	T3N	R3E	15	Gas
Tribal MR 30-13	4901321772	T4N	R3E	30	Gas
Tribal Chevron 30-11	4901320725	T4N	R3E	30	Gas
Tribal Sand Mesa 2	4901320800	T4N	R4E	24	Gas
Coastal Owl Creek 1	4901321077	T5N	R3E	26	SI
Ryan Hill Unit 1	4902520002	T32N	R84W	35	A
HSR Steele 16-31	4903521725	T34N	R109W	31	SI
Twidale 1	4902521344	T34N	R87W	15	Oil
Federal USA 17-1	4901320961	T34N	R94W	17	Oil
Wild Hourse Butte 1-16	4902522015	T35N	R88W	16	A
Nawking Draw Unit 2	4901320488	T35N	R90W	25	A
Horseshoe Creek Federal 1	4901321546	T35N	R92W	26	Si
Fuller Reservoir Unit 2	4901320565	T36N	R94W	25	SI

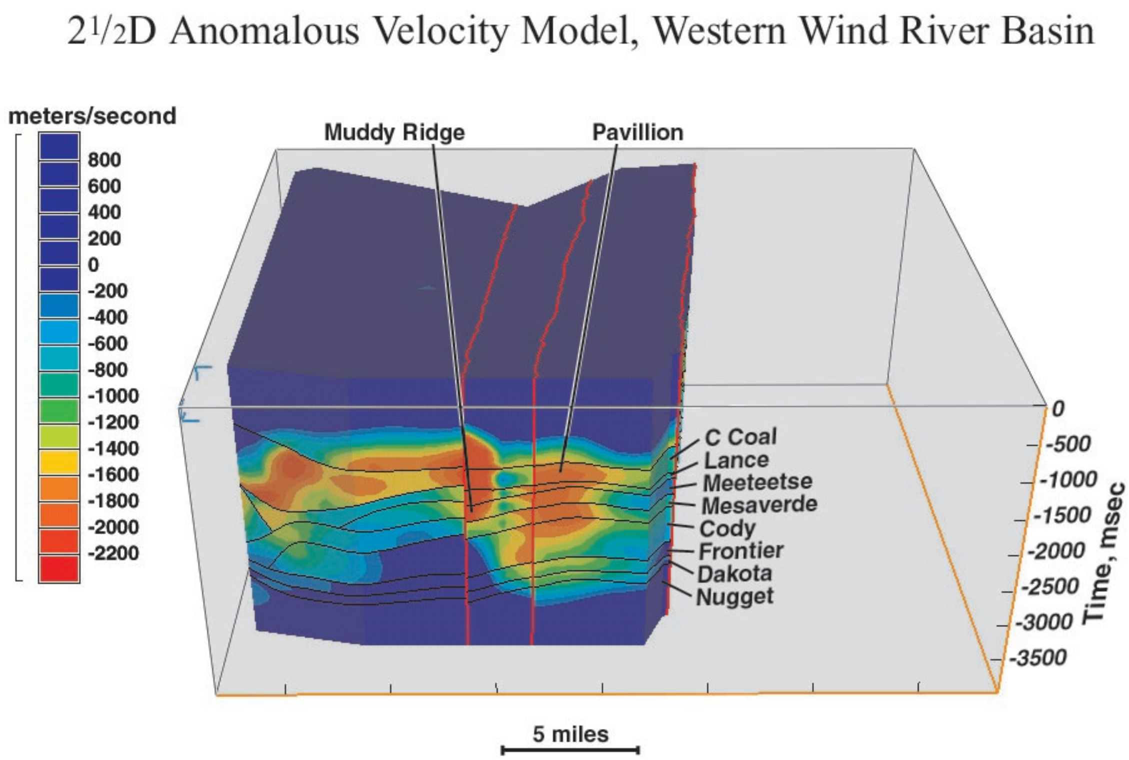

Figure 2. An east-west cross section cut through a 2 ½ D anomalous velocity model showing pressure compartmentalization in the Western Wind River Basin, Wyoming. Red and yellow areas indicate an anomalously pressured and gas-charged rock/fluid system.

