



Plains CO<sub>2</sub> Reduction (PCOR) Partnership  
Energy & Environmental Research Center (EERC)

## **BELL CREEK TEST SITE – FIRST FULL REPEAT OF PULSED NEUTRON LOGGING CAMPAIGN COMPLETED**

**Plains CO<sub>2</sub> Reduction (PCOR) Partnership Phase III  
Task 9 – Milestone M45**

*Prepared for:*

Andrea M. Dunn

National Energy Technology Laboratory  
U.S. Department of Energy  
626 Cochran's Mill Road  
PO Box 10940  
Pittsburgh, PA 15236-0940

DOE Cooperative Agreement No. DE-FC26-05NT42592

*Prepared by:*

Neil W. Dotzenrod  
John A. Hamling  
Charles D. Gorecki  
Edward N. Steadman  
John A. Harju

Energy & Environmental Research Center  
University of North Dakota  
15 North 23rd Street, Stop 9018  
Grand Forks, ND 58202-9018

2014-EERC-06-05

June 2014  
Approved

## **EERC DISCLAIMER**

**LEGAL NOTICE** This research report was prepared by the Energy & Environmental Research Center (EERC), an agency of the University of North Dakota, as an account of work sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). Because of the research nature of the work performed, neither the EERC nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement or recommendation by the EERC.

## **ACKNOWLEDGMENT**

This material is based upon work supported by DOE NETL under Award No. DE-FC26-05NT42592.

## **DOE DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

## **NDIC DISCLAIMER**

This report was prepared by the EERC pursuant to an agreement partially funded by the Industrial Commission of North Dakota, and neither the EERC nor any of its subcontractors nor the North Dakota Industrial Commission (NDIC) nor any person acting on behalf of either:

- (A) Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

- (B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the NDIC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the North Dakota Industrial Commission.

## TABLE OF CONTENTS

LIST OF FIGURES .....	i
INTRODUCTION .....	1
FIRST FULL REPEAT OF PNL LOGGING CAMPAIGN COMPLETED .....	3

## LIST OF FIGURES

1	Local stratigraphy of the Bell Creek development area .....	2
2	Map of wells showing where baseline and repeat PNLs were collected in relation to the Bell Creek oil field .....	4
3	From left to right, reference track, gamma ray log, and sigma logs for injection wells .....	5
4	From left to right, reference track, gamma ray log, and sigma logs for production wells ....	6



## **BELL CREEK TEST SITE – FIRST FULL REPEAT OF PULSED NEUTRON LOGGING CAMPAIGN COMPLETED**

### **INTRODUCTION**

The Plains CO<sub>2</sub> Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore LLC (Denbury) to study monitoring, verification, and accounting (MVA) of CO<sub>2</sub> storage associated with a commercial enhanced oil recovery project at the Denbury-operated Bell Creek oil field located in southeastern Montana. MVA techniques such as the full repeat of pulsed neutron logs (PNLs) have helped to guide a repeat vertical seismic profile by monitoring CO<sub>2</sub> breakthrough between production and injection wells to improve overall MVA efforts and understanding of sweep efficiency, effective storage capacity, and vertical and lateral flow boundaries.

This PNL logging campaign has consisted of two parts: first running a baseline set of logs and second running a repeat set of logs to compare against the baseline. The baseline logs were completed on 33 wells from November 2012 to June 2013. Repeat logs were completed on seven wells from August 2013 to January 2014. Both sigma and inelastic capture (IC) logs were run in each of the selected wellbores to effectively capture CO<sub>2</sub> presence, as well as CO<sub>2</sub>, water, and oil saturations. Sigma logs are run through the reservoir and overlying strata up to the surface for collection of high-resolution porosity and gamma ray data and to calculate and monitor fluid and gas saturations. Since the reservoir of interest has freshwater in place, the sigma log cannot differentiate between water and oil from the measured fluid saturation. Thus the IC log is run over the reservoir zone to determine water and oil saturations as well as detailed spectra lithology information. The difference between the sigma logs from baseline to repeat will show where CO<sub>2</sub> is in the near wellbore environment. Differences noted in the IC logs will show a change in water and oil saturations due to CO<sub>2</sub> flooding as well as an estimate of CO<sub>2</sub> saturations at each logged wellbore.

