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Case Studies of the ROZ CO_2 Flood and the Combined ROZ/MPZ CO_2 Flood at the Goldsmith Landreth Unit, Ector County, Texas. Using "Next Generation" CO2 EOR Technologies to Optimize the Residual Oil Zone CO2 Flood.

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ABSTRACT

The technology for CO_2 Enhanced Oil Recovery (CO_2 EOR) has significantly advanced since the earliest floods were implemented in the 1970s. At least for the Permian Basin region of the U.S., the oil recovery has been now been extended into residual oil zones (ROZs) where the mobile fluid phase is water and immobile phase is oil. But the nature of the formation and fluids within the ROZs has brought some challenges that were not present when flooding the MPZs. The Goldsmith-Landreth project in the Permian Basin was intended to first identify the most pressing issues of the ROZs floods and, secondly, begin to address them with new techniques designed to optimize a flood that commingled the MPZ and the ROZ.

The early phase of the research conducted considerable reservoir and fluid characterization work and identified both technical and commercial challenges of producing the enormous quantities of water when flooding the ROZs. It also noted the differing water compositions in the ROZ as compared to the overlying MPZs. A new CO_2 gas lift system using a capillary string was successfully applied during the project which conveyed the CO_2 to the deeper and differing ROZ reservoir conditions at Goldsmith and added a second capillary string that facilitated applying scale inhibitors to mitigate the scaling tendencies of the mixing ROZ and MPZ formation waters.

The project also undertook a reservoir modeling effort, using the acquired reservoir characterization data, to history match both the primary and water flood phases of the MPZ and to establish the initial conditions for a modeling effort to forecast response of the ROZ to CO_2 EOR. With the advantage of many profile logs acquired from the operator, some concentration on the original pattern area for the ROZ pilot was accomplished to attempt to perfect the history match for that area. Several optional scenarios for producing the ROZ were simulated seeking to find the preferred mode of producing the two intervals.

Finally, the project attempted to document for the first time the production performance of commingled MPZ and ROZ CO_2 EOR project at the nearby Seminole San Andres Unit. The analysis shows that over 10,000 bopd can be shown to be coming from the ROZ interval, a zone that would have produced no oil under primary or water flood phases. A similar analysis was done for the GLSAU project illustrating that 2000 bopd of incremental EOR oil is currently being produced. The results of the modeling work would suggest that 800 bopd can be attributed to the ROZ alone at GLSAU.

Final Report

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Executive Summary

The advancing state of producing oil using carbon dioxide enhanced oil recovery (CO_2 EOR) technology in residual oil zones (ROZs) has brought considerable excitement as the oil-in-place targets for EOR have now been extended beyond main pay zones (MPZs) and thereby dramatically enhanced. But, with the deployment of field demonstration projects, some challenges have emerged as the intervals and fluid properties within the ROZs are often different than the MPZs which are more familiar to the oil industry. The study summarized herein addressed several of the larger challenges of producing oil from ROZs including the differing water compositions, vertical profile challenges when commingling the MPZs with the ROZs, and forecasting response to EOR and oil recoveries.

The research was conducted at the Goldsmith-Landreth San Andres Unit (GLSAU) in northern Ector County, Texas on the Central Basin Platform (CBP) region of the Permian Basin. The San Andres formation is now understood to hold over one hundred billion barrels of oil in the residual oil zones with the north shelf and CBP regions. Some of the oil underlies the MPZs as it does in the GLSAU but much of it lies in “greenfield”” areas between oil fields.

This Department of Energy research project is deeply indebted to Legado Resources, the host company for the research during the first phases of studies, and to Kinder Morgan CO_2 Company the successor operator in the concluding phase.

Nine cores, several repeat formation tests, and numerous detailed wireline logs were obtained from the new wells drilled during the study and have been summarized herein. All tools were designed to better understand the geologic framework of the field, obtain the reservoir fluid properties, establish that the ROZ had commercially recoverable oil and, especially, to assist with the reservoir and fluid characterizations for the computational model construct.

A reservoir modeling effort, using the reservoir characterization data above, was undertaken to history match both the primary and water flood phases of exploitation of the MPZ and to establish the initial conditions for a modeling effort to forecast response of the ROZ to CO_2 EOR. A reasonable history match for the primary and secondary phases of production in the MPZ was established and a high quality history match was achieved for the CO_2 EOR project through the end of 2014. With the advantage of many profile logs acquired from the operator, some concentration on the original pattern area for the ROZ pilot was accomplished to attempt to perfect the history match for that area. Several optional scenarios for producing the ROZ were simulated.

One of the challenges of flooding the ROZ lies in the quality of the reservoir and production of large volumes of formation water. Development of a new CO_2 lift design was being pioneered by Mr. Ed Payne of Whiting Petroleum and was adapted and installed for the deeper dolomite formation at GLSAU. The successful application of CO_2 gas lift via a capillary tube delivery system not only avoided the occasional switch

over of lifting apparatus (submersible, beam pumps) but lowered the capital and operating costs as well. A complementary feature proved to be especially useful in that a second capillary tube could be deployed and used to treat for scale inhibition which the industry is finding is so often required for the sulfate-rich waters of the San Andres ROZs.

Commingling of the MPZ and ROZ offers the opportunity to flood more oil-in-place, but brings with it the challenge of mixing a zone that has been producing for decades with a new zone (ROZ) with original bottom-hole pressures. As a result, the desired goal of distributing CO2 to the entire vertical section has both a pressure and reservoir property complexity. Over fifty profile logs were run by the operator and provided to the project to 1) better understand the delivery of CO2 to the profile and 2) allow profile modification to allow improved oil response. Analysis of the profile data allowed estimates of the injection effectiveness and is summarized in four subzones within the ROZ.

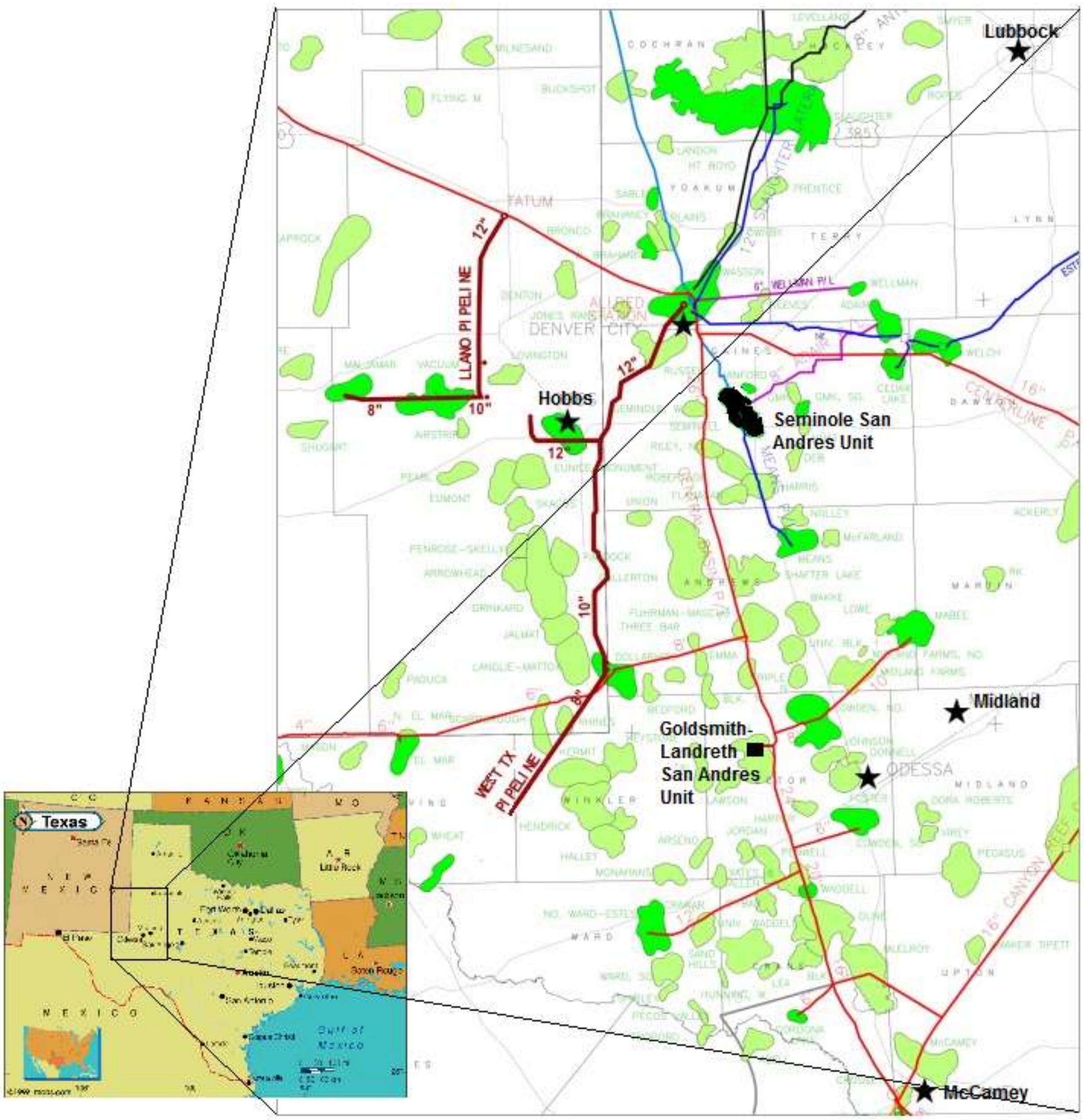
With the aid of the reservoir characterizations of both the MPZ and ROZ along with the profile log results, the ROZ pilot pattern area (Well #190) was simulated using a detailed streamtube (CO2-PROPHET) model. The results showed that flooding the MPZ first, then plugging off the MPZ and flooding the ROZ (a sequential MPZ/ROZ flood) is more effective (by measure of oil recovery) than injecting CO2 into dually completed MPZ and ROZ wells (a simultaneous MPZ/ROZ flood).

The original commingled MPZ and ROZ CO2 EOR project occurred at the Seminole San Andres Unit in Gaines County, TX to the north of GLSAU. This project has been essentially unreported to date except for two presentations at the Annual CO2 flooding conference in the Permian Basin. Hess first expanded to the ROZ from the overlying MPZ in 1996 with a pilot flood and followed it with a second pilot. Both proved successful and a decision was made to expand to a field-wide ROZ deployment beginning with Stage 1 (Oct ‘07). Results of the pilots and field wide stages to date have been analyzed are reported herein. By our analysis, over 10,000 bopd can be shown to be coming from the ROZ interval, a zone that would have produced no oil under primary or water flood phases. A similar analysis has been done for the GLSAU project but, in this case, for the commingled MPZ + ROZ flood illustrating 2000 bopd currently being produced. The results of the modeling work reported herein would suggest that 800 bopd can be attributed to the ROZ alone.

Section 1 - Introduction and Background

The Goldsmith-Landreth San Andres Unit (GLSAU) is one of the many San Andres dolomite fields of the Central Basin Platform and Northern Shelf regions of the Permian Basin (Figure 1.1, Ref 1.1).

Figure 1.1 – Map of the Central Basin Platform Region of the Permian Basin Showing Location of the Goldsmith-Landreth San Andres and the Seminole San Andres Units Together with the CO_2 Pipeline Infrastructure



The San Andres formation production represents approximately 40% of the 30 billion barrels of cumulative oil production in the Permian Basin (Ref 1.2), over 80% of the 7 billion barrels of water flood production, and is the most common CO_2 flooded formation in the world. When the opportunity to advance next generation flooding technologies occur, it seems appropriate to look at the San Andres formation.

Like the benchmark Seminole San Andres Unit (SSAU) analyzed in Section 5 of this report, the GLSAU was discovered in the 1930s and, after a long history of primary production, the many and various leases were unitized for water flooding in the 1960s. But, unlike the SSAU, its more limited size (8000 acres) and original oil in place in the MPZ (245 million barrels of oil) put it lower in the list in priority for CO_2 flooding and the tertiary (CO_2) phase was not started until 2009. With the emergence of understanding of commercial targets in the ROZ and the GLSAU ROZ oil in place estimated to be another 154 million barrels, the combined oil in place figures greatly helped justify moving the project up in priority for CO_2 flooding.

Table 1.1 recaps the history of oil exploration and CO_2 EOR development at the Goldsmith-Landreth San Andres Unit Area. The acquisition of the property by Legado Resources, their intention of flooding the ROZ interval, and willingness to host a Government funding research project lead to the project reported herein.

Table 1.1 – Tabular History of the Goldsmith-Landreth San Andres Unit Area

1934 – Field Discovery

1945 – Completed Initial Development Phase (250 Wells)

1948 – Began Gas Cap Re-injection for Conservation and Fluid Pressure Maintenance

1963 – Unitization and Deployment of Peripheral Water flood (Amoco {Stanolind} as Operator)

1965 – Begin Phasing into the Pattern Waterflood

1985 – Stripper Operations and Beginning of Well Abandonments

2008 – Legado Resources Acquires Field Operations

2009 – (July) CO_2 Pilot Operations Commence

2010 – (Oct) Phase I Initiated (Commingle MPZ+ROZ)

2013 – Kinder Morgan CO_2 Company Acquires GLSAU Field and Recycle Facility Operations

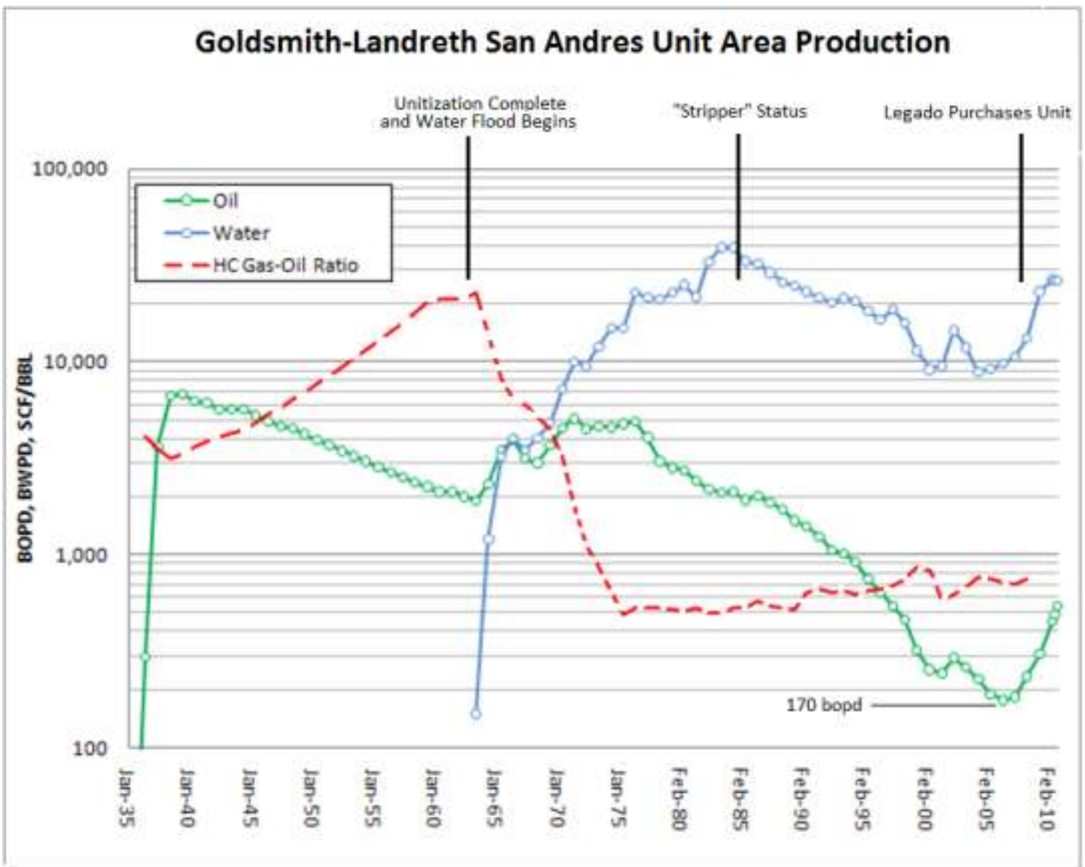
Table 1.2 (Thurmond, 2010) summarizes the GSLAU reservoir statistics in terms of original and remaining oil in place figures and production statistics by phase of production for both the main pay zone (MPZ) and residual oil zone (ROZ). Note that the terminology used for the ROZ oil-in-place at discovery does not use the term "original" since it is believed that the ROZ was naturally water flooded in its geological past and the **original** oil-in-place would necessarily refer to the oil in place prior to the natural water flood.

