Report Title:

Application of Reservoir Characterization and Advanced Technology to Improve Recovery and Economics in a Lower quality Shallow Shelf SanAndres Reservoir

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DISCLAIMER

OBJECTIVES

The Class 2 Project at West Welch was designed to demonstrate the use of advanced technologies to enhance the economics of improved oil recovery (IOR) projects in lower quality Shallow Shelf Carbonate (SSC) reservoirs, resulting in recovery of additional oil that would otherwise be left in the reservoir at project abandonment. Accurate reservoir description is critical to the effective evaluation and efficient design of IOR projects in the heterogeneous SSC reservoirs. Therefore, the majority of Budget Period 1 was devoted to reservoir characterization. Technologies being demonstrated include:

1. Advanced petrophysics
2. Three-dimensional (3-D) seismic
3. Crosswell bore tomography
4. Advanced reservoir simulation
5. Carbon dioxide (CO_2) stimulation treatments
6. Hydraulic fracturing design and monitoring
7. Mobility control agents

SUMMARY OF TECHNICAL PROGRESS

West Welch Unit is one of four large waterflood units in the Welch Field in the northwestern portion of Dawson County, Texas. The Welch Field was discovered in the early 1940's and produces oil under a solution gas drive mechanism from the San Andres formation at approximately 4800 ft. The field has been under waterflood for 30 years and a significant portion has been infill-drilled on 20-ac density. A 1982-86 pilot CO_2 injection project in the offsetting South Welch Unit yielded positive results. Recent installation of a CO_2 pipeline near the field allowed the phased development of a miscible CO_2 injection project at the South Welch Unit.

The reservoir quality at the West Welch Unit is poorer than other San Andres reservoirs due to its relative position to sea level during deposition. Because of the proximity of a CO_2 source and the CO_2 operating experience that would be available from the South Welch Unit, West Welch Unit is an ideal location for demonstrating methods for enhancing economics of IOR projects in lower quality SSC reservoirs. This Class 2 project concentrates on the efficient design of a miscible CO_2 project based on detailed reservoir characterization from advanced petrophysics, 3-D seismic interpretations and crosswell tomography interpretations.

During the quarter, work was completed on calibrating the interwell seismic-derived apparent porosity changes that result from increased CO_2 saturation. Remedial operations in the CO_2 focus area were conducted on several wells.

INTERWELL SEISMIC

During the 4th quarter of 2001, Advanced Reservoir Technologies (ART) used the estimates of relative CO2 saturations derived from the second monitor survey results to further define the CO2 saturation. Previously developed techniques were applied to these latest estimates of CO2 saturation along the south pattern's interwell lines to attain azimuthal spatial statistics. These statistics were used to extrapolate by kriging the relative saturation estimates into the full 3-D reservoir volume over the portion of th CO2 focus area covered by the interwell seismic pattern. VRML (virtual reality) image files were generated from the relative saturation data, allowing the results to be viewed, scaled and rotated interactively in 3-D for easy visualization of the results. Complete images of saturation estimates were generated for the second monitor survey as well as different images showing changes between each of the two monitor surveys and between each of these surveys and the baseline (pre-injection) survey.

Figure 1 shows the 3D interpretation of CO2 relative saturation in the vicinity of the 4852 observation well based on the first (1999) monitor survey. The CO2 injected into 4811 had nearly all flowed to the east and southeast. The second monitor survey results (Figure 2) show the continued easterly expansion of the CO2 volume originally observed on the first monitor survey. However, in the time period between the first and second monitor surveys, CO2 apparently began to flow in a westerly direction and to a lesser extent to the north and south as shown by subtracting the 1994-1999 interpretation from the 1994-2001 interpretation (Figure 3). Although there are no interwell lines oriented directly to the west of the 4852 observation well, there are interwell lines oriented to the northwest and to the southwest. The extrapolated CO2 volume between these lines supported the interpretation of a possible new flow of CO2 toward the west.