The high-resolution sigma logs have had immediate use within the Phase 1 development area at Bell Creek. Structural tops have been adjusted from the surface down through the reservoir, thus updating average thickness of these formations to better understand the local stratigraphy (Figure 1). Present-day water and oil saturation maps have also been constructed, which will help guide the dynamic history-matching results during static model validation. Long-term benefits from the sigma and IC logs will be used to construct water and oil saturation maps which represent current saturations that can help to validate history matching and predictive simulation efforts on geocellular models. The time-lapse monitoring will be useful in identifying how CO<sub>2</sub> moves through the reservoir and which parts of the reservoir CO<sub>2</sub> is accessing to better illustrate plume movement and associated sweep efficiency, effective storage potential, and flow boundaries.

# Reference Model Stratigraphy of the Bell Creek Area

EERC ND49416.AI

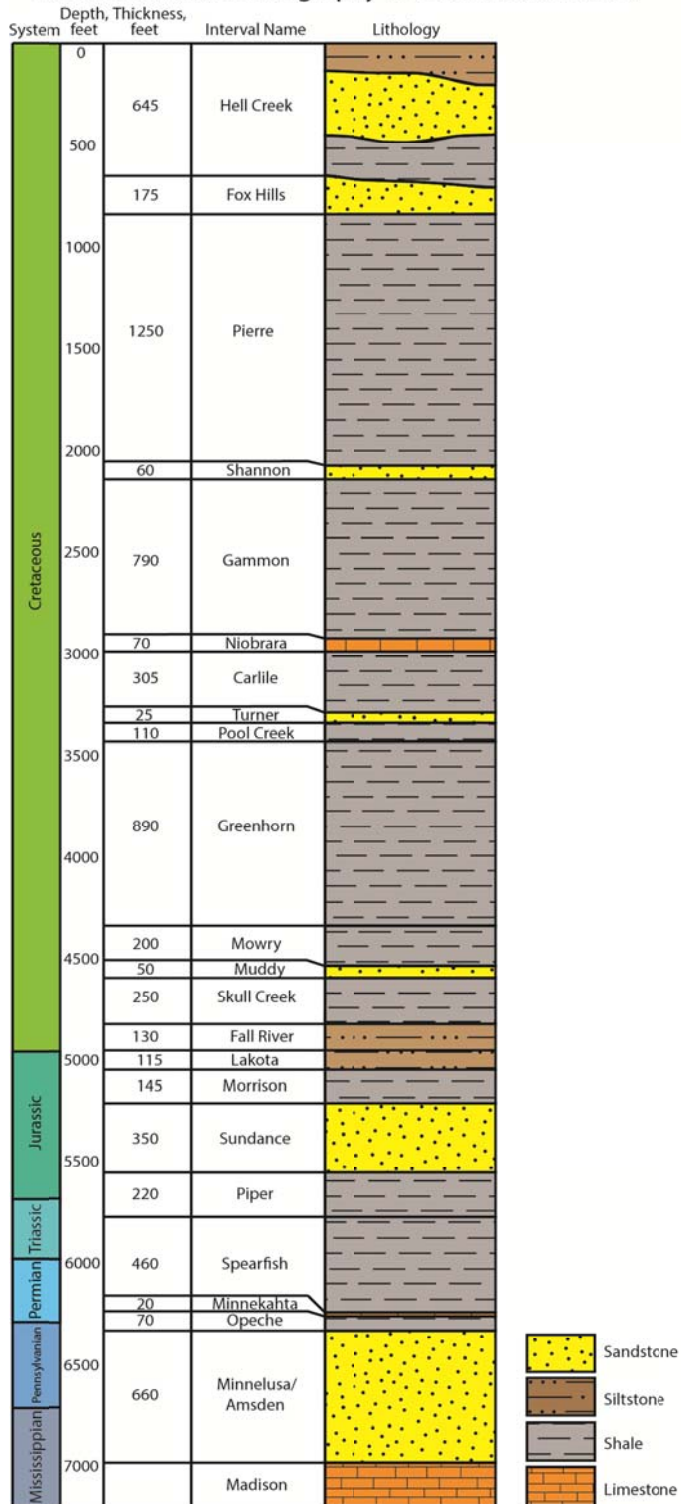


Figure 1. Local stratigraphy of the Bell Creek development area. Structural tops have been updated using PNL data from the Hell Creek Formation down to the base of the Muddy Formation.