Table 1.2 – GLSAU Reservoir and Production Statistics

Goldsmith-Landreth San Andres Unit Area Oil-in- Place and Production Statistics		
Disc OOIP (MP)	246	MMSTB
Disc OIP (ROZ)	154	MMSTB
Total	400	MMSTB
Cumulative Oil To Date (as of 2010)	74	MMSTB
Rem OIP (Gas Cap)	22	MMSTB
Rem OIP (MP)	132	MMSTB
Rem OIP (ROZ)	154	MMSTB
Total	308	MMSTB
PV Ratio (ROZ/MP)	1.16	

Figure 1.2 illustrates the full production history of the GLSAU area even prior to the unitization in 1963 when production was reported on a lease-by-lease basis. Note that the classic three peak nature of production (to include the CO_2 tertiary phase) is present at GLSAU as it is with the most of the mature water and CO_2 floods of the Permian Basin. The water flood responded well but did not perform as well as the SSAU water flood. By the mid-1990s, the field was witnessing well problems and many wells were abandoned during that time as can be noted by the increasing production decline rate through the turn of the century. Some in-fill drilling occurred in the 2001-2002 time frame to temporarily suspend the decline but the increased production was short lived.

Figure 1.2 – GLSAU Unit Area Production History



Legado Resources acquired the unit in 2008 when the production was at its low point of 170 bopd. The revival of the field required extensive well reworking and an area in the southern part of the unit was selected for the initial CO_2 pilot (Figure 1.3). Injection began in in July of 2009. Oil response proved the viability of oil recovery from the ROZ and the MPZ interval was added to the producing interval in mid-2010 and, by 2011 Phase I of the CO_2 flood was underway. This project reports primarily on the research done at the unit during the Pilot and Phase I phases but some of the next generation technologies were also applied and reported herein on the Phase II operational phase.

Figure 1.3 – GLSAU CO_2 Pilot and Phase I Area Map

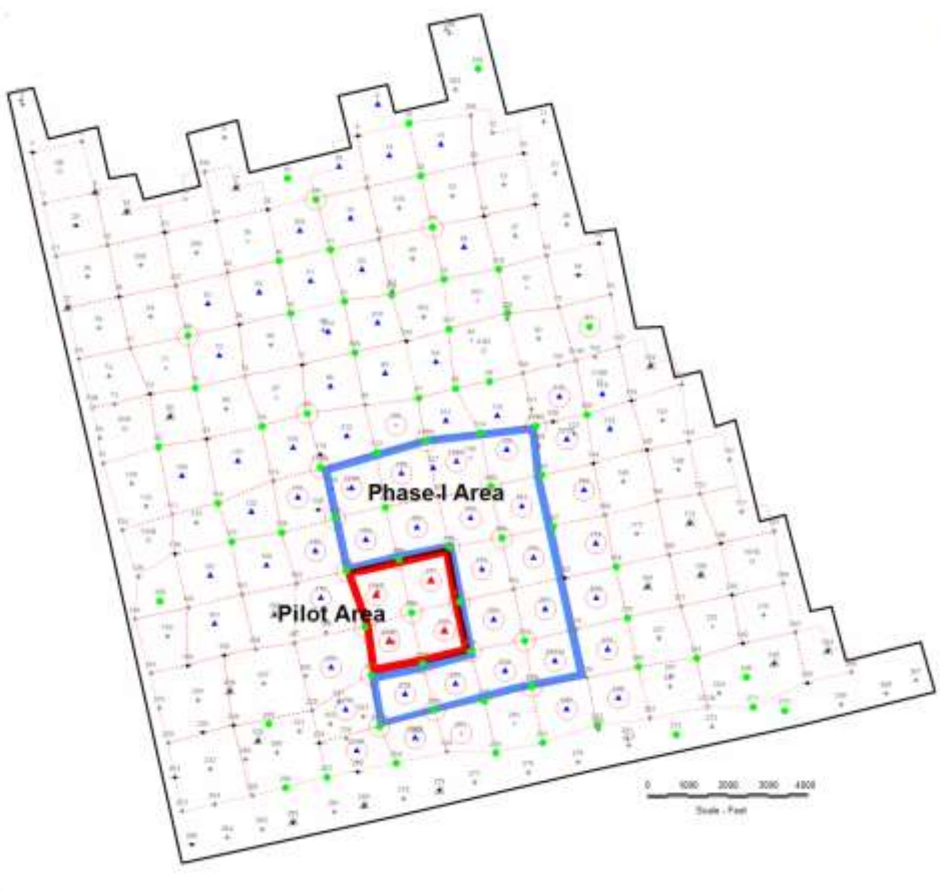
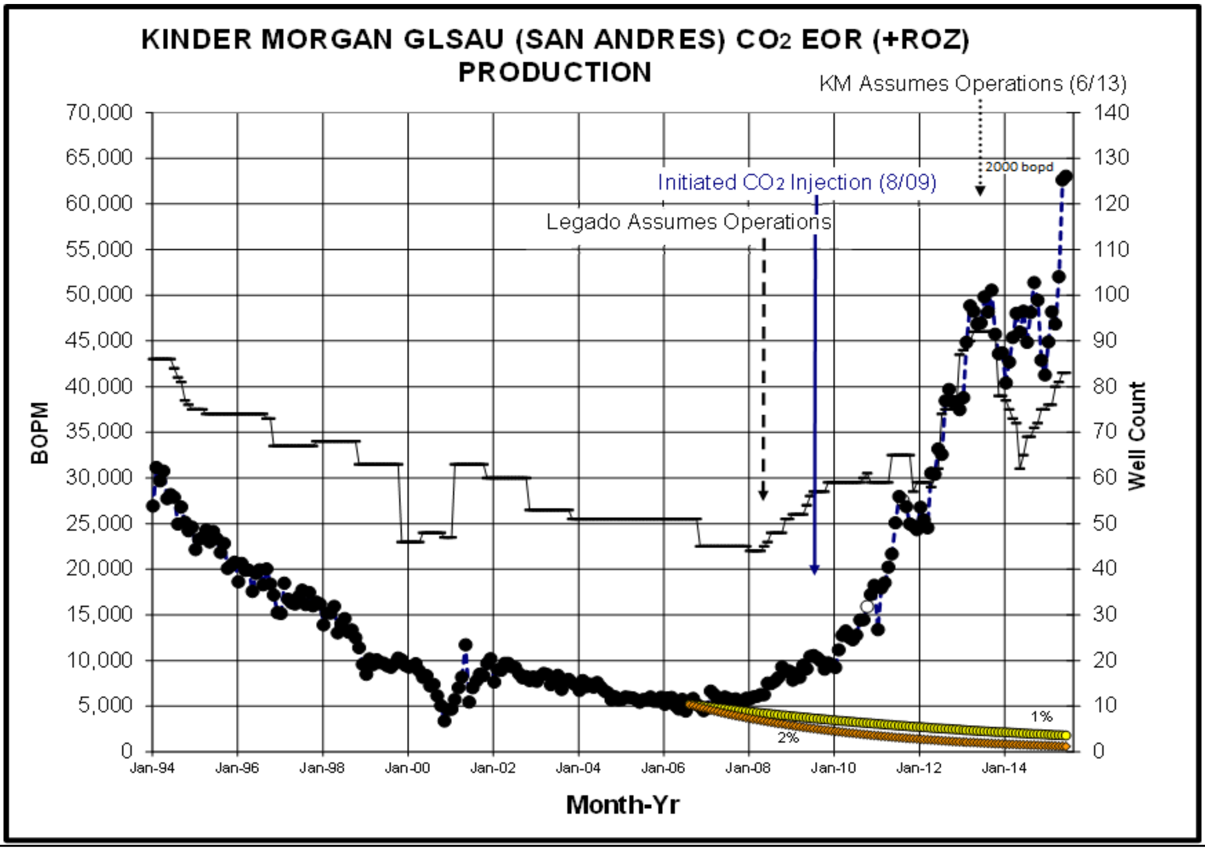


Figure 1.4 illustrates the recent 20 years of production at GLSAU and into the CO_2 EOR phase. Shown on the chart are two extrapolated declines of the existing (water flood) production noting that, when using either, essentially all of the production is coming from the CO_2 response of the combined ROZ and MPZ flood. Note also that the production has recently climbed to over 2000 barrels of oil per day as witness to the success that Kinder Morgan is having after a period of adjustment and new personnel within the field operations at GLSAU after the acquisition in mid-2013.

Figure 1.4 – GLSAU Production History: Jan 94 – Jun 15



References - Section 1

Adapted from the Trinity CO_2 Company Permian Basin Pipeline Map, personal communications

Personal Communication (Hess Corporation -2009)

Thurmond, Tom (2010), "Managing a CO_2 Development in a Privately Funding Environment: The GLSAU Project, presented at the 16th Annual CO_2 Flooding Conference, Dec 9-10, 2010 http://www.co2conference.net/wp-content/uploads/2012/12/3-3_Thurmond_Legado_Managing-a-CO2Project_Goldsmith-LandrethPilot_12-10.pdf

Section 2 - Identify, map and characterize a major Permian Basin ROZ field area

2.1 –Geologic Setting and Reservoir Properties of the ROZ and MPZ.

Introduction

The San Andres Formation is the dominant producing horizon in the Permian Basin, with>10 Billion Barrels of cumulative production from more than 120 reservoirs with > 1 Mmbbl cumulative production, and a similar number of reservoirs smaller than 1 Mmbbl cumulative production. The importance of the San Andres Formation for Permian Basin production has been a driver for the numerous studies documenting the stratigraphy, diagenesis, reservoir heterogeneity, and engineering characteristics of this formation. To better understanding the architecture and heterogeneity of San Andres reservoirs, studies of the classic outcrops of the San Andres Formation in the Guadalupe, Sacramento, and San Andres Mountains are looked to as additional sources of data. This overview of the CO_2 flooding potential in the Residual Oil Zones in the San Andres of Goldsmith Field builds on these modern subsurface reservoir studies and outcrop studies.

The San Andres Formation is late Leonardian to mid-Guadalupian (Kungurian-Roadian- Wordian) in age, Figure 2.1, and was deposited as a widespread shallow-water platform associated with the latest Leonardian global eustatic transgressions (Kerans and Ruppel, 1994), across the structural high areas of the Permian Basin. The widespread distribution of San Andres reservoirs quality rocks lead to a broad range of reservoir architectures within, and between fields, and the highly variable production.

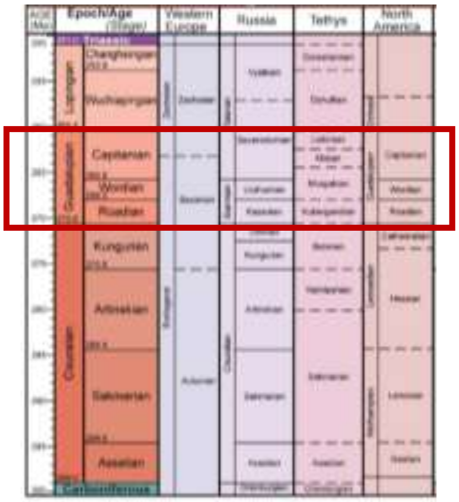


Figure 2.1. Permian Geologic Time Scale. Geologic Time Scale Foundation, 2015.

The basic model of reservoir architecture for the San Andres is that of a carbonate ramp morphing into a rimmed shelf by Grayburg time. The variations in reservoir settings are a function of variations in facies distribution in the ramp interior to ramp crest to outer ramp.

Dutton et al, 2005, have documented a number of play types or “trends” in the San Andres which are the result of complex assortment of depositional, diagenetic and tectonic elements, Figure 2.2. The lower San Andres Slaughter Trend, typified by the Slaughter and Levelland Units in Texas and the Chaveroo and Tom Tom Fields in New Mexico is the most interior (landward) fields, with flat continuous stratification and multiple stacked highstand pay zones separated by intercalated lowstand anhydrite rich sabkhas. The Artesia Trend is the terminal middle to upper San Andres shelf margin along the Northwest Shelf and western side of the Central Basin Platform, typified by cyclic inner through outer ramp strata, Stoudt and Raines (2000). The Wasson, Seminole, and associated fields (Mathis, 1986; Wang et al., 1996) are also middle to upper San Andres and have thick 200-300 ft pay intervals that have responded well to the full range of primary, secondary, and tertiary (CO_2) recovery methods. Both fields

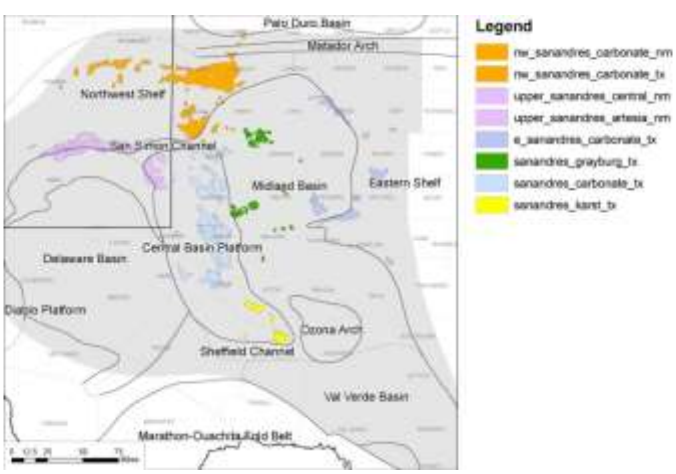


Figure 2.2. Major producing areas and play types or “trends” in the San Andres from Dutton et.al., 2005.

Previous Work

with extensive Residual Oil Zones >250 to 300’ in thickness which are now being successfully exploited with

CO_2. The Residual Oil Zones in this trend, and in Wasson and Seminole Fields, tend to be middle to lower San Andres.

The San Andres Formation has been studied extensively because of its importance as the dominant reservoir interval in the Permian Basin of Texas/New Mexico. Important early studies on the San Andres Formation outcrop were carried out by Kottlowski et al. (1956) in the San Andres Mountains where the type section is defined, and by Boyd (1958), Hayes (1964), and Kelly (1970), and others, in the more proximal southern Guadalupe Mountains. P. B. King's work in the southern Guadalupe Mountains also contributed greatly to the understanding of the San Andres interval in outcrop. Studies of the regional subsurface by Silver and Todd (1969), Ramondetta (1982), and others, and fusulinid studies by Wilde (1990), and numerous others, form the basis for many modern reservoir studies. The synthesis by Ward et al (1986) of Permian reservoirs and production in the Permian Basin represents the collective knowledge of Gulf Oil's Permian Basin staff and provides an excellent basic reference for studies of the San Andres Formation. Several in-house studies were carried out in the major oil companies (Longacre, 1990; Ward et al., 1986; Purves, 1990, and others), as were a series of reservoir studies by the Bureau of Economic Geology's University Lands Reservoir Characterization program: Bebout et al., (1984); Ruppel and Cander, (1988); Lucia et al, (1992); Major et al, (1990). Although there are a number of studies of the San Andres reservoir on the Central Basin Platform, Bebout & Harris (1986) that includes mention of the Goldsmith Field, there are no published studies specific to the Goldsmith reservoir geology. There are, however, in-house geologic studies specific to the Goldsmith Field by Pan American and Gulf that were available for this study.

The Atlas of Major Texas Oil Reservoirs (Galloway et al, 1982) focused attention on the San Andres reservoirs of the Permian Basin as a major target for future reserve growth. Production in the San Andres is characterized by moderate to low recovery efficiencies of 10-25% of original oil in place (OOIP) during primary production, and much of this has been attributed to bed/cycle scale depositional/stratigraphic heterogeneity and a strong diagenetic overprint that generates variations in permeability (Ruppel and Cander, 1986; Major et al, 1990; Bebout et al., 1984).