While these trends were suggested earlier from the interpretation of CO2 movement along the interwell line after the second monitor survey, the situation is seen clearer from the 3D depictions of the relative CO2 saturations at the time of the second monitor survey and from the changes in relative saturation in the time interval between the monitor surveys. It should be reemphasized that no method has been developed to accurately calibrate these saturation estimates in absolute terms. *Consequently all saturation estimates are relative since they are calculated as a percent of peak observed saturation.*

Does the actual well performance validate the interwell seismic interpretation of CO2 distribution in the reservoir? This is a difficult comparison to make. The monitor surveys involved six interwell lines radiating from the 4852 observation well. Since injector 4811 is near the observation well, the CO2 distribution being interpreted is the volume injected into 4811. The surrounding producers can be influenced by CO2 from other injectors. The first producer in the focus area to experience CO2 breakthrough was 4843 early in 1999, yet the interpretations shown on Figures 1-3 do not indicate any flow southward from injector 4811 toward 4843 until the second monitor survey (1Q01). Producer 4843 is located directly north of injector 4806 (Figure 4) which could be the source of the CO2. Producer 4844 also experienced CO2 breakthrough early in 1999. The first monitor survey interpretation (4Q99) shows most of the CO2 injected into 4811 flowing directly toward 4844. Producer 4841 has not experienced CO2 breakthrough which agrees with the interpretations on Figures 1-3. Overall the interwell seismic interpretation of the time-lapse CO2 distribution around observation well 4852 and injector 4811 appears to agree with actual well performance.

The indicated new flow of CO2 to the west of the 4852 observation well is in direction of the horizontal lateral completed in early 2001. CO2 injection started in October 1997. The first monitor survey, which indicated that CO2 was moving eastward of the 4852 observation well was run 4Q99. The second monitor survey was run 1Q01 shortly after the horizontal well had been completed. One explanation for the eastward flow would be that the horizontal lateral intersected injection-induced fracturing providing a path of least resistance, i.e. pressure drop, for the CO2 to follow.

It might be possible to test this hypothesis further by examining both the shear and compressional wave interwell data. Only the compressional wave data are sensitive to changes induced by replacement of original pore fluid by CO2. However, both compressional and shear wave data are sensitive to changes induced by fracturing. Therefore, alteration of both compressional and shear wave data between baseline and monitor

surveys would provide an indication of possible injection-induced fracturing in the reservoir. If injection-induced fracturing could be detected by the crosswell seismic data, the results should improve the geologic model's ability to simulate the CO2 location and movement. This approach has not been scheduled to be worked on due to budget restraints.

3-D SEISMIC INTEGRATION

No activities involving 3-D seismic were undertaken during the quarter.

NUMERICAL SIMULATION

There has been no numerical simulation activities this quarter.

FIELD DEMONSTRATION PHASE

A total of 313 MMCF (3.4 MMCFD) of CO2 was injected into the six injectors in the CO2 focus area during the fourth quarter of 2001. The total volume of CO2 injected through September 2001 is 4.2 BCF in the focus area and 5.2 BCF in the total project area since initiation of injection in October 1997.The focus area's hydrocarbon pore volume (HCPV) was processed this quarter at rate of O.3% per month. A total of 13.9% of the HCPV within the focus area has been processed through December 2001. One injector was switched from water injection to CO2 during September 2001 and another was switched from CO2 to water in December 2001. The focus area injection and production performance for the fourth quarter of 2001 is shown on Table 1.

The DOE earlier approved a six-month extension to the project life and they are currently processing another extension request that will extend the project life to September 30, 2002. These extensions will allow time for at least 15% of the focus area's HCPV to be processed by CO2. Fifteen percent is considered the minimum processed volume required for a meaningful evaluation of the CO2 potential. The total volume of CO2 injected will depend on the remaining project funding that is available.

The 4853 horizontal lateral was continued to be shut in during the quarter while various options were considered as to the well's future. Among options being considered are plugging the lateral back to a shorter length or using the lateral as an observation well to detect where CO2 sweep is occurring.