## **FIRST FULL REPEAT OF PNL LOGGING CAMPAIGN COMPLETED**

The first full repeat of the PNL logging campaign, run from August 2013 to January 2014, covers seven wells which also have a baseline set of logs for comparison before and after the CO<sub>2</sub> injection has commenced. The seven wells comprise one monitor well (05-06 OW), three active production wells (04-04, 33-12, 56-08), and three active injection wells (05-01, 05-05, 05-07) all within the Phase 1 development area (Figure 2).

Because of the nature of how the sigma curve is measured, sigma values should generally decrease in the presence of increasing amounts of CO<sub>2</sub> near the wellbore. Initially, the injection wells will show more of a change than the production wells as the near wellbore environment will be heavily saturated with CO<sub>2</sub> as it begins to penetrate the reservoir through wellbore perforations. Breakthrough of CO<sub>2</sub> will eventually occur at nearby production wells, at first through zones of high transmissibility, then through zones of lesser transmissibility. The results will show decreasing sigma values over the reservoir zone with the presence of CO<sub>2</sub> when the repeat logs are directly compared to the baseline logs.

With the exception of the monitor well, which has not yet come into contact with injected CO<sub>2</sub>, repeat sigma values are indeed lower than their respective baseline measurements. For the injection wells, sigma values in the repeat logs are 6 to 9 units less than what is measured in the baseline logs (Figure 3), indicating the presence of CO<sub>2</sub>. The production wells show a slight decrease 1 to 4 units less than the baseline measurements (Figure 4), indicating initial breakthrough in the high transmissibility zones but overall lower CO<sub>2</sub> saturations than the injection wells, as is expected. These zones correlate with the cleanest sand in the Muddy Formation (according to the gamma ray curve).

The EERC is currently reviewing the steps used to post-process PNLs on all three types of wells (monitor, injection, and production) in order to better understand fluid saturation changes in the reservoir. Efforts are being made to understand whether or not these trends will be seen in other wells and how PNL data can be correlated to other MVA-derived data such as 3-D seismic surveys and history-matched 3-D geocellular models. Once a full review of the baseline and first full-repeat logs is satisfied, a decision will be made toward continuing the PNL logging campaign.