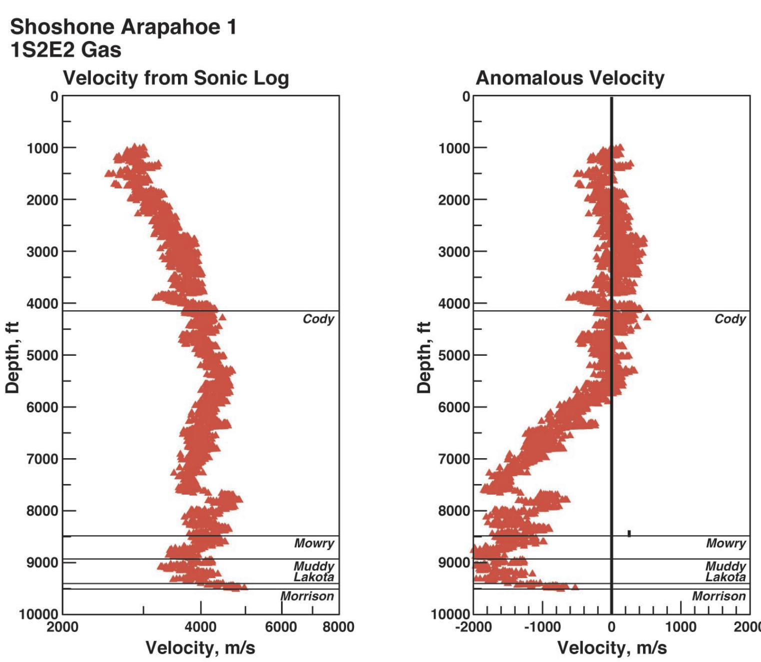

Figure 3. Sonic velocity and anomalous velocity profiles for the well Shoshone Arapahoe 1 well, Wind River Basin, WY. The pressure surface boundary is at 5700 ft.

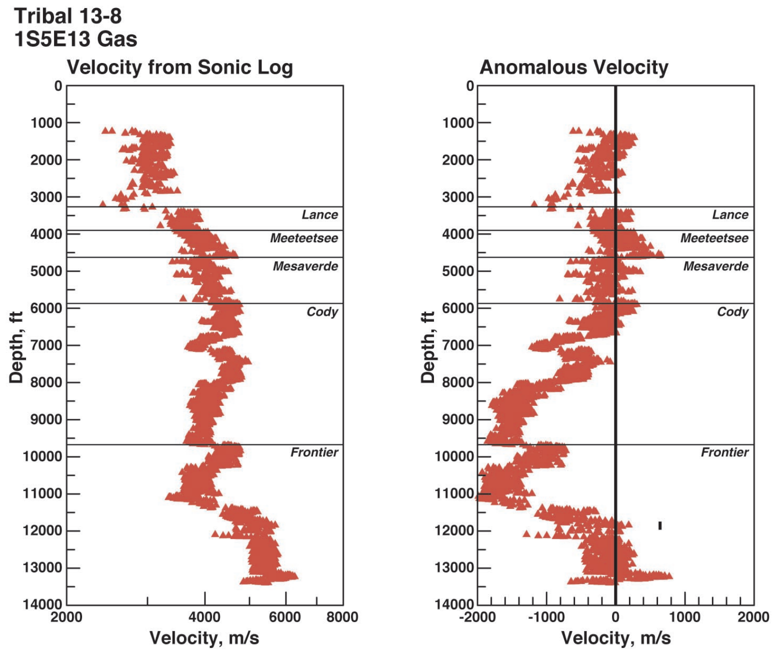

Figure 4. Sonic velocity and anomalous velocity profiles for the Tribal 13-8 well. The pressure surface boundary is at 6600 ft.

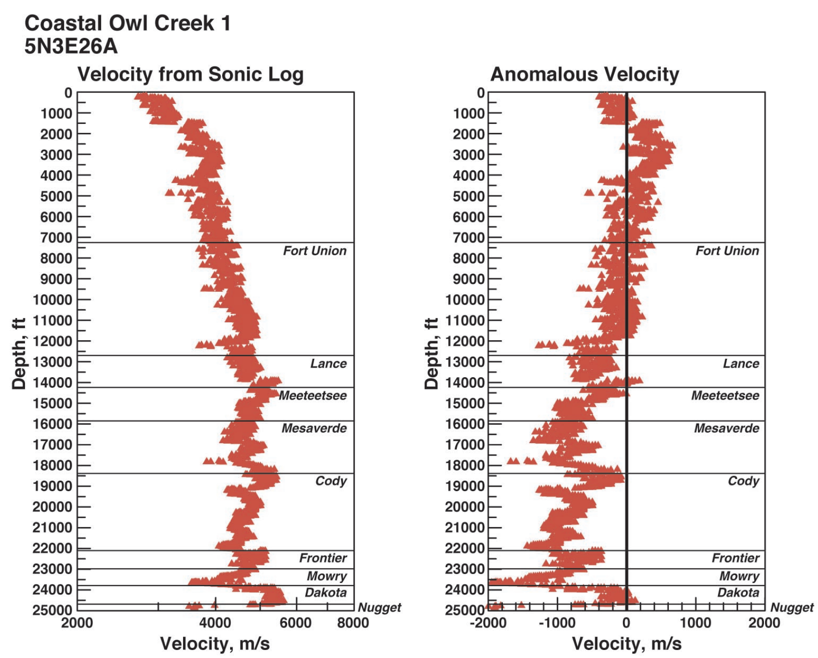

Figure 5. Sonic velocity and anomalous velocity profiles for the Coastal Owl Creek 1 well. The pressure surface boundary is at 11,800 ft.

(Figure 6). The gas-charged, underpressured section can be identified on the anomalous velocity profile by using the pressure data (i.e., DST, RFT, and mud data) (Figure 7).