Remedial operations on producers were continued this quarter with 4819 being treated to remove skin damage around the wellbore. The well was cleaned to TD, the perforations jet washed and treated with small volumes of acid, xylene and scale converter. Well 4821, which had been reactivated at a test rate of 0 BOPD and 39 BWPD, was cleaned out and given a CO2 acid frac similar to the successful treatment on 4818 (6500 gallons acid and 60 tons of CO2). Post workover well test was 11 BOPD and 100 BWPD. In contrast 4818 is still showing a 35 BOPD increase.

Injector 4808 as reported in the last quarter began to show pressure on the casing annulus and in August the well was switched to water injection to eliminate high gas pressure in the wellbore so remedial operations could be conducted without having to mud up. During the quarter the well was cleaned out and the perforations jet washed. Injector 4805 was acidized with 4000 gal, resulting in lower injection pressures.

Prior to this quarter, significant oil response to the CO2 injection had apparently occurred in three wells - 4844, 4847 and 4850. On two of these wells - 4844 and 4850 - and three other producers - 4842, 4843 and 4854 - the volume of gas had increased to the point that the wells were judged to have experienced CO2 breakthrough. During this quarter the strong oil response in well 4844 that started in the 4Q98 from a base of 15 BOPD to a peak of 40+ BOPD in 3Q99 before starting to decline in 1Q00 has stabilized around 18 BOPD. The oil rate on 4847 has flatted out around 30 BOPD. The oil response that had been reported in well

4850 has been reevaluated in light last six months performance and does not appear to be related to CO2 injection. The oil rate increase noted in 4843 last quarter has fallen off from the 50 BOPD peak, but is still around 30 BOPD and probably reflects response to the CO2. Similarly the significant increase in 4815 last quarter continued in the 25 BOPD range and is probably CO2 response also. This is noteworthy because 4815 would be the first diagonal offset to an injector to respond. Another diagonal offset, 4818, was treated with a CO2 acid frac in 3Q01 and increased from 5 to 60 BOPD and is still producing above 40 BOPD. This level of production suggests that the well is responding to CO2 injection. Well 4842 increased from 10 to 20 BOPD over a 12-month period and has held this level for six months. This could be CO2 response but is not definitive. The current response status of the producers is shown on Figure 4.

TECHNOLOGY TRANSFER

There has been no technology transfer activity during this quarter.

Table 1

CO2 Focus Area Performance
Fourth Quarter - 2001
West Welch Unit DOE Project
Dawson County, Texas

		Oct	Nov	Dec	4th Qtr
Injection					
	Average CO2 injection rate (mcfd)	3065	3915	3258	3412
	# of Injectors on CO2	5	6	4.5	5.0
	Average rate per injector (mcfd)	613	652	724	663
	% HCPV injected	0.3%	0.4%	0.3%	1.0%
	Cum % HCPV injected	13.2%	13.6%	13.9%	13.9%
	Average water injecton rate (bwpd)	337	0	150	
	# of Injectors on water	1	0	1	0.7
	Average rate per injector	337	0	150	162
	Water+CO2 % HCPV injected	0.4%	0.4%	0.4%	1.2%
	Water+CO2 Cum % HCPV injected	15.2%	15.5%	15.9%	15.9%
Production					
	Base oil production (bopd)	125	124	123	124
	Actual oil production (bopd)	174	201	231	202
	Incremental oil production (bopd)	49	77	108	78
	Gas production (mcfd)	841	860	889	863
	Gas production as % injection	27%	22%	27%	25%
	Base WOR	13	13	13	
	WOR	5.5	4.0	3.8	4.4

