BELL CREEK TEST SITE – INITIAL ANALYSIS OF EXTENDED PNL CAMPAIGN DATA COMPLETED

Plains CO$_2$ Reduction (PCOR) Partnership Phase III
Task 9 – Milestone M52

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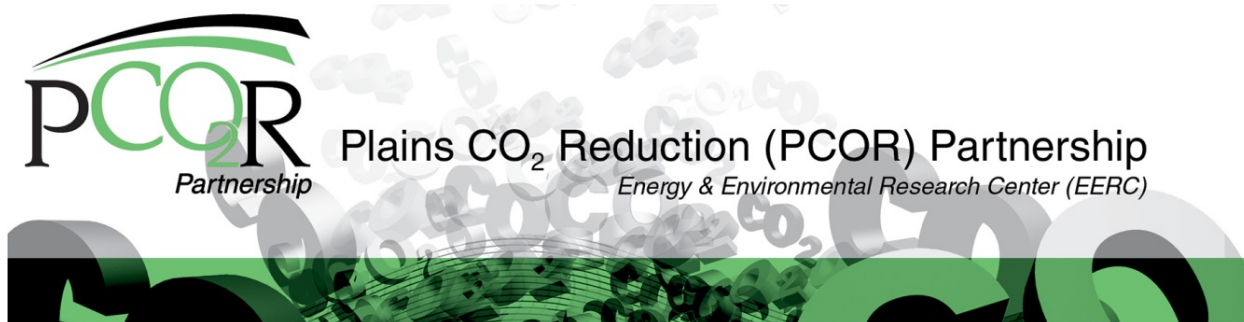
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BACKGROUND

The Plains CO_2 Reduction Partnership (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Resources Inc. (Denbury) to study carbon dioxide (CO_2) storage associated with a commercial enhanced oil recovery (EOR) project at the Bell Creek oil field located in southeastern Montana, which is operated by Denbury Onshore LLC. Denbury is managing all injection, production, and recycle activities as part of its commercial CO_2 EOR operation. The EERC, through the PCOR Partnership, is studying the behavior of reservoir fluids and injected CO_2 to demonstrate safe and effective CO_2 storage associated with a commercial EOR project. The PCOR Partnership is developing practices and technologies that will allow future commercial-scale CO_2 storage projects to make informed decisions regarding site selection, injection programs, operations, and monitoring strategies that improve storage efficiency and effective storage capacity in clastic geologic formations.

Pulsed-neutron logging (PNL) provides data important in understanding the subsurface environment during CO_2 injection. PNLs have been acquired with Schlumberger's Reservoir Saturation Tool in Bell Creek for the purposes of 1) providing baseline characterization data (lithology/mineralogy, porosity, and water and oil saturations) for the Muddy Formation reservoir interval and overlying strata, 2) monitoring for time-lapse changes in fluid saturations (water, oil, and CO_2) both within the reservoir and in the overlying strata, and 3) providing an evaluation of the utility of PNLs as a commercially viable MVA technology.

PNL acquisition began in June 2013 in Bell Creek Phases 1 and 2. The PNL campaign was extended into Bell Creek Phases 3 and 4 in October 2015 to 1) monitor CO_2 saturation response in two geologically compartmentalized regions of the field (not hydraulically linked to existing injection in Phases 1 and 2) in which CO_2 injection was beginning and 2) expand monitoring of overlying zones to additional development areas. The extended PNL campaign also included the acquisition of 13 repeat/monitor PNLs in Bell Creek Phase 1 in continuation of monitoring activities and assessment of near-wellbore saturation response to water-alternating-gas (WAG) injection.

The acquisition of 15 additional repeat/monitor PNL logs in Bell Creek Phases 1, 2, 3, and 4 will occur in winter 2016/spring 2017, which is anticipated to complete the expanded PNL campaign. With this pending campaign, a total of seven PNL campaigns will have been undertaken in Bell Creek Field (Table 1, Figure 1). Forty-five wells will have been logged, each having at least a baseline PNL but variable numbers of repeat/monitor PNLs, with a total of 96 PNLs acquired.

Table 1. PNL Campaign Completion Dates and Number of PNLs Acquired in Each Campaign

Accomplishment	Date	PNLs Acquired
1st PNL Campaign Complete	June 2013	33
2nd PNL Campaign Complete	October 2013	4
3rd PNL Campaign Complete	January 2014	4
4th PNL Campaign Complete	August 2014	19
5th PNL Campaign Complete	November 2014	4
Extended PNL Campaign: 6th PNL Campaign Complete	October 2015	17
Extended PNL Campaign: 7th PNL Campaign Complete	Pending	15
	Total:	96