Determination of Badly Damaged Productive Zones

Because the pressure transition configuration present in the study area was poorly understood or unknown to drillers when many of the RMLB gas stripper wells were drilled (prior to 1990), operators, from experience, assumed they would encounter overpressuring at depth. The drillers' primary concern, with respect to safety and control of the well, was for a transition from normal to overpressure; consequently, they increased mud weights during drilling. However, in the RMLB, underpressuring is often encountered at depth; thus, many of these underpressured zones were drilled with overcompensated mud weights (Figures 6 and 7). In this drilling situation, the potential for bypassing or highly damaging productive zones was *significant* and resulted in wells that produced only a fraction of the available gas.

In order to determine where badly damaged productive zones occur in the study area, mud logs were plotted with anomalous velocity profiles. For example, Figures 6 through 9, which include both mud weight profiles and anomalously velocity profiles, show how mud weights were overcompensated in the underpressured stratigraphic section. Figures 6 shows both

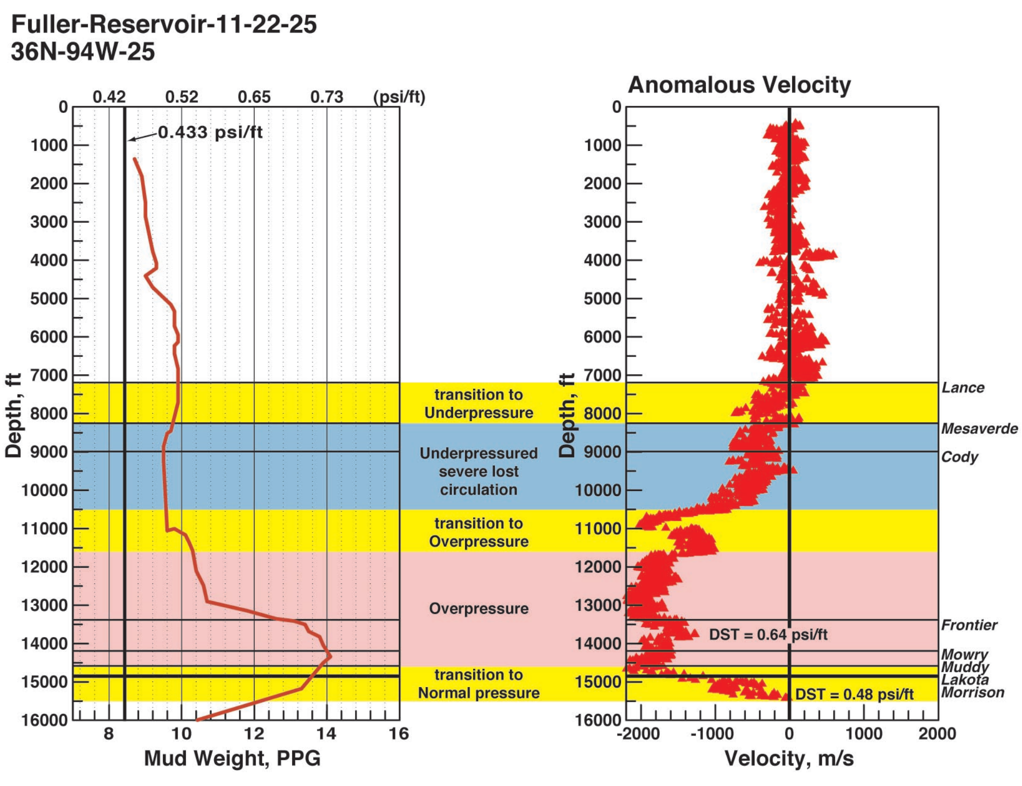

Figure 6. Mud weight profile and anomalous velocity profile for the Fuller Reservoir II 22-25 well. The regional pressure surface boundary is at the top of Lance at 7200 ft depth. The underpressured zone is from 8250 to 10,500 ft depth. The mud weight used to drill the underpressured interval was 9.6 ppg, or significantly overcompensated.

profiles for the Fuller Reservoir II 22-25 well. Here, the regional pressure surface boundary occurs at the top of Lance at 7200 ft depth, and the underpressured zone occurs in the 8250 to 10,500 ft depth interval. The mud weight used to drill this gas-charged underpressured interval was 9.6 ppg, which was significantly overcompensated. In Figure 7, shows both a mud weight profile and anomalous velocity profile for the Ocean Lake Tribal 1 well, the regional pressure surface boundary occurs at 8000 ft depth in the Fort Union Formation, and the underpressured zone occurs in the 8000 to ~13,500 ft depth interval. A pressure gradient 0.39 psi/ft from DST is measured at the depth 10,000 ft, so the mud weights should have been less than the weight of water (i.e., < 8.4 ppg). The mud weights used to drill this underpressured interval were 8.6 to 9.2 ppg, also overcompensated. In Figure 8, the profiles are from the Tribal 1 well. The regional pressure surface boundary is within the Fort Union Formation at 6300 ft depth, and the anomalously pressured zone occurs within the 6300 to ~11,200 ft depth interval. The mud weights used to drill this anomalously underpressured interval were 8.9 to 9.4 ppg, again overcompensated; there is no indication that the upper potion of this anomalously pressured zone is overpressured, but instead is underpressured. In Figure 9, the profiles are for the Federal 13 well in the Washakie Basin, Wyoming. The regional pressure surface boundary occurs at 6500 ft depth in the Fort Union Formation, and the anomalously pressured zone occurs from 6500 to DT. The mud weights used to drill this anomalously underpressured interval were 8.9 to 10.3 ppg, again, an overcompensated mud program.