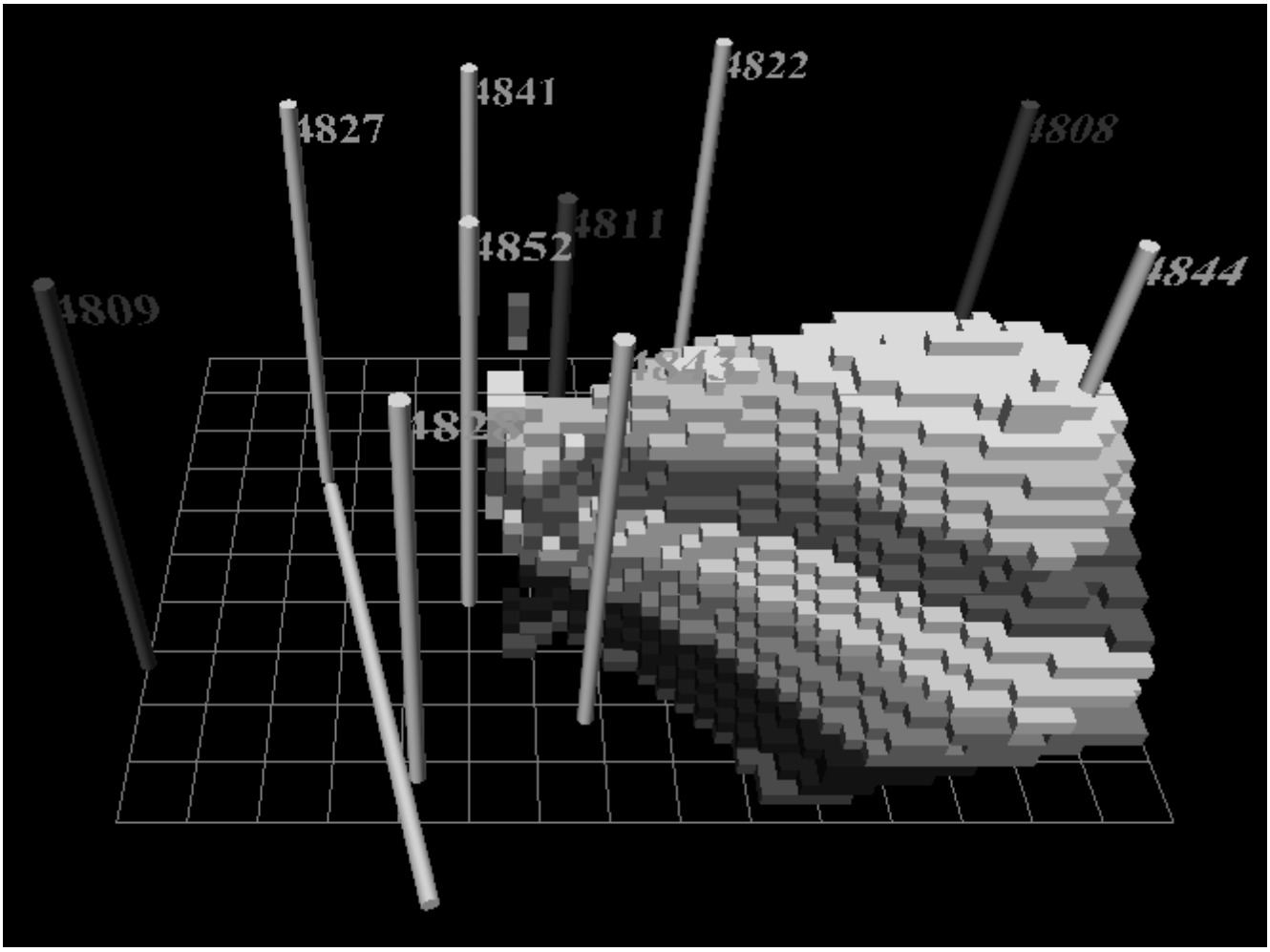

Figure 1 - Reservoir Volume Surrounding Injector 4811 Permeated by CO2 Between 4Q1997 and 4Q 1999 as interpreted from Interwell Seismic

Legend:

Grid = 200' x 200'
Depth Contour Interval = 15'
CO2 Injector = dark shaded wellbore
Oil Producer = light shaded wellbore