These diverse studies of the shallow-water open marine to restricted carbonate ramp model with repetitive facies successions highlighted the high degree of vertical and lateral heterogeneity seen in the San Andres and Grayburg, Ruppel et.al. (1995). Heterogeneities between wells on 10, 20, and 40 acres spacing in these shallow water carbonate ramps is the controlling factor in the relatively low recovery efficiencies. Almost all studies point to these heterogeneities as the primary remaining issue to be resolved in reservoir characterization projects. These studies all note the San Andres reservoir needs to be understood on a case by case basis within a larger stratigraphic context. Beginning in the 1980's, the San Andres was the first reservoir in the Permian Basin to receive outcrop-based sequence stratigraphic studies, Sarg and Lehman (1986); Sonnenfeld and Cross, (1993); Lucia et al., (1992); Kerans et al., (1993); and Stafleu and Sonnenfeld, (1994). However, it took almost two decades after the introduction of sequence stratigraphy as a reservoir characterization tool, Vail et al (1977), before sequence stratigraphic based models were applied to San Andres reservoirs by smaller to intermediate size companies in legacy major company properties like Goldsmith. This project is the first to apply a sequence stratigraphic based model to the Goldsmith Landreth San Andres Unit.

Regional Tectonic Setting

The Permian Basin of Texas and New Mexico is best described as a complex foreland basin that developed during the Ouachita Orogeny beginning in latest Mississippian, continuing thru the Pennsylvanian, and mostly ending during the early Permian (Ye et al, 1996; Ross, 1986). The key structural elements influencing San Andres deposition include the Northwest Shelf, Northern Shelf, Eastern Shelf, and Southern Shelf, San Simon and Sheffield Channels, Central Basin Platform, Delaware, Midland, and Palo Duro Basins, Ozona Arch, Matador Arch, Figure 2.3. The peak of structural activity in the basin was during the Early Permian Wolfcampian, and the direct impact of the structural evolution of the basin has traditionally been believed to have ceased prior to the San Andres time. This is largely based on the outcrop studies in the Guadalupe Mountain, and projected into the subsurface reservoirs on the Northwest Shelf. Though significant fault movement and tectonic rotation diminish through the

Early Permian, differential movement and compaction associated with the Ouachita derived tectonic elements influenced facies patterns and reservoir quality throughout the Permian as illustrated in numerous 3D seismic volumes (Sonnenfeld et al 2003; Ruppel and Cander, 1986).

Specific to this project and other fields in on the Central Basin Platform, is an area referred to as the “Spine” of the platform, where there is a series of San Andres fields above, and proximal to, the trend of uplifted and heavily eroded lower Paleozoic structures, Figure 2.4. The “Spine of the Platform” is identified by the presence of eroded lower Paleozoic cored blocks beneath the Base of Strawn, Wolfcamp, and/or Leonardian age rocks. The San Andres reservoirs associated with the spine are typically less than 1000’ thick, as opposed to >1300 elsewhere, and are reservoirs where the upper San Andres is missing due to erosion or non-deposition, from Ward, 1992.

Figure 2.3. Tectonic setting of Permian Basin and Ancestral Rockies. From Ye et al. (1996).

Dutton, et.al, 2005, identified 3 “plays” on the Central Basin Platform, Figure 2.5, however, in the Goldsmith Field, and elsewhere on the southern 2/3rds of the Central Basin Platform there is significant variability in the thickness, reservoir distribution, and production in the San Andres. These variations can be directly related to flexing of the shallow section associated with periodic movement, at depth, of large structural elements developed during the Pennsylvanian and lower Permian, Figures 2.6 and 2.7. The San Andres varies in thickness on the Central Basin Platform from +/-600’ to >1400’. Although some of that variability in thickness is due to the transgression of the eroded Glorieta surface, mush of the variation is due to karsting associated with the three eustatic related surfaces within, and at the top of, the San Andres and erosion associated with periodic flexing of the bounding and interior faults of the deep structure elements.

Although there are similarities in the fields in the Slaughter Levelland trend in Texas and New Mexico, and in fields in the Artesia Trend, the San Andres production on the Central Basin Platform varies and one of the controlling variables is the association with proximity to the Spine of the Platform. In Figure 2.8 (B), a comparison is made of the San Andres isopach (A) with Initial Production of oil from 1925-1940 wells (C), when many were either competed with nitroglycerine or flowed naturally. There is a strong relationship (B) between areas with high quality reservoir where the well flowed upward of 10,000 BOPD on Initial Potential. The highest quality wells were not associated with either the thickest San Andres (>1200') or the thinner (<800') San Andres, but with the interval in between where it is proposed that the upper San Andres is absent due to erosion or non-deposition. This relationship can be seen in the regional east west cross section across section across the Central Basin Platform thru the

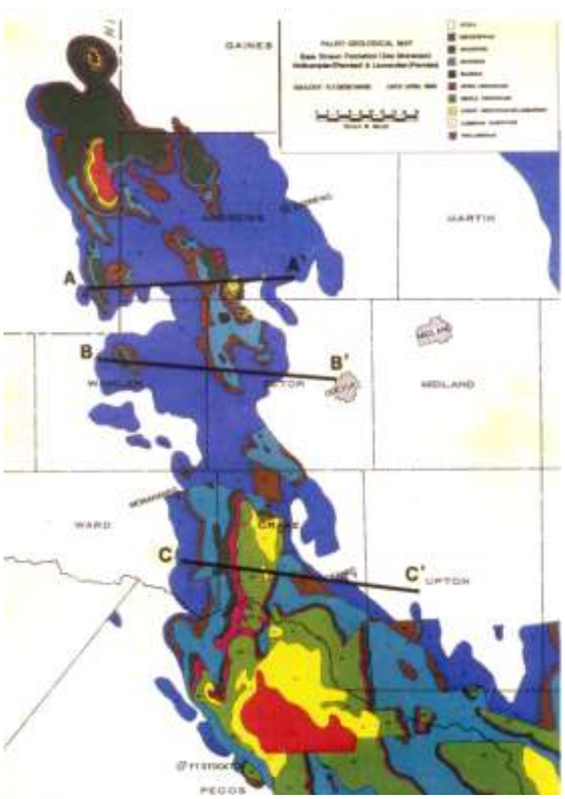


Figure 2.4. The "Spine of the Platform" as identified by the presence of eroded lower Paleozoic units beneath the Base of Strawn, Wolfcamp, and/or Leonardian age rocks. The San Andres reservoirs associated with the spine are typically less than 1000' thick and are reservoirs where the upper San Andres is missing due to erosion. From Ward, 1992.

\Figure 2.5. San Andres fields on the CBP into the San Andres Platform Carbonate Play (1), the Upper San Andres and Grayburg Platform Mixed Carbonate Play (2), and the San Andres Karst-Modified Platform Carbonate Play (3), Dutton et.al., 2005..

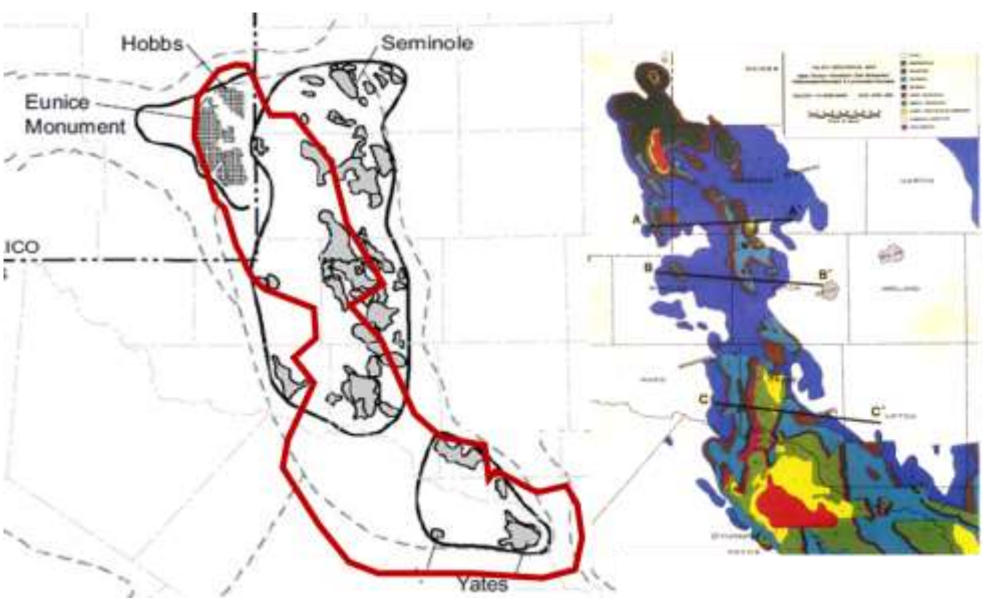


Figure 2.6. Relationship between the "Spine of the Platform" and the three types of plays identified by Dutton, et. Al., 2005. Note that the grouping of the spine related fields transects the play types identified by Dutton.

Goldsmith Field, Figure 2.9. The schematic cross section shows the variability in thickness of the different members within the San Andres. Note that the Upper San Andres varies for zero (0') in eastern Winkler County to 240' at the east end of the section. The upper San Andres is estimated to be less than 40' thick in the Goldsmith Field.

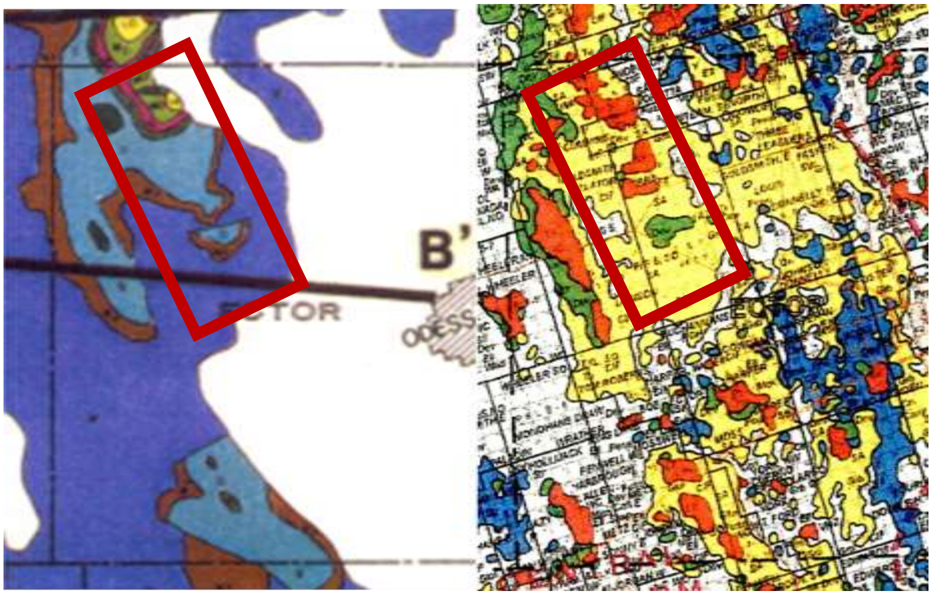


Figure 2.7. Detail from Spine of Platform map (fig 2.4) showing location of Goldsmith Field relative the deep, lower Paleozoic cored structural elements formed during Permo-Penn.

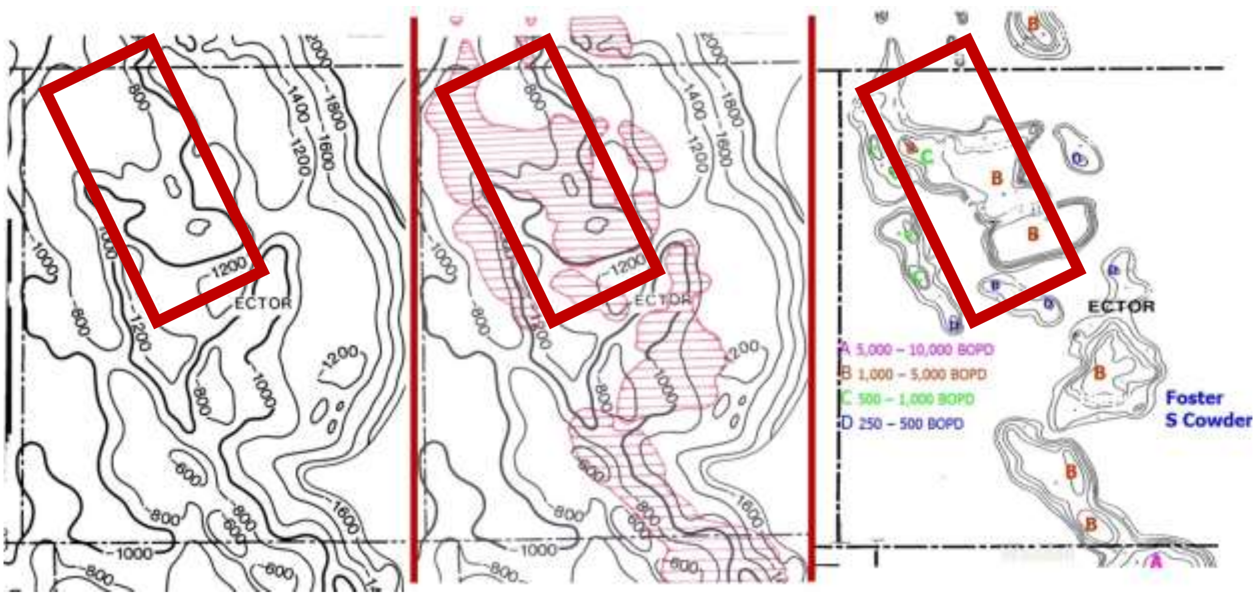


Figure 2.8. Comparison of San Andres isopach (A) with Initial Production of oil from 1925-1940 (C). Note relationship (B) between the thinner <1000' thick San Andres and the higher IP's.

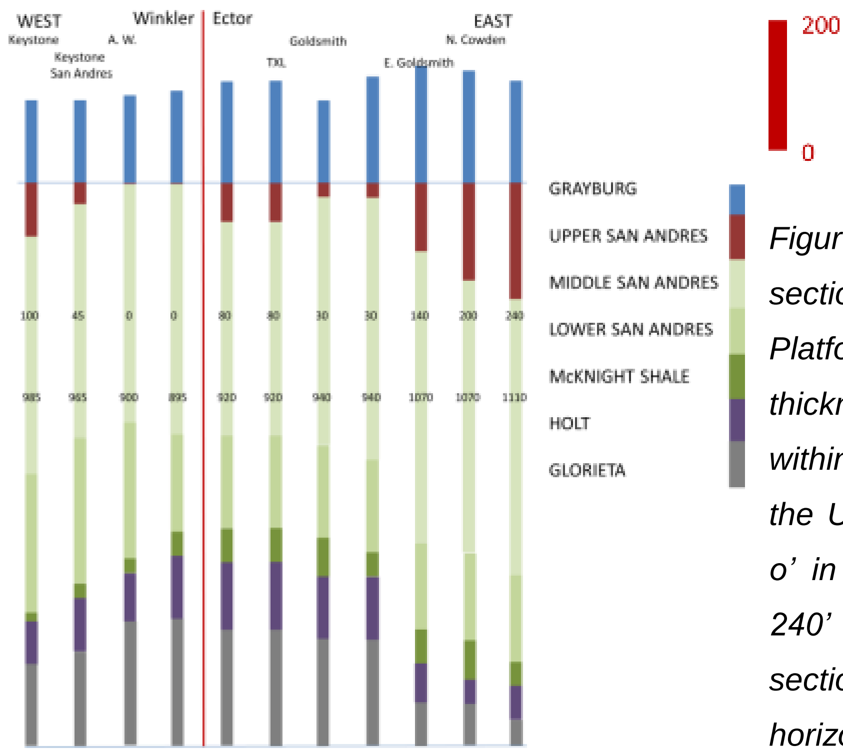


Figure 2.9. Schematic cross section across the Central Basin Platform showing the variability in thickness of the different member within the San Andres. Note that the Upper San Andres varies for o' in eastern Winkler County to 240' at the east end of the section. Vertical to scale, horizontal not to scale.