It is clear from these preliminary results that the mud weights used to drill gas-charged underpressured sections were significantly overcompensated (and potentially damaged the zone) and were common in the both Greater

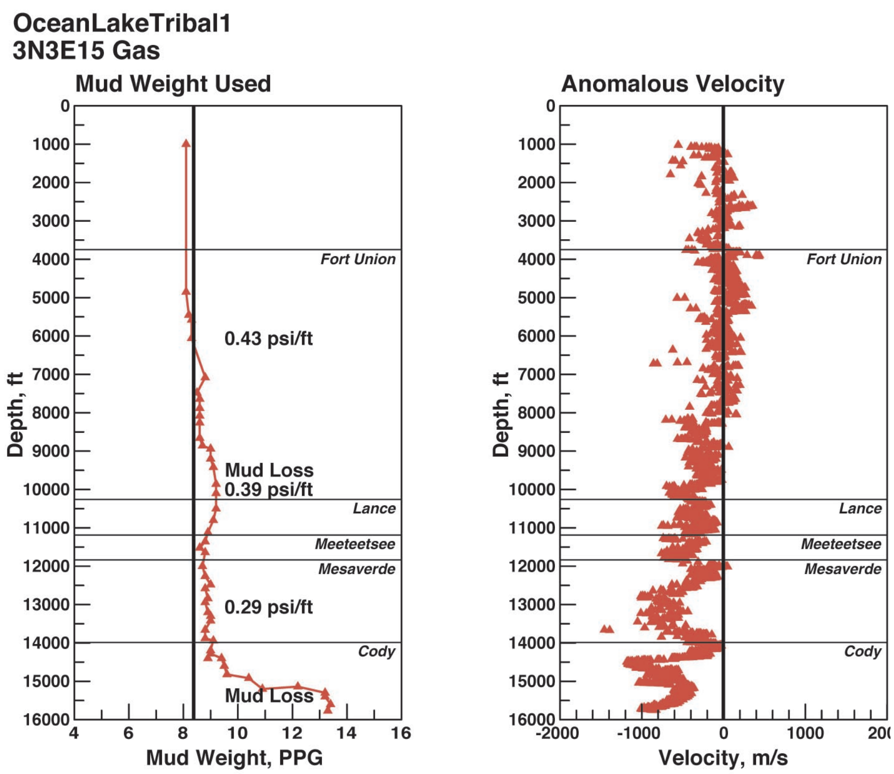

Figure 7. Mud weight profile and anomalous velocity profile for the Ocean Lake Tribal 1 well. The regional pressure surface boundary occurs in the Fort Union Formation at 8000 ft depth. The underpressured zone is from 8000 to ~13,500 ft depth. A pressure gradient 0.39 psi/ft from DST is measured at the depth 10,000 ft, so the mud weights should have been less than the weight of water (i.e., < 8.4 ppg). However, the mud weights used to drill this underpressured interval were 8.6 to 9.2 ppg, also significantly overcompensated.

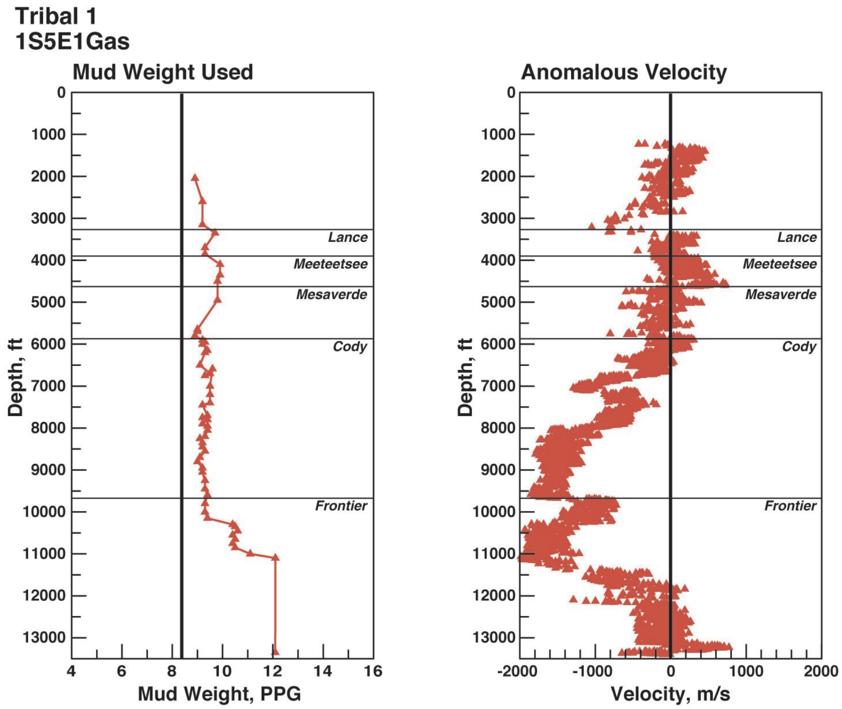

Figure 8. Mud weight profile and anomalous velocity profile for the Tribal 1 well. The regional pressure surface boundary is within the Fort Union Formation at 6300 ft depth. The underpressured zone is from 6300 to about 11,200 ft depth. The mud weights used to drill this interval were 8.9 to 9.4 ppg. There is no indication that the upper potion of the anomalously pressured zone is overpressured rather than underpressured. Thus, the mud weights used to drill the gas-charged, underpressured section were significantly overcompensated