INITIAL ANALYSIS OF EXTENDED PNL CAMPAIGN DATA COMPLETED

Initial analysis of extended PNL campaign data has been completed, satisfying Milestone 52 (M52). Initial analysis suggests no vertical out-of-zone migration. Porosity and fluid saturation data from baseline PNLs have provided direct modeling inputs. Repeat PNLs are being compared with numerical simulation results to enable better history matching and achievement of more accurate predictive simulation results. Comparison of baseline and repeat PNLs in producing wells have verified suspected CO_2 breakthrough. With the field's injection following a WAG scheme, comparisons of successive repeat PNLs in injection wells cycling from CO_2 to water injection have given insight into irreducible CO_2 saturation (Figure 2). Preferential fluid flow zones have been identified. A comparison of PNL data from the October 2015 campaign, acquired in conjunction with a repeat 3-D seismic survey, indicated that an average CO_2 saturation of 3%–4% over a thickness interval of approximately 20 feet may produce a noticeable change in seismic amplitude (in a minimum measurement sense). Statistical analyses have been developed to assess the repeatability of PNLs between surveys, from reservoir to surface, in an attempt to illuminate any anomalies needing further investigation. Each of these efforts will continue to be developed and refined. It is expected that fully processed, interpreted, and analyzed results for the extended PNL campaign data will be completed in June 2017.
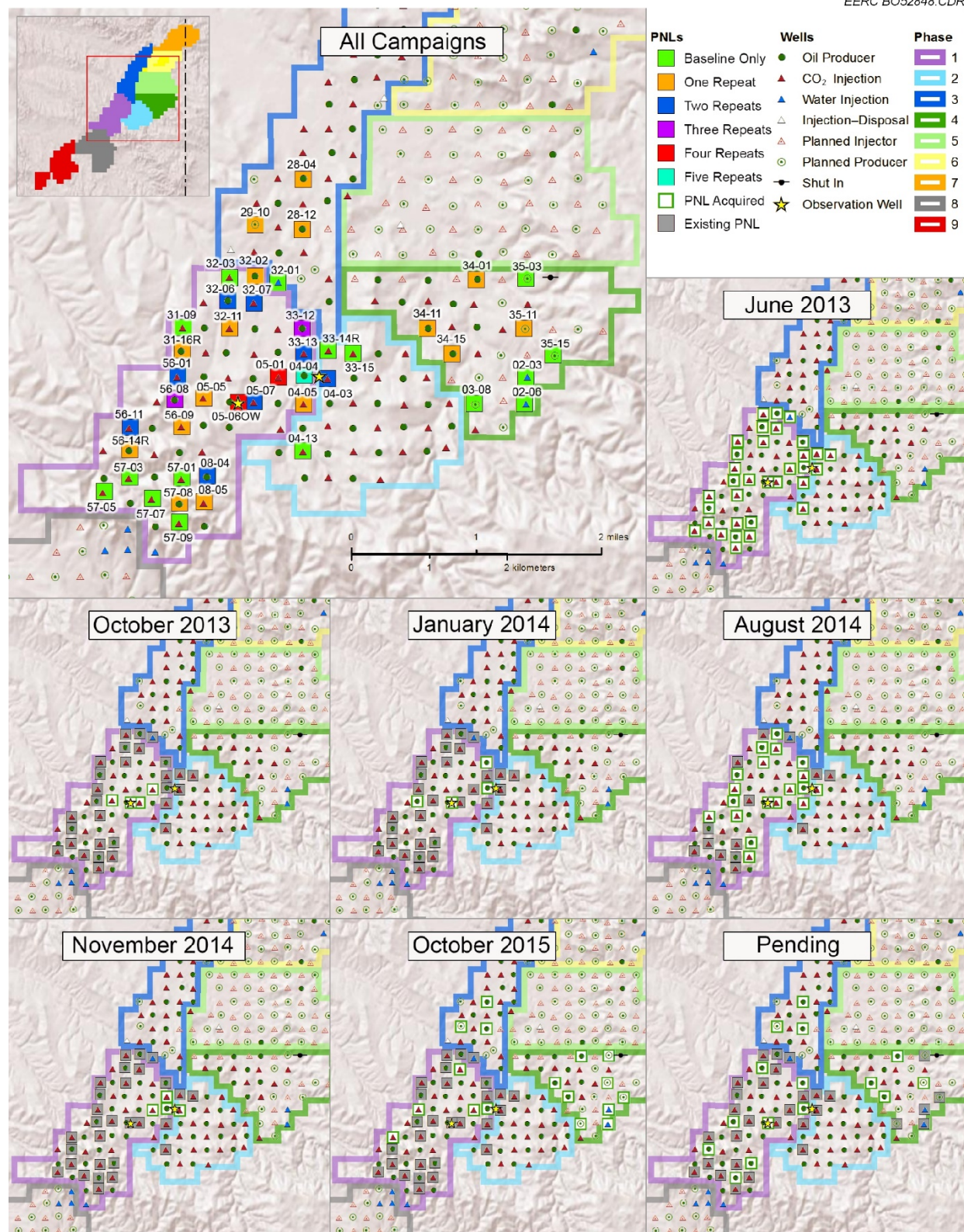
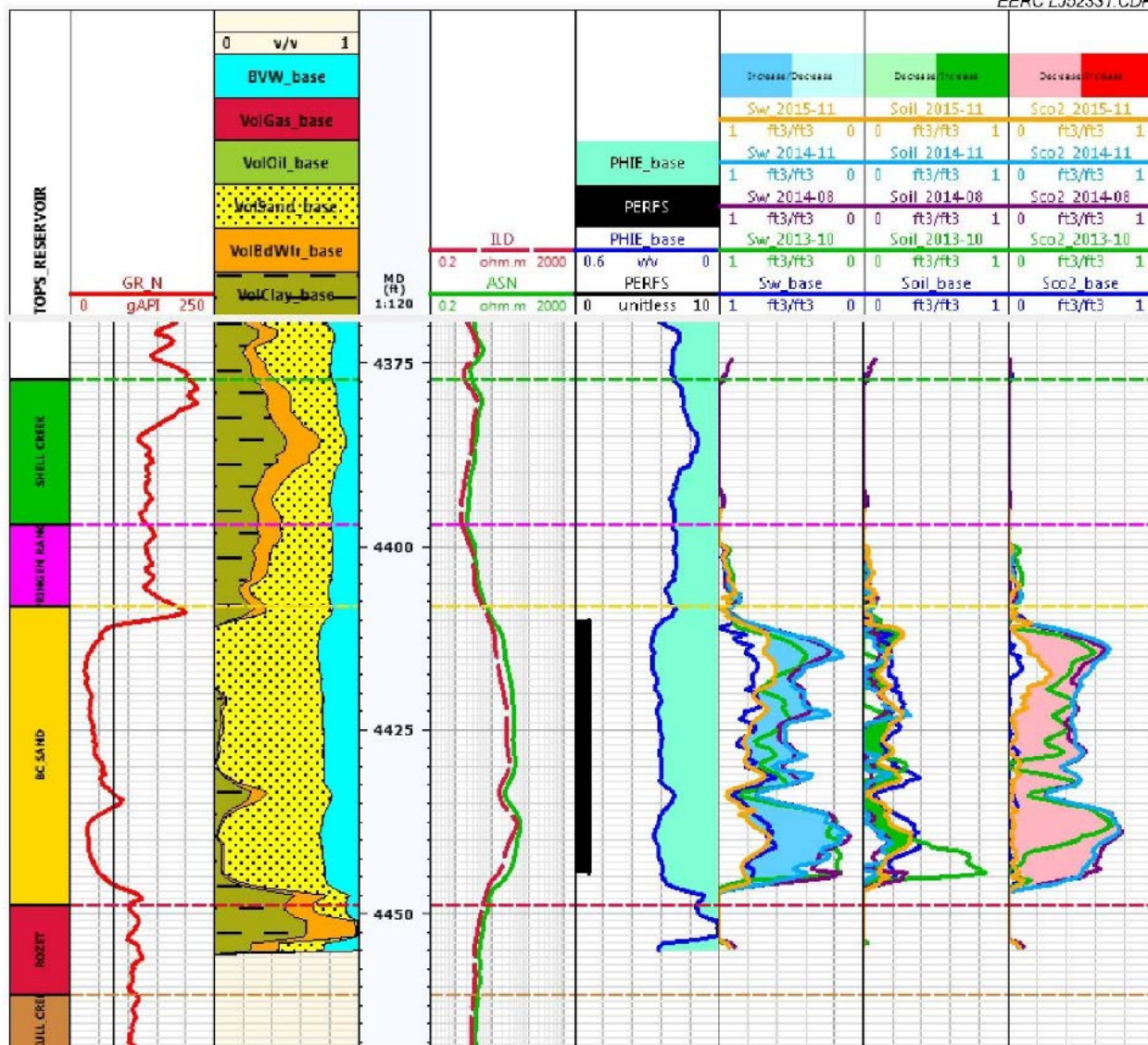Figure 1. Bell Creek Field map showing all PNL campaigns.

Figure 2. 05-01 injection well (Phase 1) PNL display within the Muddy Formation. Track descriptions are (from left to right) Muddy Formation subintervals (members), gamma ray (GR) log, component volumes, measured depth reference track (feet), resistivity log, perforations and effective porosity, water saturation, oil saturation, and CO_2 saturation. Regarding the saturations, color fill is indicative of increase or decrease in repeat PNL measurement (from November 2014 to November 2015). Interval tops shown are (from bottom to top) Skull Creek, Rozet, Bell Creek sand, Springen Ranch, and Shell Creek shale. This well was undergoing water injection at the time of measurement (note the decrease in CO_2 saturation and increase in water saturation). Irreducible CO_2 saturation to water appears to range from 2% to 5% in the lower perforation interval but increasing upward, reaching as high as 25% near the top of the perforation interval.