Historically, It was "common knowledge" that all San Andres fields have similar production and flooding characteristics. This is simply not true as an understanding of the impact of the variation in the upper San Andres and the development of sequence stratigraphic models for the fields demonstrates.

Sequence Boundaries, Paleokarst Surfaces, and erosion in San Andres Reservoirs

Important karst surfaces are developed at the top of the G4, the G8, and the G9, Figure 2.10. Each of these karst surfaces is found developed throughout the Permian Basin and can be marked by solution-collapse features up to 100 ft deep. The top of the G4, equivalent to the Brushy Canyon bypass surface in outcrop and the Pi Marker in the subsurface of the Northwest Shelf, is also shown in outcrop to have a paleokarst profile developed with >10 m thick collapse breccia's. This karst event is equally developed in the subsurface, where its presence has been noted at Vacuum, Raines and Stoudt (2002), and it is also present at the Hobbs San Andres reservoir, Kerans, 2011.

Although it is not well developed in core in the Goldsmith Field, it can be correlated in logs across the southern 2/3rds of the Central Basin Platform.

The second karst surface from the outcrop model occurs at the top of the G8, immediately below the Lovington Siltstone marker, a persistent siltstone that can be mapped from the outcrop across the Northwest Shelf at least as far as Wasson, and equivalent to the Cherry Canyon Tongue. This karst event is also widespread and is associated with small (m-scale) sinkholes and fracture systems that likely impact fluid flow in several of the fields, particularly in the NW Shelf mixed San Andres-Grayburg play. The pre-Lovington exposure has resulted in one of the two major erosional events on the southern 2/3rds of the Central Basin Platform (G 8 and G 9). It is typically identified by reddening of the interval below the exposure surface, karst features, and a dirty gamma ray signature in fields such as the McCamey Field, where there is a deeply invasive karst with a pervasive diagenetic overprint. In the Goldsmith Field, the exposure surface is above the top of the producing interval and the surface is masked by the deep erosion associated with the top of the San Andres (G9). Over most of the interior of the Northwest Shelf, the interval is composed of correlative shallow subtidal to intertidal dolomites, some sands and extensive supratidal evaporites. On the Northwest Shelf, there is no evidence of Lovington or post Lovington periods of non-deposition and/or major erosional events.

The top G9 karst event that marks the San Andres-Grayburg boundary is the most widespread and vertically extensive event. This karst surface has been recognized throughout the Permian Basin (French and Kerans, 2004; Stoudt and Raines, 2004; Craig, 1988; Tinker and Mruk, 1998; and Lucia et al, 1992) and is known to have affected reservoir properties in several of the play trends (mainly the Karst-modified San Andres play of Dutton et al., 2005). In the fields associated with the spine of the platform, the event has resulted in extensive erosion or non-deposition. If the top of the San Andres were relatively flat, deep erosion would only be possible at the platform

	Guad Mts.	Downdip Northwest Shelf	Updip Northwest Shelf NM	Updip Northwest Shelf TX	Delaware Basin	Central Basin Platform	Eastern Shelf, NE Midland Basin
	Guad. 10	Grayburg 1 Premier Sand	Evaporites		U. Cherry Cnyn	L. Grayburg	L. Grayburg
Upper San Andres Composite Seq. CS10	Guad. 9	Upper S A Lovington Sand	Evaporites		L. Cherry Cnyn	U. San Andres Lovington Sand	
	Guad. 8	Upper S A	P1-3	Slaughter 1-3		U. San Andres	U. San Andres Cedar Lake, Welch
	Guad. 7				Brushy Canyon		
	Guad. 6						
	Guad. 5						
Lower San Andres Composite Seq. CS9	Guad. 4	Upper S A2	P4	Slaughter 4	U. Bone Spring or Cut Off	San Andres	San Andres
	Guad. 3	Upper S A 1	P5	Slaughter 5		San Andres	
	Guad. 2	Middle S A2	P6			McKnight Shale	
	Guad. 1	Middle S A 1	P7				
	Leonardian 8	Lower S A 2	P8			Holt	Lower San Andres Howard Glasscock, Iatan, Ddiamond M
	Leonardian 7	Lower S A 1	P8		Pipeline Sh		
	Leonardian 6	Glorieta	Glorieta		Bone Spring	Glorieta	San Angelo

Figure 2.10. Stratigraphic Terminology, Kerans, 2006, Modified after Kerans, 2000, Trentham and Smith, 2002.

edge. However, the Post Lovington interval is absent, or mostly absent, across the spine area. It is proposed that there may be one or two periods of movement at depth and flexing at the surface during and/or at the end of the upper San Andres. This would have resulted in significant reduction in the thickness of the upper San Andes interval thru non-deposition and erosion.

The Upper San Andres (G9), Lovington sand and Carbonate is present across the Northwest Shelf. Over most of the interior of the shelf, it is composed of correlative shallow subtidal to intertidal dolomites, some sands and extensive supratidal evaporites. On the Northwest Shelf, there is no evidence of Lovington or post Lovington periods of non-deposition and/or major erosional events.

2.2 –Distribution of the Residual Oil In the ROZ

Goldsmith Field Stratigraphy

Since the early geological models of the field, the reservoir has been characterized as being composed of a shallowing upward Open Shelf, - Shallow Shelf - Shoal to Tidal Flat sequence, Figure 2.11. The ROZ is composed primarily of Open Shelf Fusulinid Packstones and Wackestone. However to better understand the reservoir and to provide a sequence stratigraphic based model for the history match and reservoir simulation, a more detailed picture of the San Andres was necessary.

The San Angelo, referred to as the Glorieta in New Mexico and on the Northern Central Basin Platform, is uppermost Leonardian in age and has been identified as “L6” in the widely accepted update of the sequence stratigraphy of the Permian Basin (Kerans, 2006). At Goldsmith, Figure 2.12, it is a dense, hard, microcrystalline to sucrosic, tan to brown, dolomite. There is abundant nodular and intercrystalline anhydrite and some thin bedded, green, fissile dolomitic shale. There is minor production from the interval on the flanks of the south dome on the Goldsmith San Andres Unit leases south of SH 158 where it is referred to as the “Holt Pay”. Shows and production are associated with intercrystalline and relatively fine solution vuggy porosity. The interval is also productive in the East Goldsmith Field and has been considered as a target for CO2 EOR there. In the Goldsmith San Andres Unit leases south of SH 158, production from the upper San Angelo “Holt” and lower San Angelo “Lawson Simpson” pay has been reported as included in the “5600” pay.

In Ector County there is some confusion as to the “pay name” Holt and its position in the section. The original “Holt: pay was a deeper, lower San Andres pay zone identified in the Gulf #1 Holt, Section 1, Block A, PSL, in northcentral Ector County. However, in the Keystone Field 30 miles to the west in Winkler County, the “Holt Pay” is not stratigraphically equivalent to the North Cowden pay zone but is San Angelo in age. The Holt Pay referenced above is also not stratigraphically equivalent to Holt elsewhere. The “Holt” is considered to the stratigraphic equivalent of the Shumard

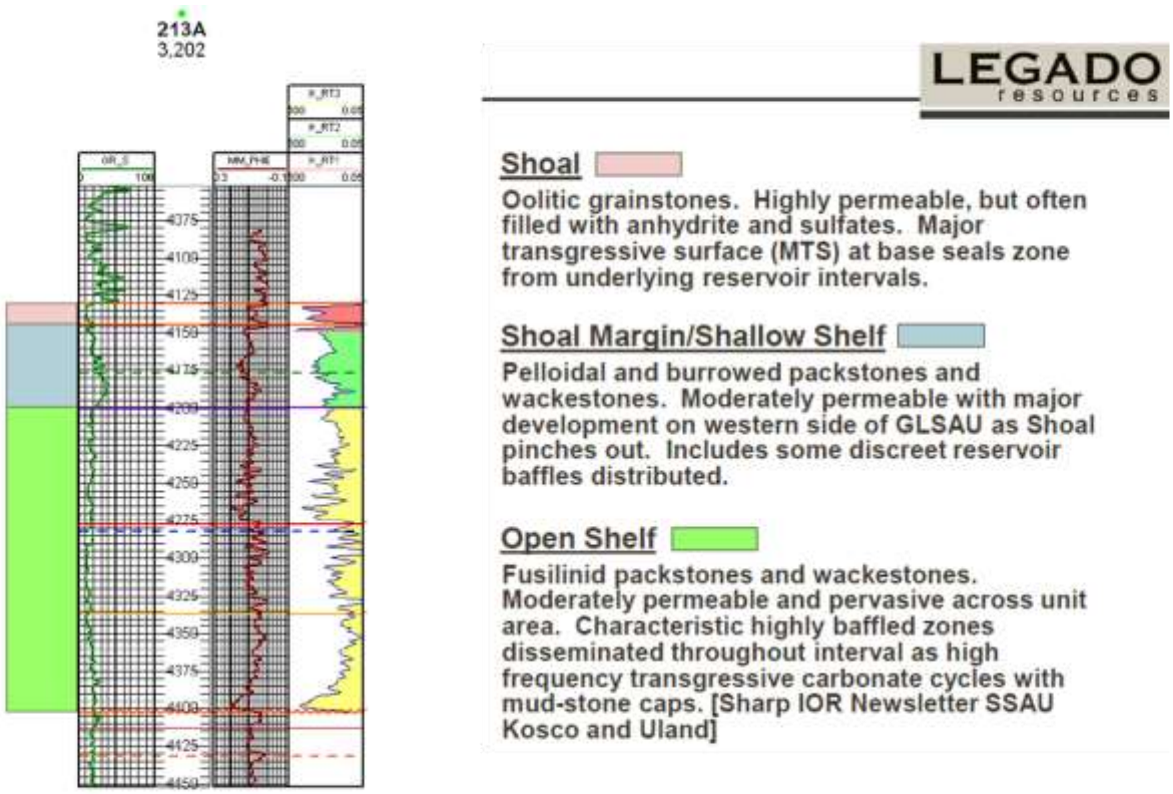


Figure 2.11. "Classic" interpretation of the depositional environments in the Goldsmith Field. Legado, 2013.

Member of the Cutoff Formation in the Delaware Basin. The L7 interval is composed of a rapidly deepening open marine wackestone to packstones with abundant brachiopods, bryozoans, corals, and fusulinids. The L8 represents a continued backstepping and deepening relative to the underlying L7. The overlying McKnight Shale represents the maximum flood on the interior of the Central Basin Platform, Figure 2.12.

In the Goldsmith Landreth San Andres Unit (GLSAU), the Holt is upper Leonardian, L7 and L8, and rests uncomfortably on the San Angelo, Figure 2.13. The L7 and L8 interval are distinct with a minor gamma ray signature separating the L7 from L8. They are sugary, dense, cherty, anhydritic and glauconitic limestone and dolomite. The interval is locally referred to as "McKnight" but this designation is more properly used to identify the McKnight

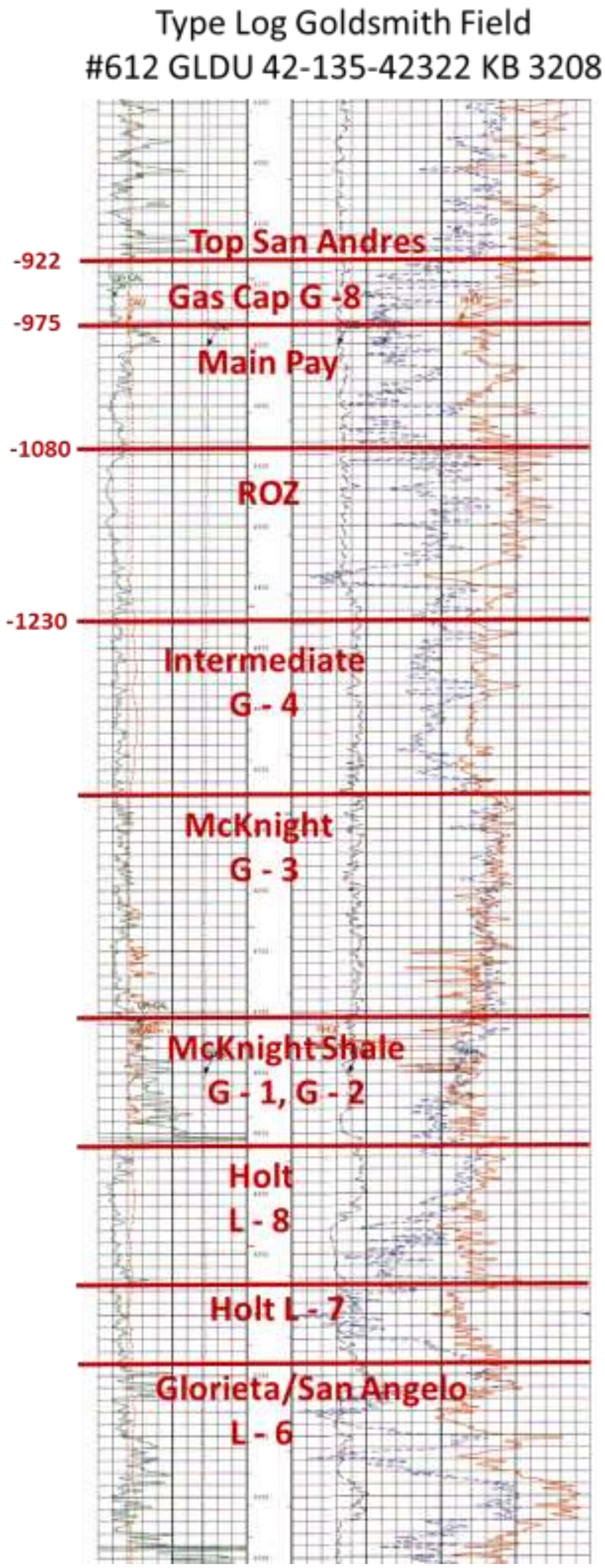


Figure 2.12. San Andres Type Log, Goldsmith Field. The G9 is missing due to non-deposition or erosion.

shale (G1 – G2) above the Holt, and the limestone interval above the McKnight shale as (G3). The dolomite portion is porous and productive in the area, with shows in the Goldsmith and East Goldsmith fields. The interval is known for producing “sour” or sulfide-rich water. This suggests the interval has been swept by last stage meteoric derived waters. Elsewhere on the platform, the rapidly deepening L7 is referred to as the “Dense Zone” as it typically is a dolomite lacking porosity.

The McKnight Shale, Figure 2.12, which rests on the L8 limestone without an apparent hiatus, is considered to be lowermost Guadalupian, G1 – G2. The McKnight Shale is a high gamma ray, shaley, dark brown, dense, hard and cherty limestone. The easily correlatable shale is restricted to portions of Ector and Andrews Counties. However, it can be correlated across the Central Basin Platform with some difficulty. It is proposed to be the Maximum flood of the lower San Andres transgressive sequence and would be correlated to the El Centro member of the Cutoff Shale in the Delaware Basin and the “P4”member of the lower San Andres on the NW Shelf, Gratton & LeMay, (1969). The deeper water P4 limestone interval extends furthest north of all the lower San Andres intervals on the northwest shelf and is considered to represent the maximum flood of the lower San Andres and be equivalent to the El Centro Member of the Cutoff. The McKnight Shale in the pilot area is at an approximate depth of 4850 to 4900’.