Green River and Wind River basins (Figures 8 and 9). In fact, numerous gas-charged intervals were overcompensated with heavy mud. The logic for these conclusions is as follows:

1. The rock/fluid systems are gas-charged (i.e., have anomalously slow velocities), so they must be either overpressured or underpressured, as they cannot fall on the hydrostatic gradient as a result of the gas charge.
2. If the section being drilled were overpressured, it would have to be drilled with mud weights greater than 8.5-9.0 ppg, otherwise the control of the well would have been lost.
3. If the section being drilled were underpressured (Figure 7), mud weights of 8.5 to 9.0 ppg would be significantly overcompensated.
4. In the examples shown in Figures 8 and 9, the portion of the section of interest is anomalously slow (i.e., gas-charged) and, thus, anomalously pressured. The mud weights are approximately 9 ppg; thus, the rocks are not overpressured. If they are not overpressured or normally pressured, they must be underpressured. If so, the mud weight program utilized in Figures 8 and 9 in the upper portion of the anomalously slow velocity section was grossly overcompensated as this portion of the section was penetrated.

These badly damaged zones still contain a huge gas resource that operators can exploit if they can design effective remediation and recompletion strategies or select new completion zones for gas stripper wells and some abandoned wells. Therefore, it is important to design techniques to identify bypassed pay and highly damaged productive zones in RMLB gas stripper wells, because in most of these wells, these zones are characterized by an underpressured rock-fluid system (Figures 6 and 7).

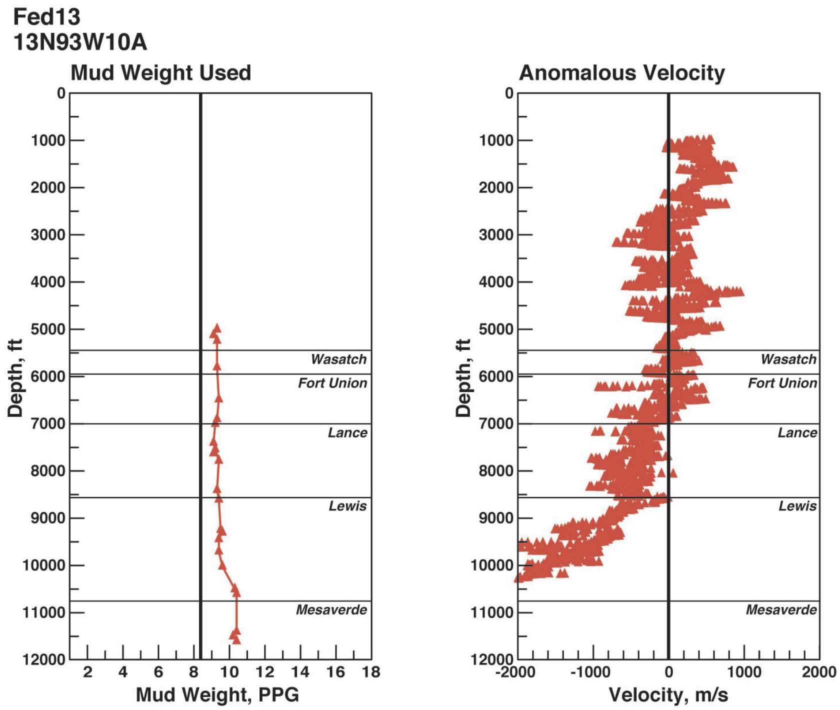

Figure 9. Mud weight profile and anomalous velocity profile for the Federal 13 well, Washakie Basin, WY. The regional pressure surface boundary is within the Fort Union Formation at 6500 ft depth. The anomalously pressured zone is from 6500 to DT. The mud weights used to drill this anomalously underpressured interval were 8.9 to 10.3 ppg, again, overcompensated.

Recent Accomplishments

For 45 wells, we have evaluated mud weights, velocity inversion surfaces, anomalous velocity profiles, lithology, resistivity, porosity, pressure tools, gas shows, and production data. In every case, for the upper portion of the anomalously slow velocity domain (i.e., gas-charged volume), the mud weights were typically 9 to 10 lb/gal. Thus, if any underpressured rock/fluid systems were present in these wells, they would have been badly damaged during drilling. The key question is how significant and widespread are underpressured rock/fluid systems in the Wind River and Greater Green River Basins? If underpressured rock/fluid systems are significant and widespread, there is huge bypassed gas potential in both gas and gas stripper wells.