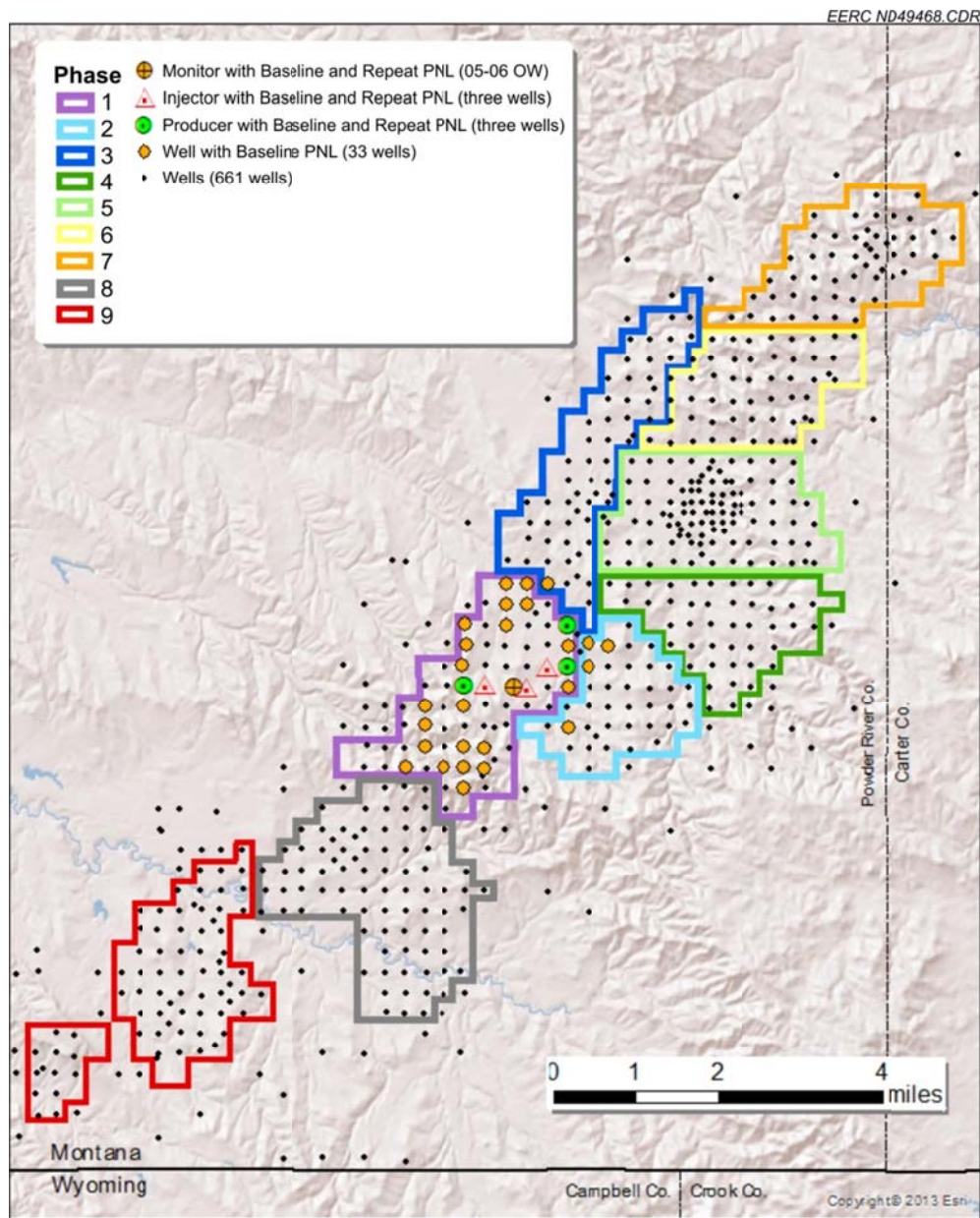


Figure 2. Map of wells showing where baseline and repeat PNLs were collected in relation to the Bell Creek oil field.