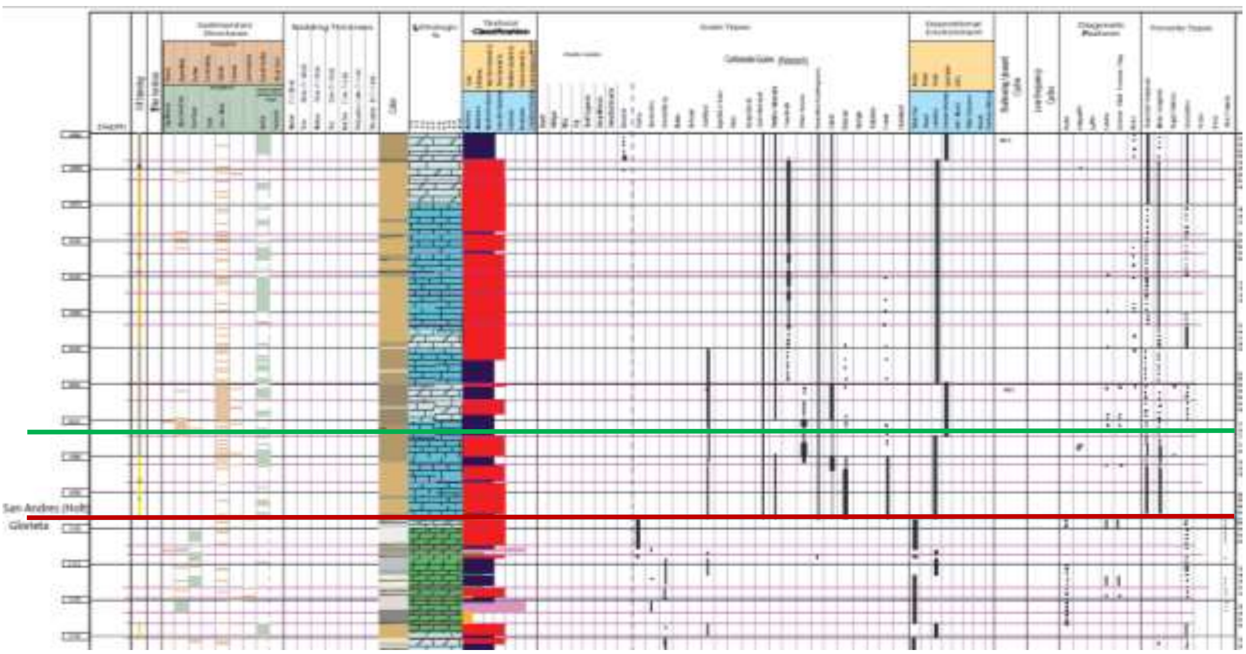


Figure 2.13. Core Description of Lower San Andres “Holt” from East Goldsmith Field. Red line is top Glorieta/Base Holt. Green line estimated to be top L7. Top of L8 is +/-10’ above top of core. Both intervals are interpreted to be open marine (Red boxes) and deeper open marine (dark blue boxes).

The interval above the McKnight Shale is called the “McKnight” pay in Crane County (G3). This limestone is sugary, dense, buff to brown, and cherty with abundant interstitial anhydrite. It typically lacks significant porosity. This interval elsewhere has been described as being deposited on a deep shelf with abundant crinoids, brachiopods, and bryozoans. Chert nodules, often focused around skeletal grains, are abundant. This interval has no associated production or significant reported shows in the Goldsmith area, but on the west side of the Central Basin Platform, where it has been dolomitized, it has produced minor amounts of oil in scattered wells. The McKnight in the pilot area is at an approximate depth of 4500 – 4850'.

The productive carbonates in the Slaughter-Levelland trend are believed to be G3-G4 (?) sequences, with the underlying San Andres limestones being the equivalents of the L8, G1, and G2. The G1-4 model/facies assemblage as observed along the Algerita Escarpment is the best analog for the Northwest Shelf San Andres Platform carbonate and the San Andres platform carbonate play of Dutton et al (2005).

The interval immediately above the McKnight Limestone (probably G4) between the McKnight and the Judkins has been designated as the "Intermediate Zone" in Crane and Ward Counties and the Lower "Judkins" (G4) in the Goldsmith Field. The interval is below the ROZ and is dominantly composed of fusulinid wackestones to packstones deposited in an open marine environment. The interval is predominantly limestone at the base with variable percentages of euhedral, fabric selective dolomites crystals increasing upward, ranging from 20 to 80% of the matrix only. There is 5 to 15% porosity in the matrix and intraskeletal porosity in the fusulinids. The variable amount of dolomite leads to a suppressed dolomite neutron-density log signature (on limestone matrix log) and a PE signature that falls between dolomite and limestone (~4.0). In core the fusulinids and other skeletal grains are well preserved and yield an active reaction to HCL. At the top of the interval, picked as the base of the ROZ, the fusulinids are either replaced with anhydrite or are leached. This transition is abrupt, typically occurring across a few inches to feet. Although there can be some oil stain in the "limestone" interval, there is a significant increase in stain visible above the transition.

The "Judkins Dolomite" (G8), the upper of two producing intervals in the San Hills Field in central Crane County where the pay name Judkins originates, is one of the major producing intervals basinwide in the San Andres. The Judkins (G8) is represented at Goldsmith by the Residual Oil Zone and Main Pay and is often referred to as Lower San Andres in the older field descriptions of the interval on the Central Basin Platform, in the Vacuum Field, and in other fields on the northwest shelf. The interval is commonly gray to brown, micro-crystalline to sugary dolomite, and contains nodular and interstitial anhydrite and crystals of gypsum. Scattered re-cemented vertical fractures and numerous stylolitic shale partings are present, the porosity is principally of a secondary nature and consists of solution vugs and fusulinid cast types. Pays are distributed across the field and in portions of the TXL-Goldsmith saddle area. There is a “Shoal” in the upper portion of the Main Pay which is composed of light tan, hard, oolitic grainstone in upper part, which is the top of commercial oi bearing porosities in the Judkins. In ascending depth order, major depositional units of the ROZ and Main Pay included bryozoan/sponge/pelmatozoan wackestones and packstones, fusulinid/peloid pack/grainstones, ooid/peloid pack/grainstones, and tidal flat capped cycles. A probable third order sequence boundary, marked by deposition of the Lovington Sand **(**Stoudt & Raines, 2000) , identified as a major sequence boundary in the San Andres formation on the Algerita Escarpment represents the top of the San Andres pay in the field.

The upper San Andres Lovington Sand and post Lovington Carbonates are not identified at Goldsmith. There is an interval between 4085 and 4130’ in the #612 GLDU, Figure 2.12, which may be G9 or lower Grayburg. In the Foster Field, the transition between the upper San Amdres (G 9) and the lower Grayburg is unclear. In areas where the Premier Sand is present at the base of the Grayburg the boundary is clear. That is not the case at Goldsmith Field.

Core Based Sequence Stratigraphy

Nine (9) wells, Figure 2.14, were cored as part of the study to make a complete sequence stratigraphic model of the reservoir. During the waterflood development of the field, a number of cores were recovered from the Main Pay Zone and Gas Cap.

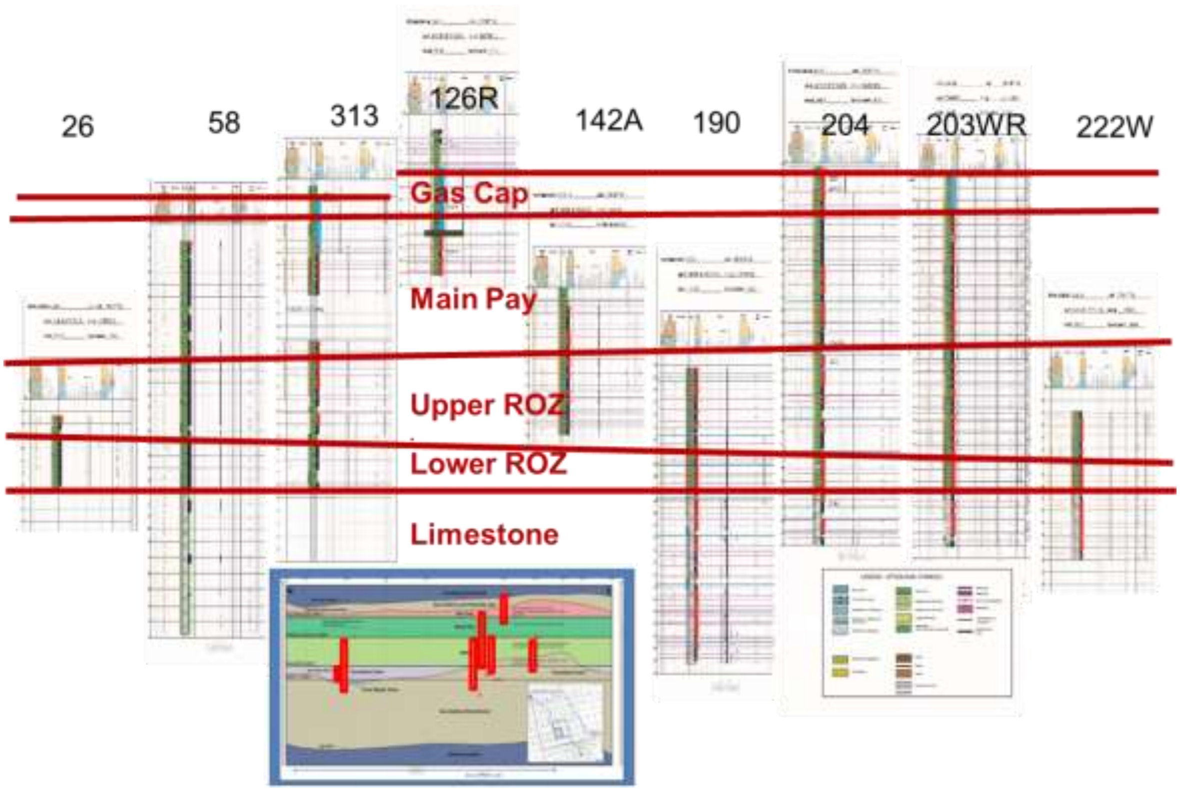


Figure 2.14. Small scale, Northwest to southeast core cross section of the 9 cored wells in the study.

However, there were no cored recovered from the ROZ or the limestone below the ROZ during that time frame. For the first time, therefore, the ROZ and the limestone interval below the ROZ were purposely cored. This was in order to generate a data set of oil and water saturations, porosities and permeabilities of the ROZ for comparison to the waterflooded main pay, determine the facies, sequence stratigraphy, and diagenesis of the ROZ, and provide data to compare to the saturations calculated using open hole logs. Cores were also recovered from the Main Pay and Gas Cap to determine the residual to waterflood saturations for comparison with the saturations in the ROZ.

Legado, compared the oil saturations in the Main Pay and ROZ and determined that the residual to waterflood saturations were similar to the saturations in the ROZ which are the result of Mother Nature’s Waterflood. Figure 2.15 is a comparison of oil

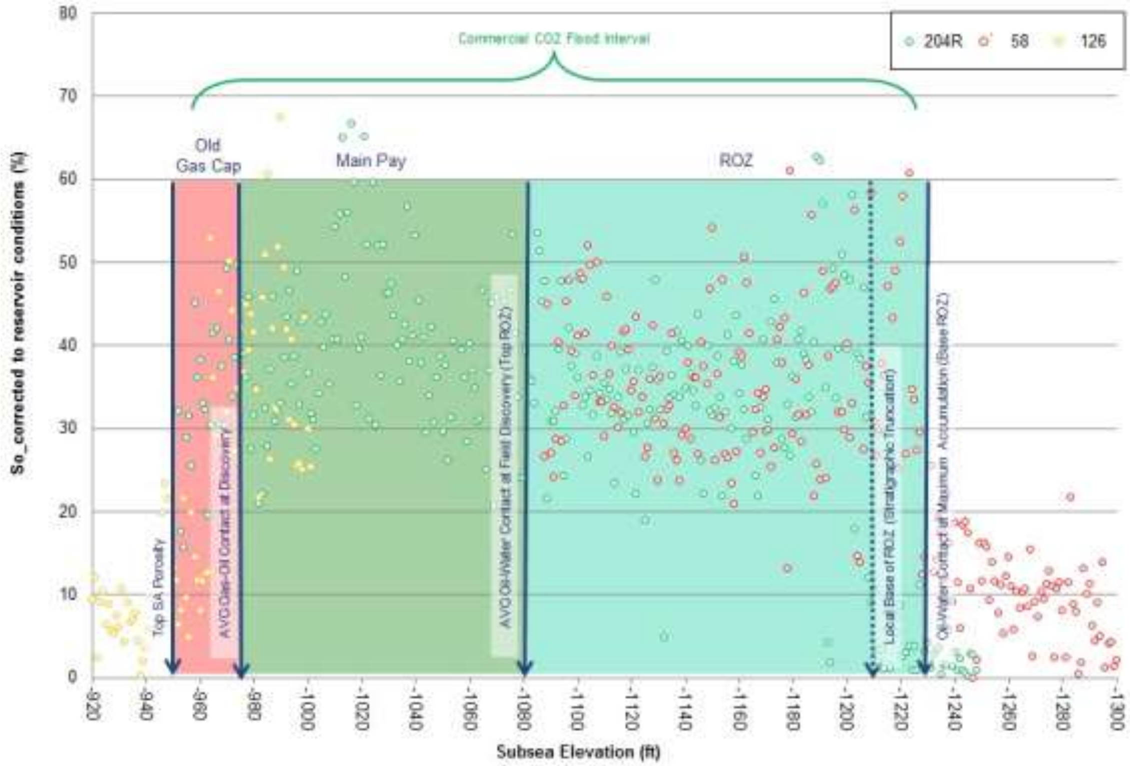


Figure 2.15. Comparison of oil saturations from the #204 W, #126, and #58 GLSAU cored wells. Note that the saturations from the Main Pay (residual to waterflood) and the ROZ are almost identical. The Gas Cap has oil saturation as a result of having been resaturated during the waterflood. The saturations decrease rapidly below the ROZ indicting the presence of the Paleo Oil/Water contact at that depth. Legado, 2013.

*s*aturations from the #204 W, #126, and #58 GLSAU cored wells. Note that the saturations from the Main Pay (residual to waterflood) and the ROZ are almost identical.

The Gas Cap has oil saturation as a result of having been resaturated during the waterflood. The saturations decrease rapidly below the ROZ indicting the presence of the Paleo Oil/Water contact at that depth. This was found to be consistent with the other cored well recovered during this study. It is also consistent with work done by Hess at Seminole Field where similar values for saturations in the ROZ were determined.

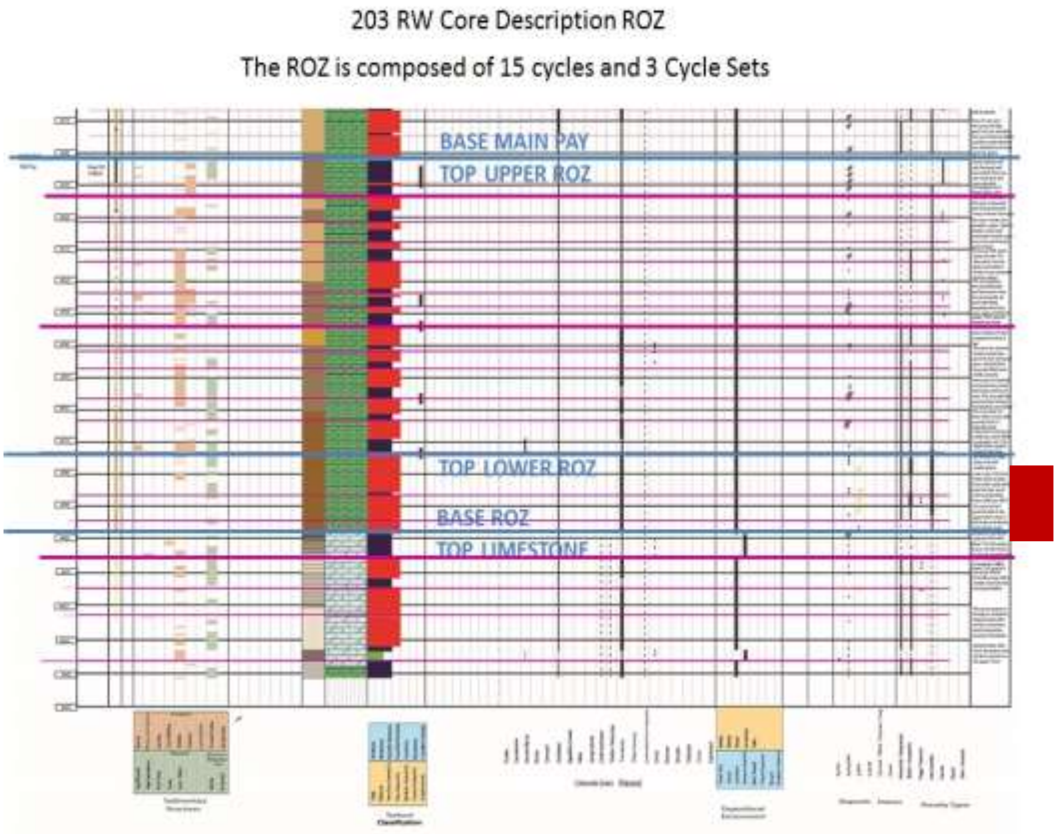


Figure 2.16.Goldsmith Landreth San Andres Unit #203RW core description. The heavy red bar on the right is the interval with increased saturation, believed to be in the CO_2 flood related oil bank. Thin red lines are Cycle boundaries, thicker red lines are Cycle Set boundaries.