At present, we are evaluating the answer to the above question based on the 45 wells selected for analysis. This evaluation is taking place according to the following sequence of steps:

1. First, the regional normal velocity/depth trend is removed from the observed sonic velocity/depth profile (Figure 10). The results of this operation are two-fold: (1) isolation of anomalously slow sonic velocities and (2) definition of the regional velocity inversion surface. The isolated anomalously slow velocity domains beneath the regional velocity inversion surface in the RMLB are gas-charged (Surdam, 1997; Surdam, 2001a,b). It is known from previous work that the regional velocity inversion surface is the boundary between normally pressured rock-fluid systems above and anomalously pressured, gas-charged rock-fluid systems below (Figure 10).
2. The next step is to integrate pressure data, derived from drill stem tests and other pressure indicators, with the anomalous velocity profiles (Figure 10). This integration allows underpressured and overpressured portions of the anomalously slow velocity domain to be delineated (Figure 10).

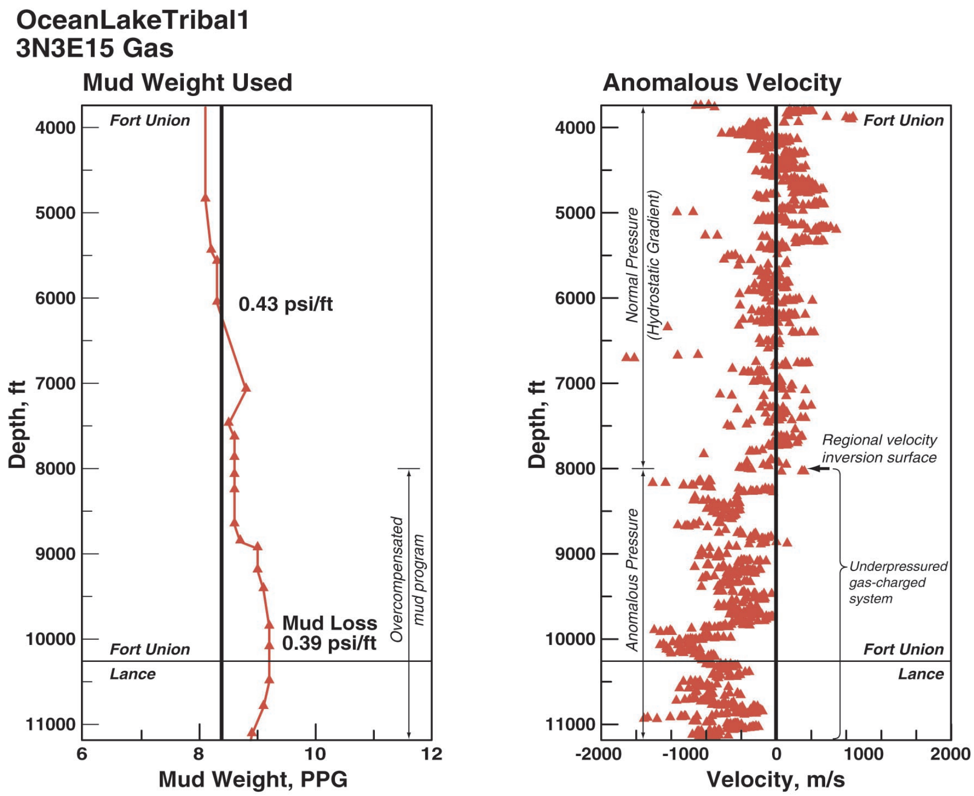

Figure 10. Left: mudweight profile for the Ocean Lake Tribal 1 well, with available pressure gradients from DSTs. Right: Anomalous velocity profile for the same well. Velocity along the regional normal velocity/depth function falls on the vertical black line; velocities falling left of the vertical black line are anomalously slow and indicate rocks will tend to be gas-charged and anomalously pressured.

3. Step three is the evaluation of the distribution of potential reservoir sandstones within the section characterized by anomalously slow velocities and underpressuring (Figure 11). Typically, the relatively thick sandstones within the underpressured anomalously slow velocity domain are characterized by low gamma ray, high resistivity, high density porosity, and low neutron porosity (Figure 11). These log characteristics are compatible with a gas-charged sandstone interpretation. Where possible, information with regard to background gas, gas shows, and gas flows are integrated into the evaluation.

This evaluation is used to determine the presence or absence of underpressured, gas-charged potential reservoir sandstones. From this sequence of steps, it is possible to detect significant thicknesses of underpressured, gas-charged sandstone reservoirs in 30 of the 45 wells studied (Table 1). It is important to note that each of the 30 wells where underpressured, gas-charged reservoirs exist were drilled with 9 to 10 lb/gal mud (i.e., grossly overcompensated mud programs).