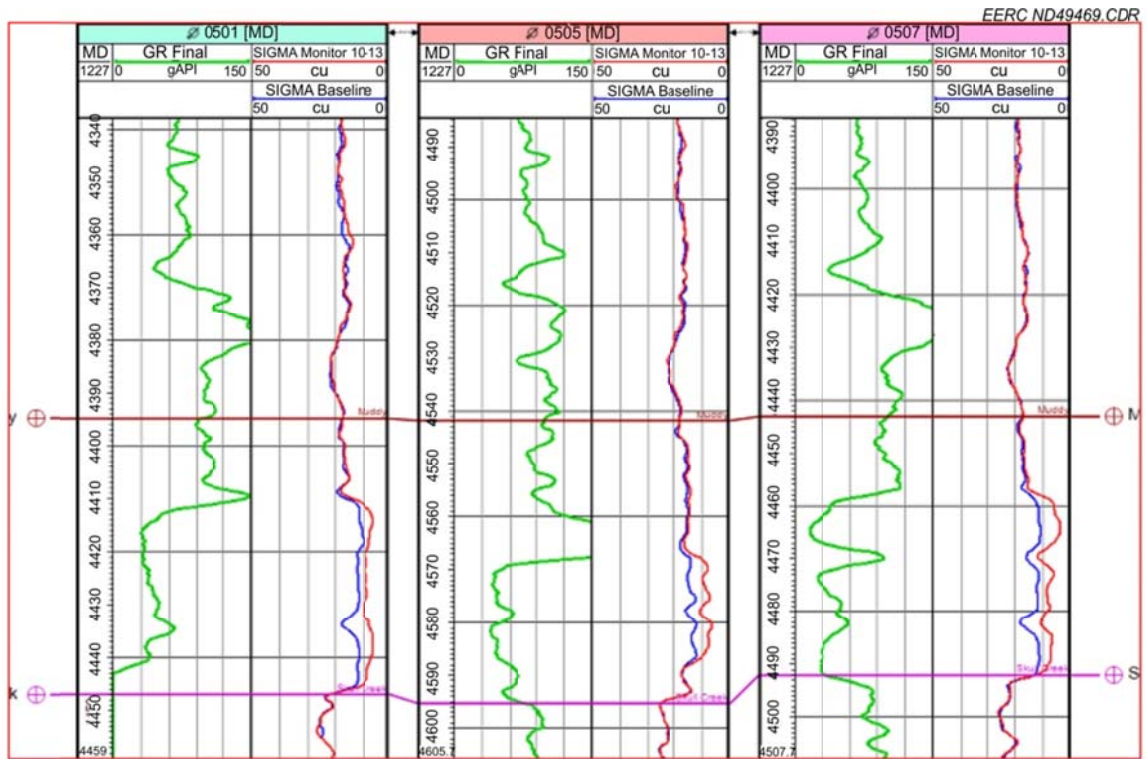


Figure 3. From left to right, reference track (measured depth in feet), gamma ray log, and sigma logs (baseline in blue, repeat in red) for injection wells. Formation tops shown are Muddy and Skull Creek.

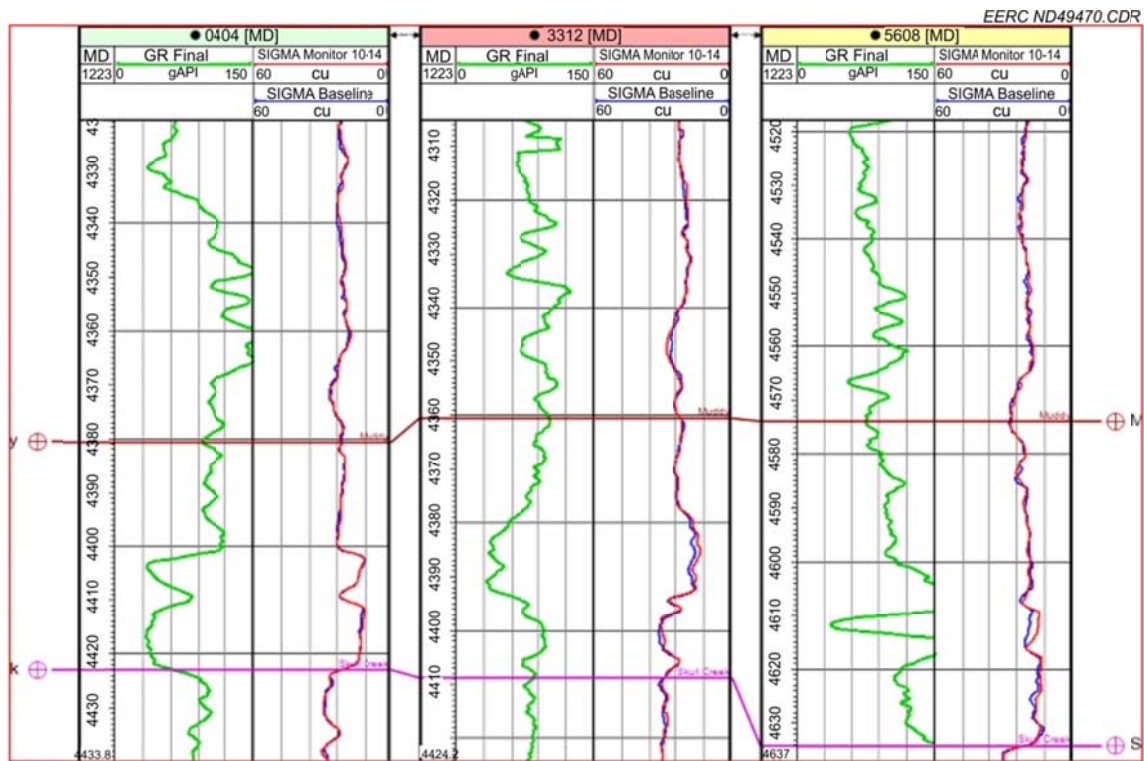


Figure 4. From left to right, reference track (measured depth in feet), gamma ray log, and sigma logs (baseline in blue, repeat in red) for production wells. Formation tops shown are Muddy and Skull Creek.