The cored wells form a roughly northwest to southeast cross section across the Goldsmith Landreth San Andres Unit. Each of the cores were described by the geologic team and matched to the open hole logs run in the cored wells. The cores were examined to identify individual cycles and cycle sets, and the flow units present in the reservoir. The generation of flow units was essential in guiding the reservoir characterization. The identification of a lower and upper ROZ in the cores allowed for a rock based interpretation of the injection profiles.

The cores were critical to the understanding of the reservoir. Oil response in the GLSAU #203 RW was excellent and very rapid in the pilot and, early in the injection history, it was necessary to plug back from the fast processing lower unit of the ROZ (LROZ), and concentrate the injection in the upper member of the ROZ (UROZ), Figure 2.16. The operator's most desirable solution was to replace the original well (#203W) and drill and core a replacement well (#203 RW). The new well was drilled ~135' from the original well, just outside the original pattern (see Figure 2.17 below). Both the MP and ROZ were cored and it became apparent that there were elevated oil saturations (So) in the LROZ when compared to other cores taken before the inception of the CO2 flood. These

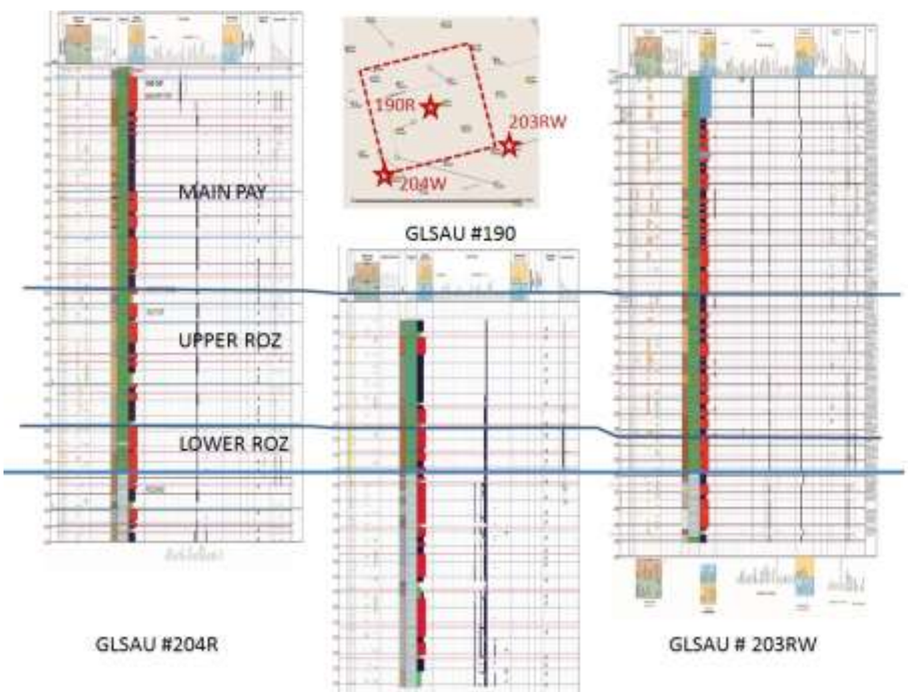


Figure 2.17 Pilot pattern and cores from pilot wells. Correlations of Main Pay, Upper and Lower ROZ is consistent across the field.

elevated So values just outside the pilot pattern serves as proof of oil 'bank' development in LROZ that had provided the fast response inside the pattern and was caught in the act just outside the pilot pattern. As CO2 had been injected in the lower ROZ for a brief period, the flood front had advanced to the center producer but not moved far beyond the location of the replacement well (#203 RW) outside the injector. The evaluation of the saturations, and the presence of CO2 in the core when it was first recovered from the core sleve, confirms the decision to divide the ROZ into a Lower and Upper members, Figure 2.17.

Sulfur was believed to be present in the reservoir based on limited data from a number of other ROZs. This was confirmed by the presence of native sulfur crystals immediately above the base of the ROZ. The sulfur is found as fractures and fusulinid molds, and in vugs associated with calcite and anhydrite. The presence of sulfur is believed to be associated with Mother Nature’s Waterflood and the activity of anerobic bacteria.

2.3 - Develop A Geologic Model For the ROZ

Cycles, Cycle Set, and Flow Units.

The question: why is the ROZ swept by Mother Nature’s Waterflood and the Main Pay not? The geologic answer is that the ROZ in most fields, and in the Goldsmith Field in particular, is composed of thicker, open marine cycles than the main pay, have fewer baffles and barriers to flow, have slightly higher average porosity and permeability, less karst, and simply swept better than the main pay interval. Multiple thick, open marine cycles are seen in all the cores taken from the ROZ and the mixed dolomite and limestone interval below the ROZ. Also as noted above, these cycles have muddy bases and grainy tops. In the ROZ in the pilot area, there are two packages, the lower and upper, that have higher percentages of grainy tops, and a central interval that is primarily mud rich. This creates two flow units within the ROZ which have had an influence on sweep efficiency. The lower unit has slightly higher permeability and porosity, and thicker open marine cycles, although it is composed of the same lithologies as the upper ROZ.

Numerous karst features are seen, primarily in the MPZ, but also in the ROZ to a lesser extent, which are comparable to similar features seen on outcrop. They include dissolution, cave development, vertical solution pipes, and collapse structures. Sandstone infiltration present on the northwest shelf and the northern Central Basin

Platform is not present at the Goldsmith Field as the upper San Andres/lower Grayburg aeolian sands had not progressed past the northern 1/3rd of the platform at this time.

Tidal flat capped cycles widespread in the MPZ but are not present in the ROZ. They are tight, and function as local vertical and lateral permeability barriers. Use of the outcrop analog enables prediction of the 3 dimensional distribution of tight cycles and their impact on reservoir continuity.

Below the ROZ, in the G4, or “Intermediate Zone”, the core is a partially dolomitized fusulinid/crinoid/ brachiopod wackestone to grain dominated packstone. Dolomite is largely confined to the rock “matrix”, grains are calcitic, resulting in a “limestone” log signature. Only 5 of the 9 studied cores penetrated significant intervals of the mixed limestone/dolomite interval (G4) below the ROZ, and none penetrate the McKnight (G3). The #190 and the #58 both penetrate almost the entire interval. The #190, Figure 2.18, which is one of the injection wells in the original 5 spot CO_2 injection pilot, is higher structurally and is immediately above the deep seated, lower Paleozoic cored uplift, whereas the #58 is off the flank of that deep structure and in a lower area at the top of the San Andres, Figure 2.19. The #58 is composed primarily of wackestones

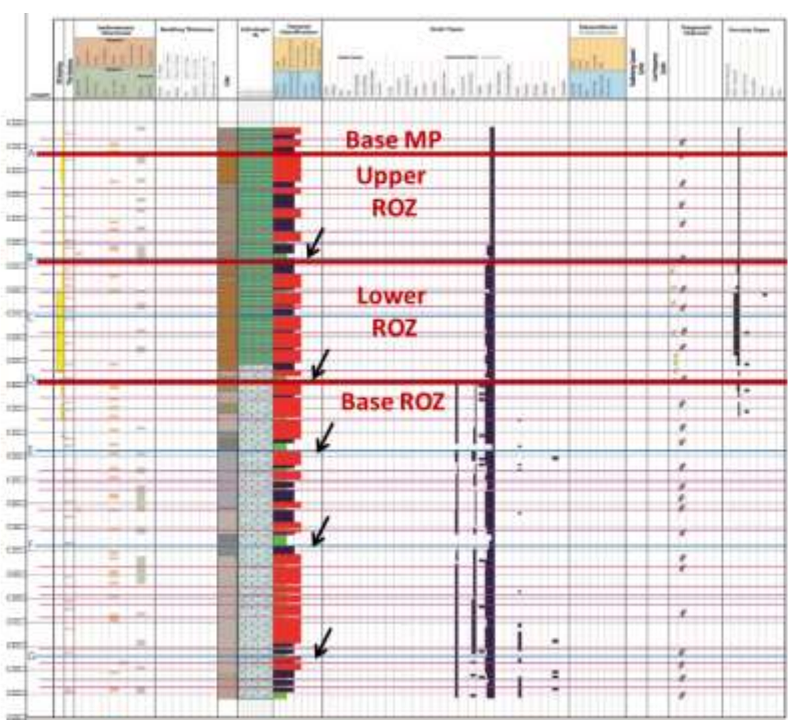


Figure 2.18. Detailed Core Description of the GLSAU #190 Well, Goldsmith Landreth Unit, Ector County, Texas. Note well developed maximum flooding surfaces marked with black arrows. The lower “Limestone interval with 20% mud-rich packstones. The fusulinids, brachiopods and corals are representative of

a deeper water open marine environment. The #190, is composed of grain-rich packstones with minor mud-rich packstones and wackestones. This indicates a higher energy open marine environment, suggesting that the #190 was on a paleotopographic higher area than the #59, Figure 2.19. The penetrations of the mixed limestone/dolomite in the #204R, #203RW, and #222W all have similar percentages

below the base of the ROZ is not 100% limestone and contains up to 80% dolomite in the matrix. The lower and Upper ROZ flow units are defined by the fusulinid brachiopod grain-rich packstones(stacked red blocks) and are separated by the wackestones to mud-rich packstones(dark blue boxes).

of grain-rich packstones with minor mud-rich packstones and wackestones. All these wells are also above the deep-seated structural high suggesting the presence of a paleotopographic high at the location of the original 5 spot CO_2 injection pilot, and the surrounding southern portion of the study area. Porosity in this interval is intercrystalline and moldic, averages 10-12%, but contains only water. The internal fusulinids are perfectly preserved in this interval, as are the other fossils and all fossils are 100% calcite. There are small, euhedral dolomite rhombs throughout the matrix of the limestone. The percentages of dolomite in the matrix range from 20 to 80%. There is good to excellent intercrystalline and intragranular porosity in most of the interval. Figure 2.20 is a comparison of (A) Limestone below ROZ with small euhedral dolomite crystals (white crystals) and fusulinids with preserved internal structure, #204 W GLSAU, depth 4445.85, with (B) subhedral to anhedral dolomite with fusulinids replaced with anhydrite from ROZ, depth 4326.25. This is typical of the rapid changes in mineralogy seen in all the cores. Because of the small size (>.1mm) and the non-fabric destructive aspect of the dolomite it is believed the dolomite was deposited early by brines moving thru the sediments.

The #58 is also the only core where there is a considerable amount of chert. It is suspected that this indicated that the #58 was in the furthest down structure position as the chert is typically found in the deepest water environment in an area.

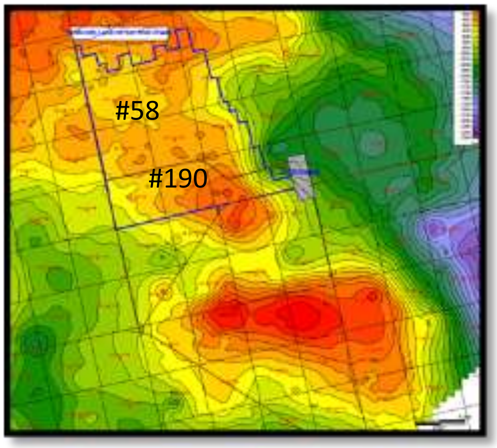


Figure 2.19. Relative Structural position of the #58 and #190 GLSAU. Top San Andres Structure of Goldsmith Field. The Goldsmith Landreth San Andres Unit is outlined in blue in the northwest portion of the field. Legado, 2011.

Depositional cycle boundaries are difficult to pick in most of the fusulinid wackestone to grain dominated packstone intervals. However at least two significant dark brown, mudstone to wackestone cycle bases were identified below the ROZ. Although these have no impact on reservoir quality, sweep efficiency, or production, however, these can be carried across the Landreth Unit and help in establishing the extent of baffles to vertical flow when inserted into the reservoir model.

The lower ROZ interval rests immediately on the top of the mixed limestone/dolomite interval. The transition between small fabric selective euhedral dolomite crystals in the limestone matrix only to larger subhedral to anhedral fabric destructive crystals with the fusulinids replaced with anhydrite or dissolved occurs within inches to a foot or two in all the cores which penetrated the transition.

Lithologies in the ROZ are also fusulinid/crinoidal wackestone to packstone, but they are 90-95% dolomite, with traces of calcite cement or remnant crinoid grains and anhydrite. Fusulinids have been leached, resulting in moldic porosity, Figure 2.18.

The GLSAU #204 well was cored down to below the base of the ROZ. Lithologies are fusulinid wackestones to packstones, but very little limestone remains. Cycle bases are more micritic, cycle tops are grainy. Porosity is intercrystalline and moldic, averages 10-12%, with primarily water in the pores. There is no difference in rock type between the main pay and the ROZ in the GLSAU #204 core.

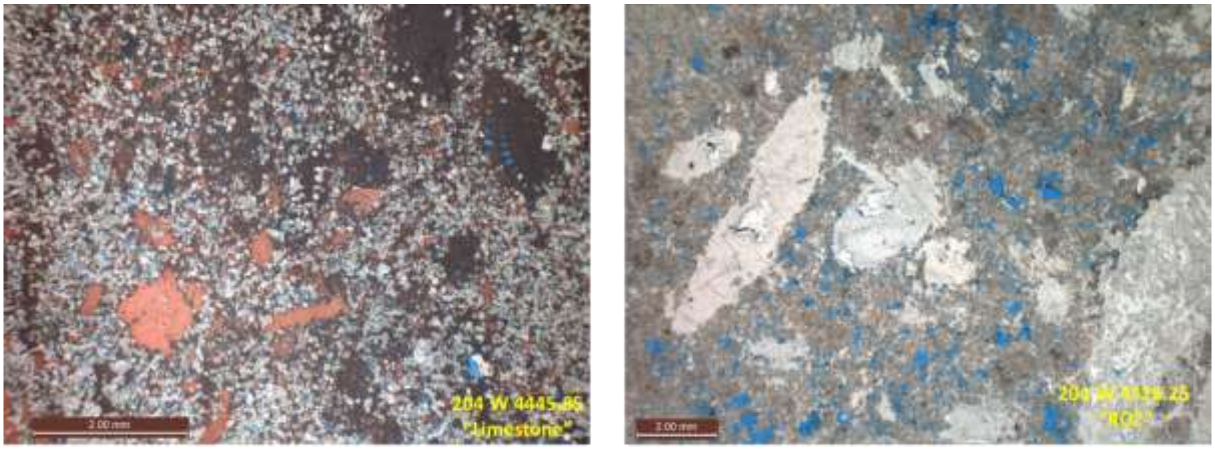


Figure 2.20. Comparison of (A) Limestone below ROZ with small euhedral dolomite crystals (white crystals) and fusulinids with preserved internal structure, #204 W GLSAU, depth 4445.85, with (B) subhedral to anhedral dolomite with fusulinids replaced with anhydrite from ROZ, depth 4326.25.

Near the top of the cored interval in the GLSAU #204 core, fusulinids decrease significantly and grains appear to be mostly peloids and ooids. Grains are both leached and preserved as ghosts. Intercrystalline and moldic pores average 5-10%. Note that the core appears less "oil stained" because the interval is situated in the gas cap for the field.

The first evidence of stromatolitic algal laminated tidal flat deposits occurs at the top of the GLSAU #204 core. Porosity is significantly reduced (1-3%). Cycle tops are picked relatively easily in intervals that display tidal flat deposits.