This zone of underpressured, gas-charged, rock/fluid has been unrecognized in so many of the RMLB because, relative to the San Juan and Alberta basins, it tends to be thin in most other basins (Figure 12). In the San Juan and

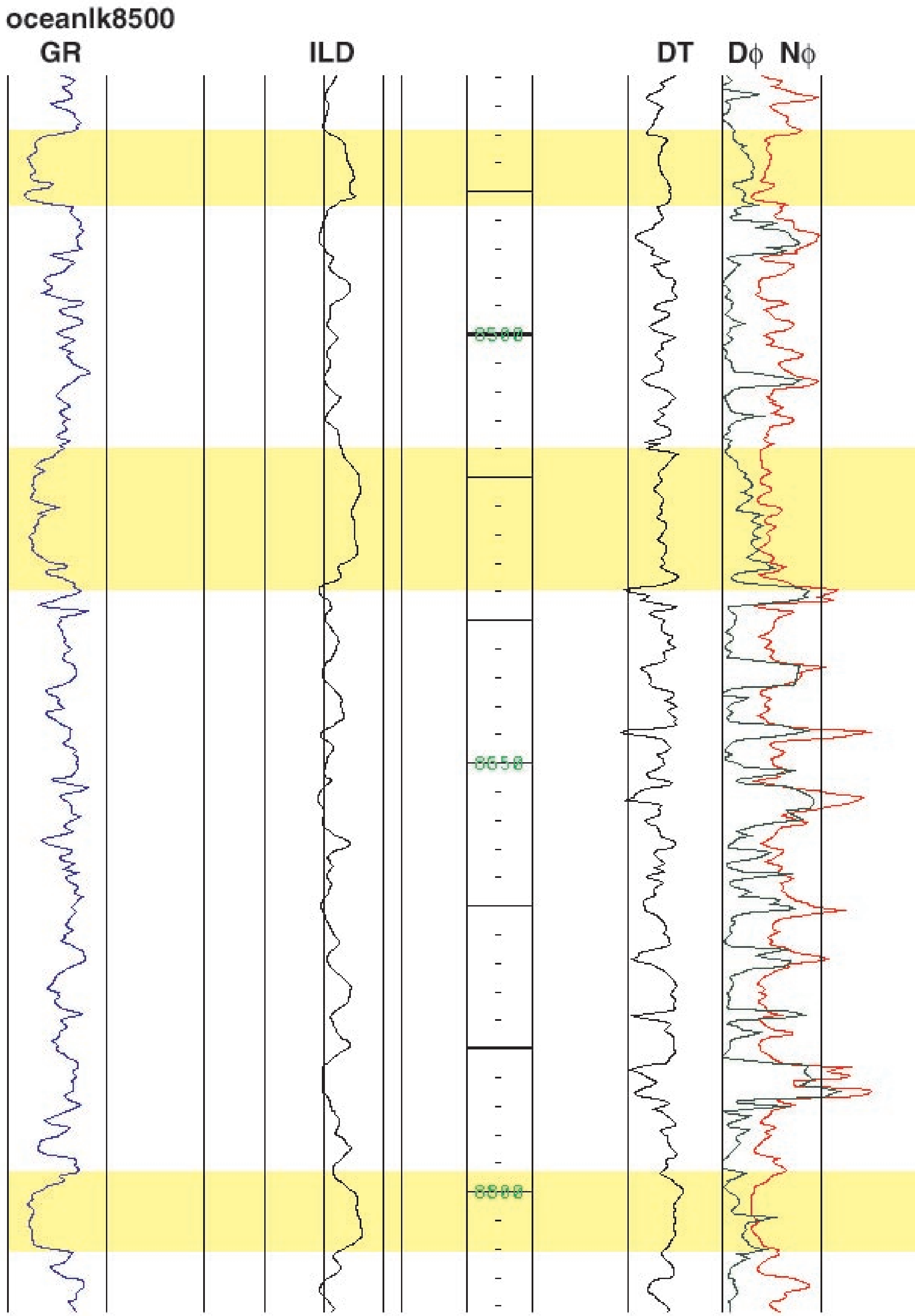

Figure 11. Log suite profiles from a portion (8500-8800 ft) of the Ocean Lake Tribal 1 well. The yellow zones are sandstone intervals that, based on log characteristics, are gas-charged and, from Figure 10, are underpressured.