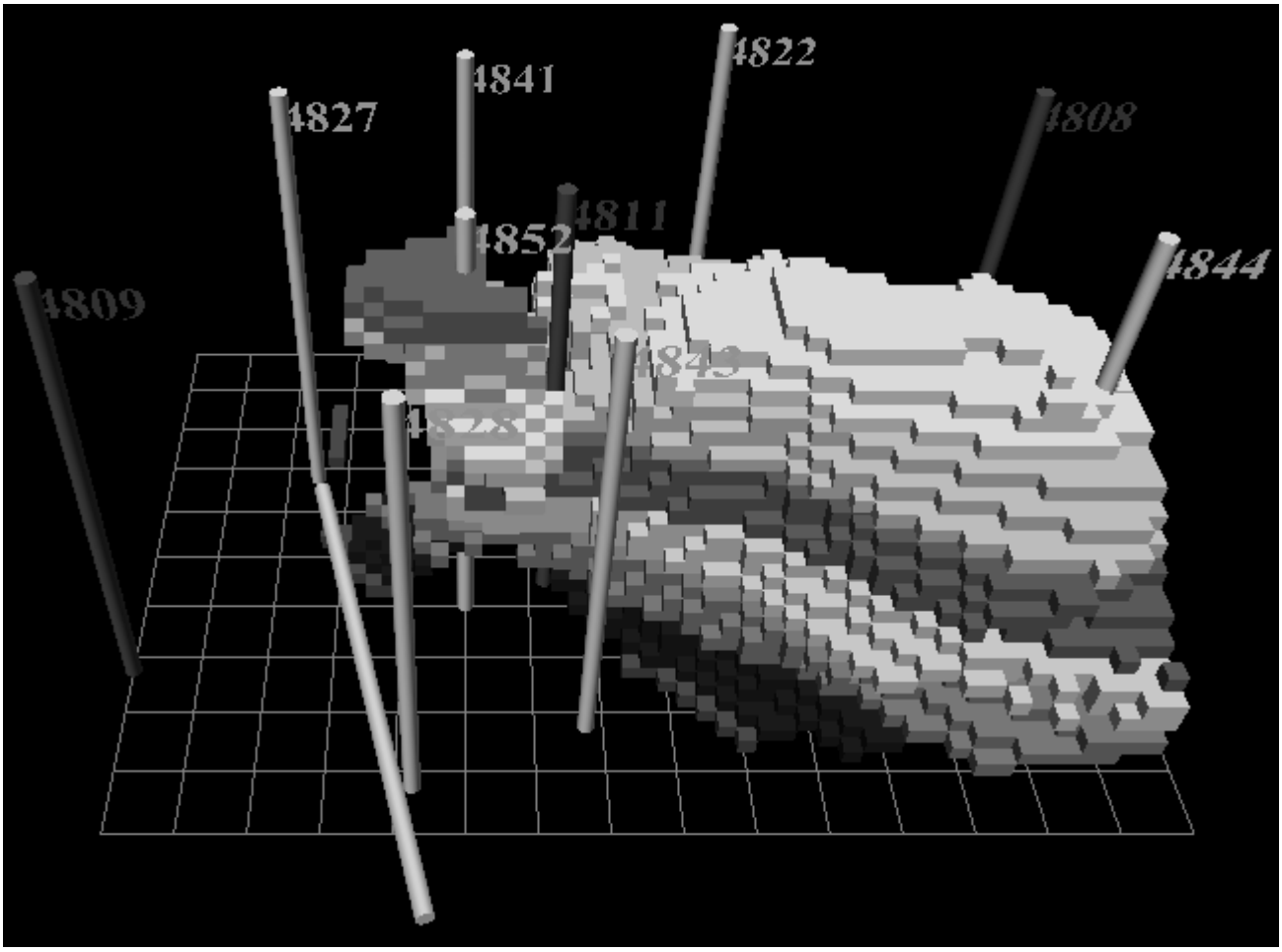

Figure 2 - Reservoir Volume Surrounding Injector 4811 Permeated by CO2 Between 4Q1997 and 1Q2001 as interpreted from Interwell Seismic

Legend:

Grid = 200' x 200'
Depth Contour Interval = 15'
CO2 Injector = dark shaded wellbore
Oil Producer = light shaded wellbore