Both the GLSAU #190 and the GLSAU #204 cores contain San Andres lithologies that are skeletal (fusulinid/crinoid/brachiopod) wackestones to grain dominated packstones. The basal 30 feet of the # 190 core also contains rugose corals and bryozoa, indicating that the most open marine deposits occur at the bottom of the core. The top 10-20 feet of the #204 core is composed of peloidal (oolitic?) grain-dominated packstones and also displays the first stromatolitic algal laminated deposits.

Porosity is slightly higher below the ROZ, but all intervals have porosities in the 6-12 % range except the stromatolitic algal laminated lithologies.

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Section 3 - Reservoir modeling to optimize the Residual Oil Zone (ROZ) CO_2 flood design at the Goldsmith-Landreth Unit

3.a.1 Introduction

Legado Resources LLC, purchased the Goldsmith-Landreth San Andres Unit (GLSAU) northwest of Odessa, TX, in 2008. A detailed technical evaluation using core studies, petrophysical analysis and pilot operations were conducted, which revealed the fact that oil saturations in residual oil zone (ROZ) are similar to the main pay zone (MPZ) saturation following water flooding and prior to the onset of CO_2 injection. Under the right conditions, the oil in the ROZ section can become miscible and significant oil recovery can be attained, much like those MPZ CO_2 enhanced oil recovery (CO_2-EOR) operations in many other Permian basin projects.

The GLSAU is located in the Permian Basin of West Texas and has been producing oil since 1937. The San Andres formation was unitized for peripheral waterflood operations in 1969 and due to significant production decline in the mid-1980s, many wells were abandoned during this period. The field operations were acquired by Legado in 2008 for the purposes of reworking the field and implementing CO_2-EOR injection in the MPZ and ROZ.

As discussed in Section 1, Legado's intent was to roll the project out in a number of phases, paying close attention to deepening those wells that were required to access the ROZ during CO_2-EOR. For Phase I of the development, there are 25 wells in the model area, which are completed in either the MPZ, ROZ, or both horizons. Since this is the earliest phase of development for the project, the amount of performance data lends itself for further study with fully compositional reservoir modeling. The modeling is focused on the Phase I area, shown in Figure 3.1.

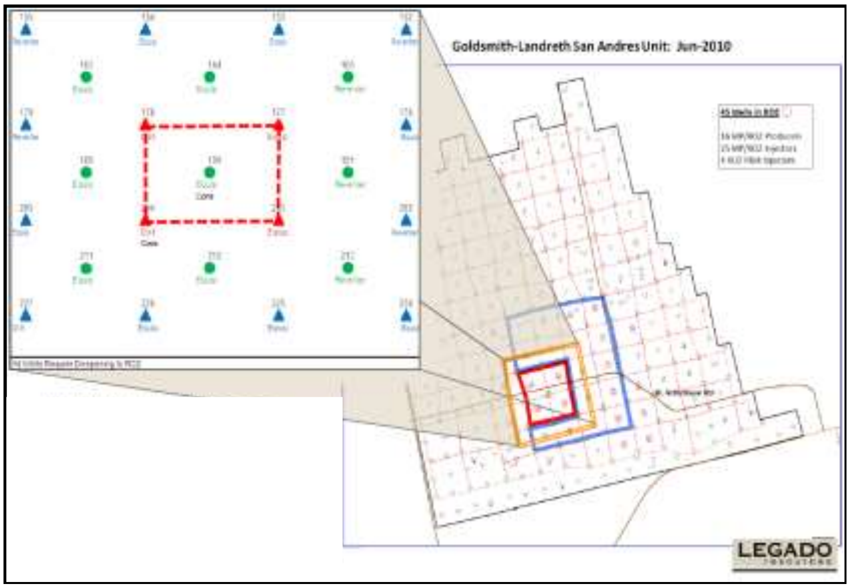

Figure 3.1. Phase I Model Area

3.a.2 Geologic Properties

Extensive core and log data with excellent spatial coverage exists in the field (Figure 3.2). Fluid saturations in the gas cap, main pay zone and ROZ were determined using the core data provided by Legado. Core saturations, fluorescence, and log response were also used for identifying the base of the ROZ. Further, porosity determined from sonic and neutron logs were calibrated using measured core porosity[1].

Geological maps were generated using the provided Petra projects and geological marker interpretation, which were based on conventional log analysis provided by Legado (Figure 3.3). Net pay cutoff values of 6% porosity were used on

[1] "Goldsmith Field Goldsmith Field: GLSAU Geology & Volumetrics" , Berry,A.; Trentham, B.; Stoudt, E., Legado resources

neutron porosity (NPHI) logs to identify dolomitic zones, as illustrated in the type log shown in Figure 3.4.

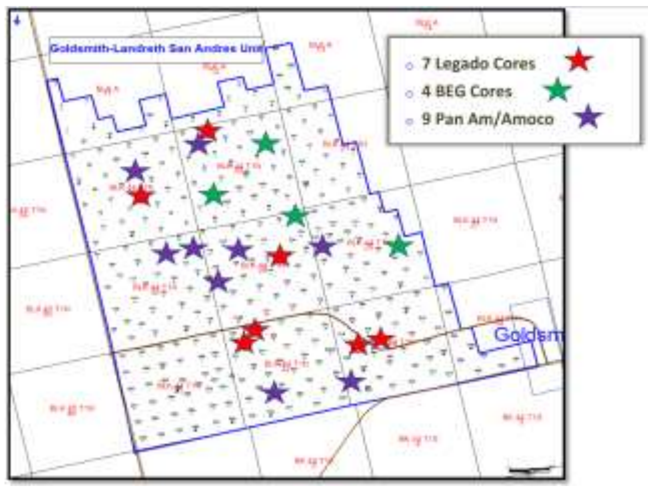

Figure 3.2. Core data coverage across the field.

The log and production data clearly show that the gas cap and the main pay zone are in communication. Also it was perceived that an area-wide, continuous, tight permeability streak is present between the MPZ and ROZ, which fully isolates the zones from one another as no apparent significant faulting is identified within the field.

The core and log descriptions for the GLSAU "Study Area" indicate that while it is possible to develop a simple correlation between the core data and the log gamma ray curve, developing a sequence stratigraphic model that identifies flow units and barriers

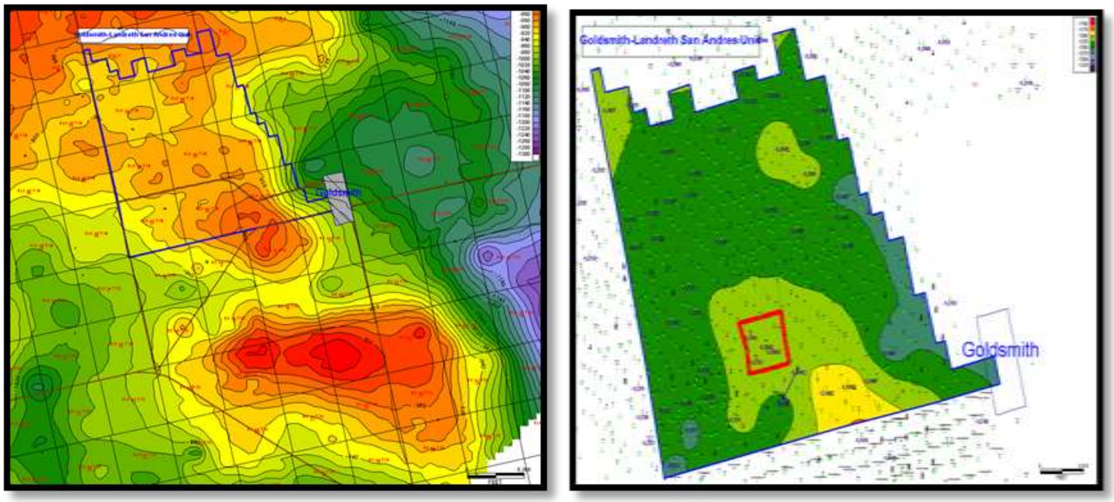

Figure 3.3. Top of San Andres structure (Left) and Base of ROZ (Right)

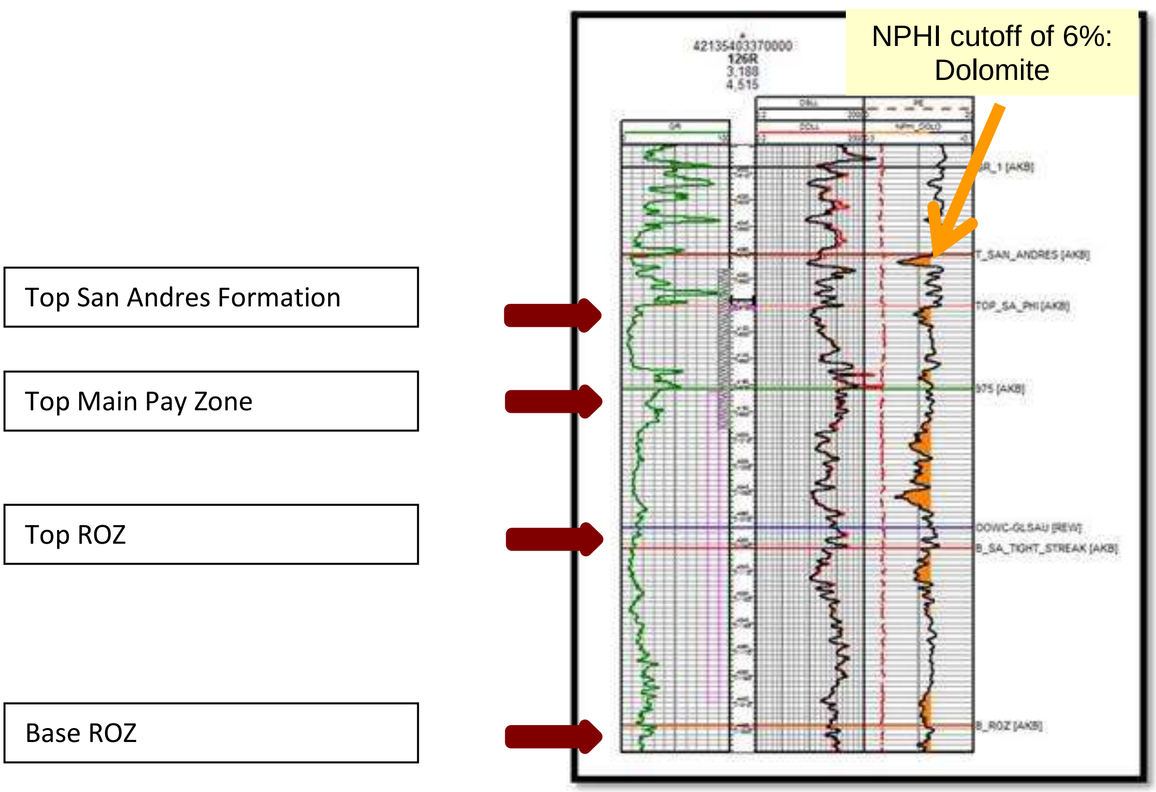

Figure 3.4. Type log

and baffles to vertical flow is more challenging. As such, the core porosity values (and their assessed relationship to permeability), the oil saturation data, the recognized "tight" intervals, and the qualitative descriptions of the primary faces of the rock matrix were used to establish a series of reservoir flow units. The core data shows that there the MPZ exhibits slightly higher reservoir quality than the ROZ, and has a lower permeability-porosity correlation factor, which might be an indicative of more heterogeneity.

Four geological layers were defined in the reservoir model, including three primary flow units designated the Gas Cap (GC), Main Pay Zone (MPZ) and Residual Oil Zone (ROZ), along with a flow barrier comprising a low permeability streak (Low K streak) separating the MPZ from ROZ.

Except for the low permeability streak, which is already a thin layer of 2 to 5ft, all other layers were subdivided into 10 to 15ft thick sub-layers to add granularity during numerical simulation. As a result, the reservoir model has 23 simulation layers, out of which 2 layers belong to GC, one to the low permeability streak, and 10 to each the MPZ and ROZ. The model was divided into 36 elements in the X and Y directions, resulting in a total number of 29,808 grid blocks. Each grid block has a dimension of 122 ft in X and 120 ft in Y direction. The study area covers 435 acres. Figure 3.5 shows the top of the structure and thickness distribution in the first layer.

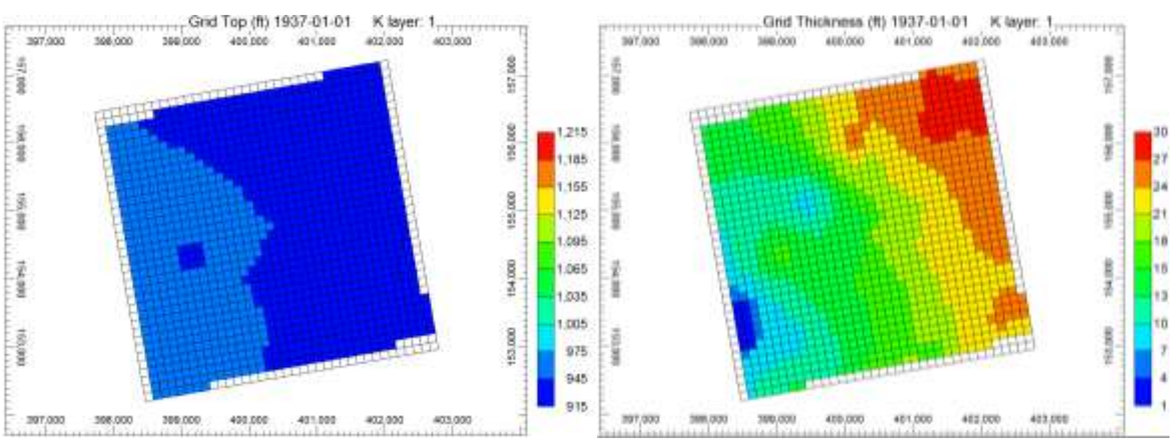

Figure 3.5. The top (Left) and thickness (Right) maps in the first layer

GLSAU core data was obtained for the MPZ interval in Well 204R, as part of the reservoir characterization for the study area. The core-based data and porosity of the net pay, along with the oil saturation obtained through integrating this data with the log data for well #204R are shown in Table 3.13 for the Gas Cap and the MPZ. This information is consistent with the values employed in the reservoir model. Additionally, a constant porosity of 2% and permeability values of 0.01mD and near zero in the horizontal and vertical directions were given to the low permeability streak between the MPZ and the ROZ.

Table 3.13.Gas Cap and MPZ Reservoir Properties for GLSAU Well #204R

Well # 204R				
San Andres Interval	Core Depth	Net Pay	Average Porosity of Net Pay	Average So of Net Pay
		(Feet)]	(%)	(%)
Gas Cap	4150-4160*	2	9.8	40
	4160-4170	10	11.7	41
	4170-4180	8	8.3	43
Main Pay	4180-4190	8	10.9	31
	4190-4200	9	10.3	45
	4200-4210	6	10.2	32
	4210-4220	8	12	45
	4220-4230	9	10.6	50
	4230-4240	9	9.1	42
	4240-4250	8	12.6	40
	4250-4260	7	13.5	40
	4260-4270	7	12.4	42
	4270-4280	5	9	40
	4280-4290	8	10.2	39
	Total	**104**	**10.8***	**42***

*Net pay weighted average for porosity and net pay.

Available core (log assisted) data was used as a basis for assigning the porosity and permeability values in different ROZ layers. Out of five cored intervals in the ROZ, two belonged to wells located in the study area (wells #190 and #204R). The net pay, porosity, and oil saturation calculated was based on integrating core data with the log data for these wells and is shown in Table 3.14. This data is provided in 10 foot intervals from the top of the ROZ to the base of the ROZ, which covers depths of 4,280 ft to 4,390 ft for well #190 and depths of 4,290 ft and 4,410 ft for well #204R. According to the core data, there is a correlation between the porosity and permeability (Figure

3.6), this correlation along with the general field information was used for assigning the permeability values to different ROZ layers.

Table 3.14 Core-based reservoir properties in ROZ.