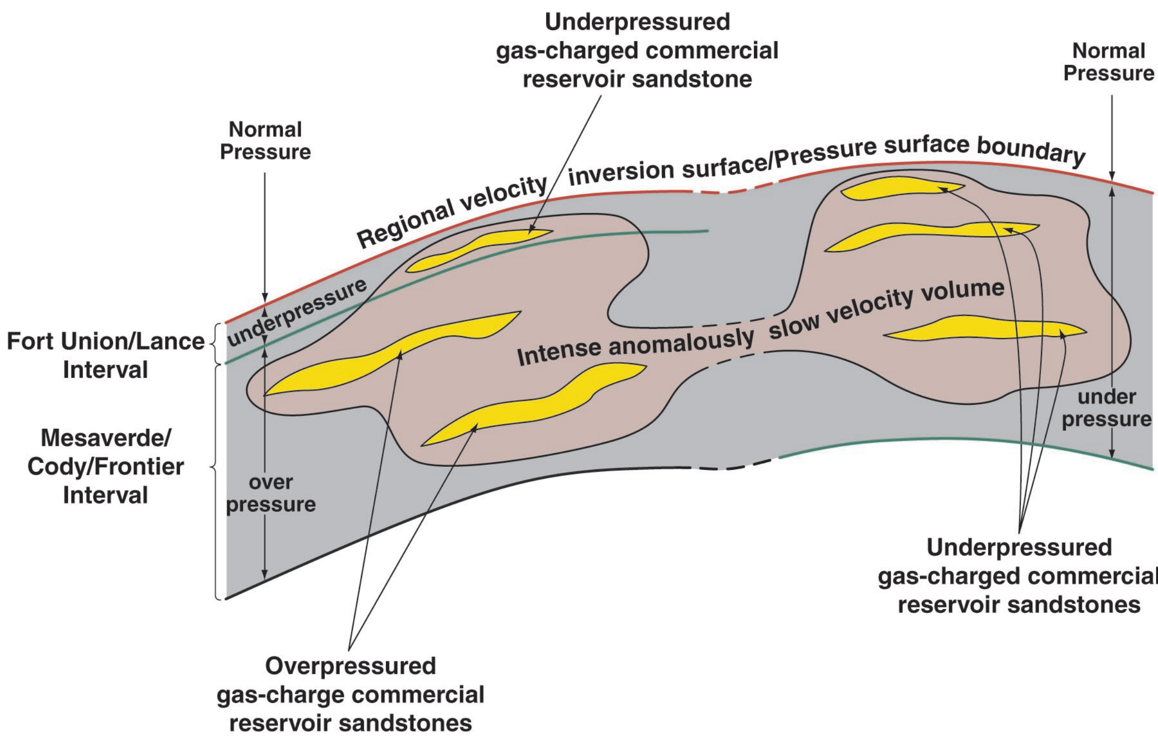

Figure 12. Schematic diagram illustrating the differences in pressure regimes in basins like the San Juan and Alberta basins, as compared to basins like the Wind River and Green River basins. In the San Juan and Alberta basins, the pressure transition is from normal pressure to a thick, underpressured, gas-charged and productive section (right side of diagram). In contrast, in basins like the Wind River and Green River basins, the transition is from normal pressure to a relatively thin, underpressured, gas-charged section, underlain by a relatively thick, overpressured, gas-charged and productive section (left side of diagram).

Alberta basins, operators drill from normally pressured sequences, across the regional velocity inversion surface, into a very thick and productive underpressured section (Figure 12). In contrast, in the other RMLB, operators drill from normally pressured sections, across the regional velocity inversion surface, into a relatively thin and historically unrecognized underpressured, gas-charged section, *then* into a thick, overpressured productive zone. Thus, historically the driller's primary concern has been to prepare for the transition from normal pressure to overpressure; consequently, most wells, excluding the San Juan and Alberta basins, have been drilled with significantly overcompensated mud programs.

Conclusions

It is concluded that, in 30 of the 45 wells studied in the Wind River and Green River basins, there are large columns of rock/fluid that are underpressured and gas-charged. Each of these 30 wells were drilled with significantly overcompensated mud weight programs. Thus, there is high potential for serious damage during the drilling of the underpressured, gas-charged sandstones, or for bypassed pay, over a significant stratigraphic interval.

Future Work

In future work, presently being considered by the Stripper Well Consortium, the IDT team will evaluate the size of the heretofore unrecognized, underpressured gas resource in the RMLB (excluding the San Juan and Alberta basins).

The essential problem that will be addressed is how to delineate underpressured, gas-charged rock/fluid columns just below the regional velocity inversion surface in the Wind River Basin. This basin was chosen for study because the following data are available to IDT: (1) ~3000 mi of 2-D seismic lines; (2) 200 log suites and thousands of mud logs and 10,000 DSTs; and (3) U.S.G.S. depositional models and detailed analyses of the stratigraphic frameworks.

This work will include the following tasks: (1) isolate those portions of the Lance (uppermost Cretaceous) and Fort Union (lowermost Tertiary) formations below the regional velocity inversion surface characterized by anomalously slow sonic/seismic interval velocities (i.e., gas-charged rock/fluid systems); (2) construct a 3-D volume of gas-charged rock/fluid systems; (3) integrate mud logs and DSTs with the volume to determine underpressured areas; (4) determine the spatial distribution of commercial gas reservoirs in the study interval; (5) determine where Lance-Fort Union potential reservoir rock volumes intersect the underpressured gas-charged volume; and (6) evaluate the size of the unexploited gas resource in underpressured, gas-charged sections of the Lance-Fort Union reservoir volume by approximating petrophysical properties of the Lance-Fort Union clastic reservoir rocks.

The results from the project will allow operators to:

- Determine the size, configuration, and importance of underpressured, gas-charged hydrocarbon resources beneath the regional velocity inversion surface in the WRB;
- Delineate sections likely to contain badly damaged or bypassed productive zones;
- Design new drilling and completion strategies that will allow the maximum gas production from underpressured, gas-charged reservoirs; and
- Determine the potential for similar assets in RMLB other than the Alberta and San Juan basins.

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