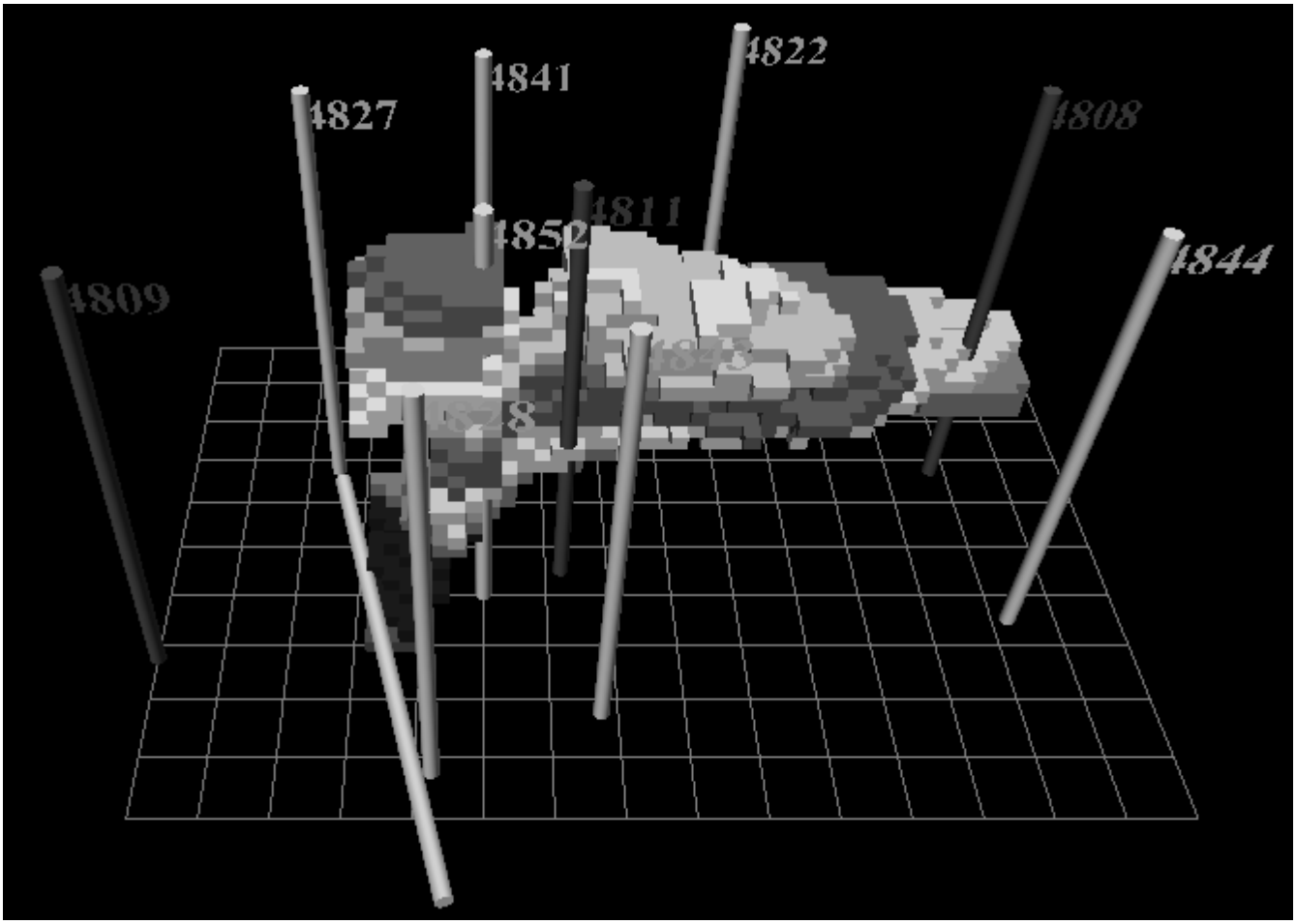

Figure 3 - Reservoir Volume Surrounding Injector 4811 Permeated by CO2 Between 4Q1999 and 1Q2001 as interpreted from Interwell Seismic

Legend:

Grid = 200' x 200'
Depth Contour Interval = 15'
CO2 Injector = dark shaded wellbore
Oil Producer = light shaded wellbore

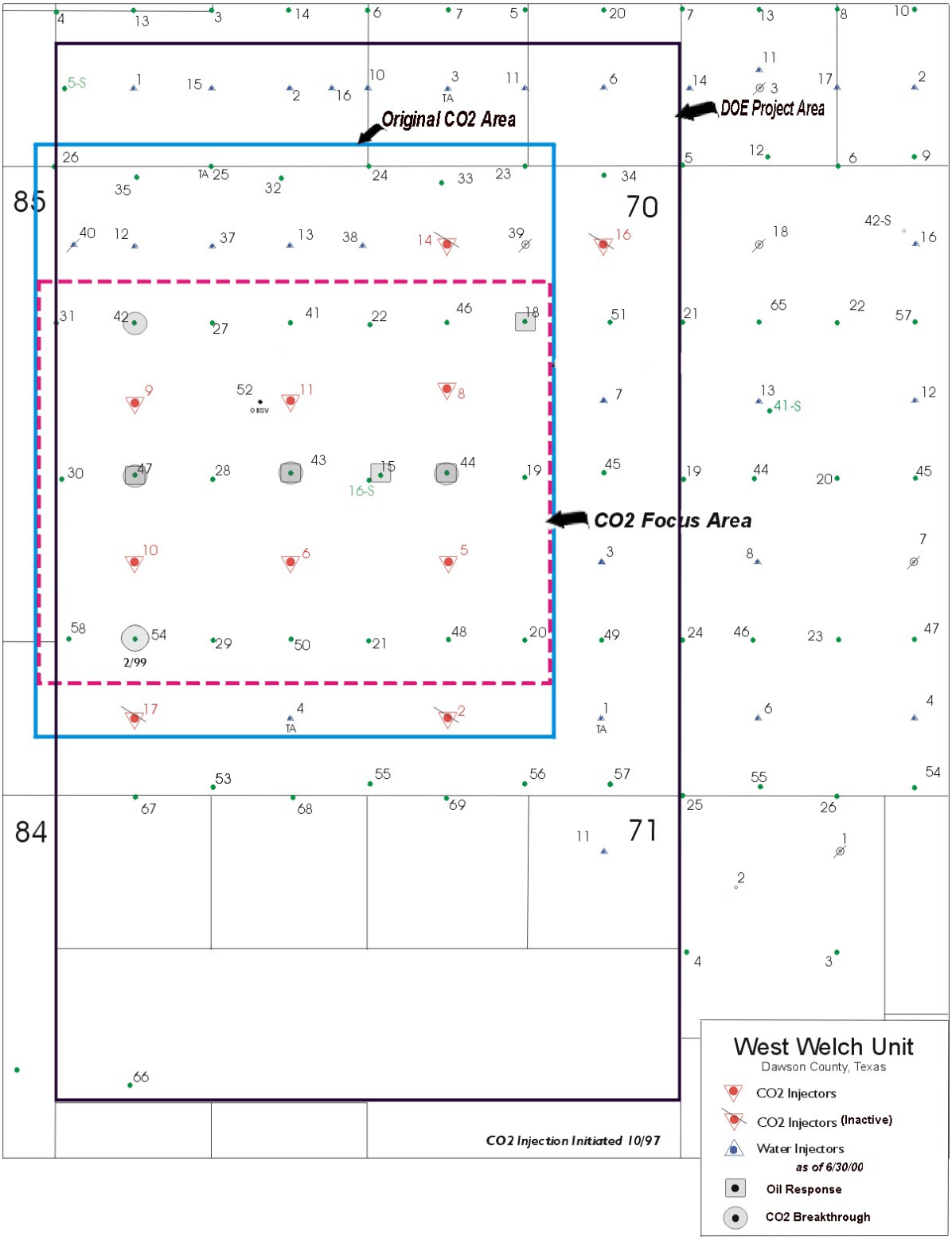

Figure 4 - CO2 Performance 4th Quarter 2001