Ft from Top of ROZ	Well #190			Well #204R		
	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay
	(feet)	(%)	(%)	(feet)	(%)	(%)
10	7	8	45	4	11.1	48
20	5	7.8	50	7	9.7	40
30	9	10.0	53	10	14.3	41
40	6	10.9	43	6	8.9	41
50	2	6.7	46	6	10.0	35
60	6	7.2	47	6	8.1	45
70	5	8.6	45	5	8.7	46
80	8	9.3	40	2	7.7	45
90	8	11.2	56	5	7.4	44
100	10	15.7	44	8	7.7	30
110	10	17.3	32	10	10.4	34
				10	12.7	27
Total	**76**	**11.0**	**46**	**79**	**10.2**	**38**

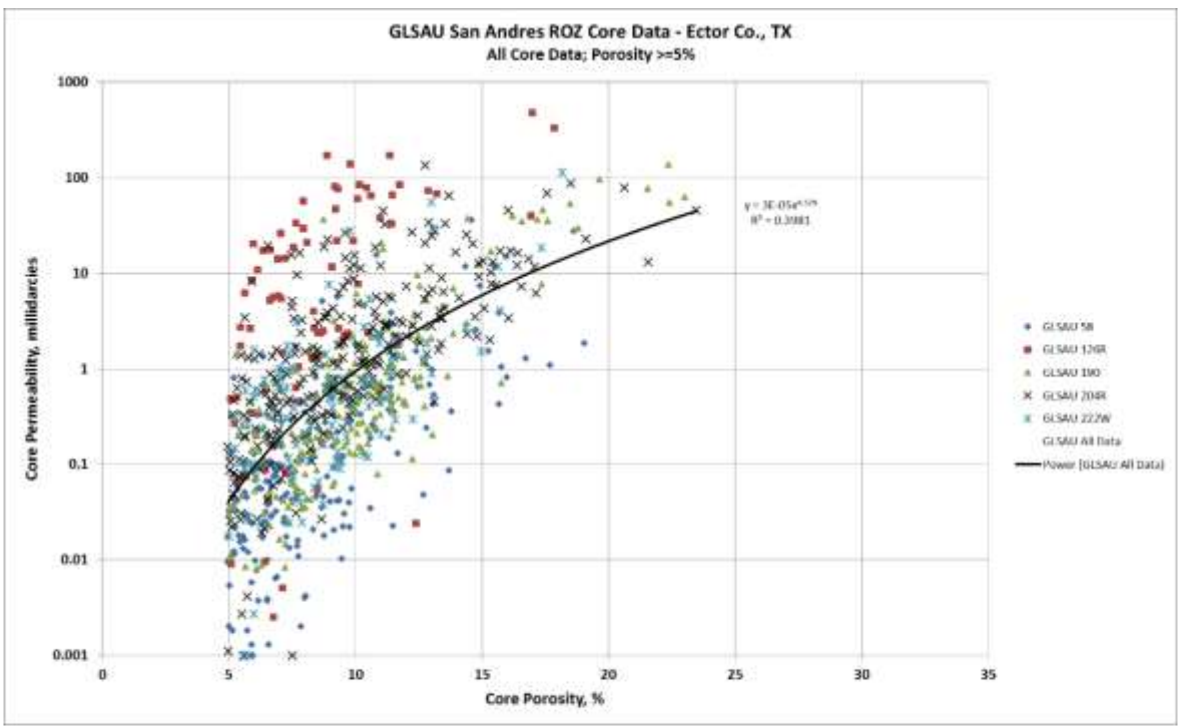

Figure 3.6. Porosity-permeability correlation in ROZ

Table 3 15. Non-commercial interval (Below ROZ) reservoir properties

	Well #190			
	Depth (ft)	Net Pay (ft)	Porosity of Net Pay (ft)	Oil Saturation of Net Pay (%)
Below ROZ	4390-4400	9	9.1	15%
	4400-4410	10	10.6	13%
	4410-4420	10	10.3	8%
	4420-4430	6	8.6	15%

	Well #204R			
	Depth (ft)	Net Pay (ft)	Porosity of Net Pay (ft)	Oil Saturation of Net Pay (%)
Below ROZ	4410-4420	7	10	14%
	4420-4430	7	10.3	23%
	4430-4440	10	9.8	12%
	4440-4450	10	11.0	11%

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Table 3.16 shows the average reservoir properties in each layer of the constructed model.

Table 3.16. Average reservoir properties in each simulation layer

	Layer	Avg. h(ft)	Porosity %	Horiz. K (mD)	Vert. K (mD)
GC	L1-2	9	11	12.5	1
MPZ	L3-12	105	11	12.5	12.5
	L13	~13	5	0.01	1E-15
ROZ	L14	12	8	12.5	12.5
	L15	12	8	6.25	6.25
	L16	12	11	6.25	6.25
	L17	12	8	6.25	6.25
	L18	12	8	6.25	6.25
	L19	12	8	6.25	6.25
	L20	12	8	6.25	6.25
	L21	12	20	62.5	62.5
	L22	12	20	62.5	62.5
	L23	12	20	62.5	62.5

Below the commercial base of ROZ, there is an extensive free water zone with very low (non-commercial) oil saturation. This non-commercial interval below the base of the commercial ROZ interval has relatively attractive porosity (9% to 11%) but low oil saturation (9% to 23%) according to the core-based (log-assisted) data from wells #190 and #204R (Table 3 ***15***). This region is not included in the reservoir model as the operator did not conduct recovery operations within this horizon.

3.a.3 Fluid Data

The reservoir is initially oversaturated and the bubble point pressure is estimated to be 1,750 psia. Some PVT data was available for the field, initially reported by Amoco (

3.a.4 Model initial conditions

Based on repeat formation tests (RFT), the initial reservoir pressure was estimated to be 1,750 psia at a depth of 4,200 ft in the MPZ. This data, provided by Legado, corresponds to a pressure gradient value of 0.416 psia/ft. Static BHP tests indicated that ROZ was still at virgin conditions in 2007-2010, with a reservoir pressure of 1,810 at 4,350 ft, which is also a pressure gradient of 0.416psi/ft.

Table 3.17). The reported initial oil formation volume factor is between 1.36 and 1.4. Equation of State (EOS) interaction coefficients are usually estimated during history matching reservoir hydrocarbon PVT data. These PVT data are obtained during routine tests such as Constant Composition Expansion and Differential Liberation, saturation pressure and viscosity tests. In this specific case, no PVT test was available. As such, available in-situ data from the Wasson Denver Unit was used and modified to achieve the oil gravity of 34º API. Table 3.18 lists the mole fraction of each of the 11 components of reservoir fluid in the gas cap and the other flow units. Peng-Robinson EOS was selected to model fluid properties, whereas the Jossi-Stiel-Thodos equation was used to model oil viscosity. Water properties were extracted from literature (SPE paper-133089), as no site-specific data were provided. Thereby, the density of the water was set as 62.18 lb/cft, and viscosity was set to be 0.718 cp at a reference pressure of 14.75 psia. Based on the Amoco data, minimum miscibility pressure was estimated to be 1,150 psia at a reservoir temperature of 95ºF. Figure 3.7 shows the AMOCO fluid PVT data.

3.a.4 Model initial conditions

Based on repeat formation tests (RFT), the initial reservoir pressure was estimated to be 1,750 psia at a depth of 4,200 ft in the MPZ. This data, provided by Legado, corresponds to a pressure gradient value of 0.416 psia/ft. Static BHP tests indicated that ROZ was still at virgin conditions in 2007-2010, with a reservoir pressure of 1,810 at 4,350 ft, which is also a pressure gradient of 0.416psi/ft.

Table 3.17 Fluid data - Source: Amoco

Pressure (psig)	Oil Formation Volume Factor (RB/STB)	Oil viscosity (cp)	Gas Formation Volume Factor (RB/Mcf)	Gas viscosity (cp)	Solution Gas-oil-ratio (Mcf/STB)
0	1.000	3.10	63.12	0.0122	0.023
50	1.064	2.67	55.32	0.0124	0.083
100	1.093	2.24	27.52	0.0126	0.143
200	1.122	1.83	13.41	0.0128	0.194
300	1.142	1.60	6.76	0.0130	0.235
400	1.159	1.46	6.46	0.0132	0.272
500	1.174	1.38	5.09	0.0135	0.307
600	1.188	1.33	4.14	0.0138	0.341
700	1.202	1.30	3.51	0.0141	0.374
800	1.215	1.26	3.01	0.0145	0.406
900	1.227	1.23	2.61	0.0147	0.438
1000	1.239	1.21	2.31	0.0149	0.469
1200	1.264	1.18	1.84	0.0157	0.550
1400	1.268	1.16	1.53	0.0165	0.589
1600	1.266	1.18	1.30	0.0179	0.589
1800	1.264	1.20	1.13	0.0194	0.589
2000	1.262	1.22	1.01	0.0215	0.589
2400	1.258	1.26	0.83	0.0240	0.589

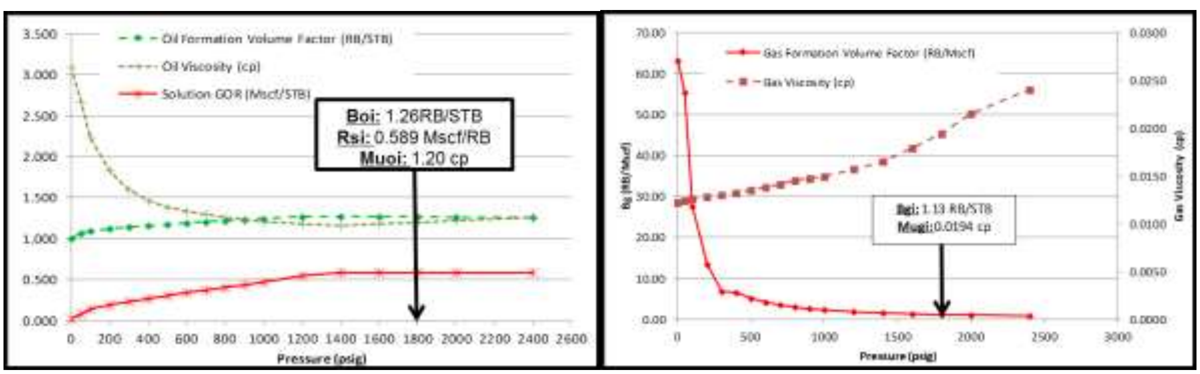

Figure 3.7. Fluid PVT Data - Source: AMOCO Report

Table 3.18. Reservoir fluid composition used in the model

Component	Mole percent in Gas Cap	Mole Percent in MPZ,K-Steak and ROZ
CO2	0	0
C1	95	35.77
C2	5	5.84
C3	0	5.97
C4	0	5.36
C5	0	3.58
C6	0	1.16
C7-13	0	22.82
C14-20	0	8.1
C21-28'	0	4.16
C29+	0	7.24

Having already constructed the elevation and thickness maps in the model, the pressure gradient was used to distribute initial pressure values in different layers. Based on Legado completion reports, the ground level is almost 3,200 ft above sea level. The numerical model employs subsea (SS) elevations, which subtracts ground level from total vertical depth (TVD). As such, the gas oil contact is located at 975 ft SS and water oil contact is at the depth of 1,300 ft SS.

Core sample average saturations were used to estimate the approximate initial oil saturation of GC, MPZ and ROZ (Figure 3.8). While the MPZ is fully charged with oil (74%) at the onset of production, the ROZ is at a much lower oil saturation (~40%).

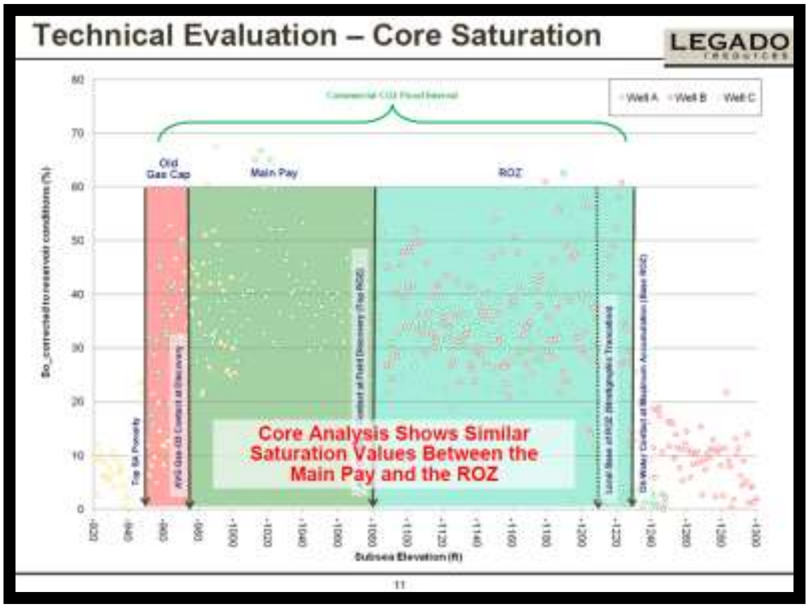

Figure 3.8. Core saturation analysis result in GC, MPZ and ROZ.[2]

In order to model "mother nature's water flood" in the ROZ, the model was endowed with an initial oil saturation from the base of the ROZ to the GC of 74%. Within the ROZ, water was flooded for more than 250 years to emulate (at a faster rate) the flushing of oil out of the ROZ. The pressure and oil saturation maps for each layer were extracted at the beginning of year 1937. In order to save the numerical run time, a new model was created based on these maps which replicated the initial condition of the reservoir, comparing favorably to core/log data.

Figure 3.9 shows the pressure and oil saturation distribution at 1937. The reservoir initially contains 35 million barrels of oil and 24 Bcf of hydrocarbon gas.

[2] "GLSAU MPZ and ROZ Development update – D. Cantwell, April 2011, SPE ROZ Symposium Midland, TX

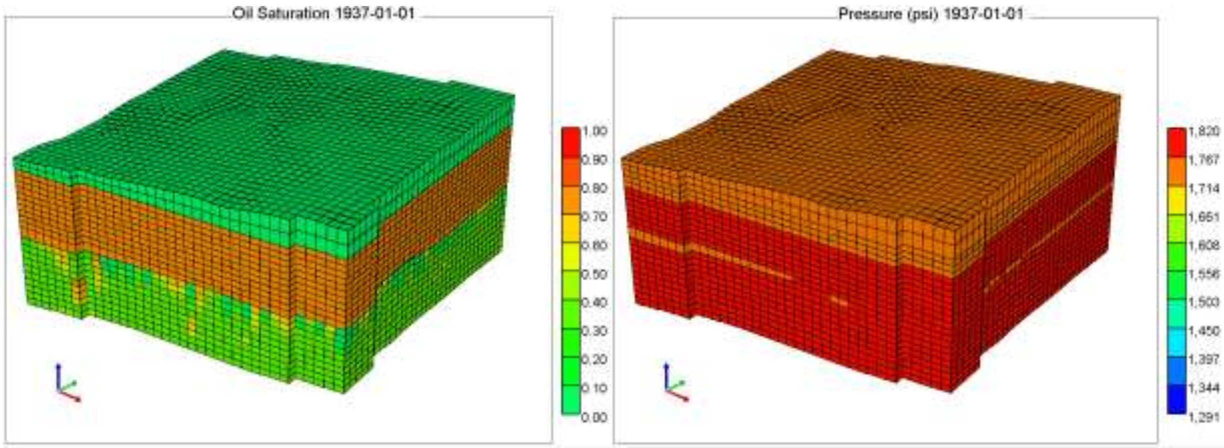

Figure 3.9. 1937 Initial oil saturation (Left) and Pressure (Right) distribution in the reservoir

3.a.5 Relative Permeability

As no data was available, the oil-water relative permeability end point information was acquired from SPE-133089, implemented, and modified in the model. Analogy was used to generate the water-gas relative permeability and capillary pressure curves. Capillary pressure curves were modified from Hawksoak sands to represent average permeability water-wet dolomitic reservoir (Figures 3.10 and 3.11). Table 3.19 lists the end points used to generate the relative permeability curves in the base model.

Table 3.19. End point values used for generating the relative permeability curves in the reservoir base model

Oil-Water Rel. Perm. Curve		**Gas-Liq. Rel. Perm. Curve**	
Sw_{irr}	20%	Sg_r	5%
So_{rw}	40%	Sl_{rg}	36%
Kr_{wmax}	1	So_{rCO2}	12%
Kr_{omax}	0.8	Krg_{max}	0.8
		Krl_{max}	0.8

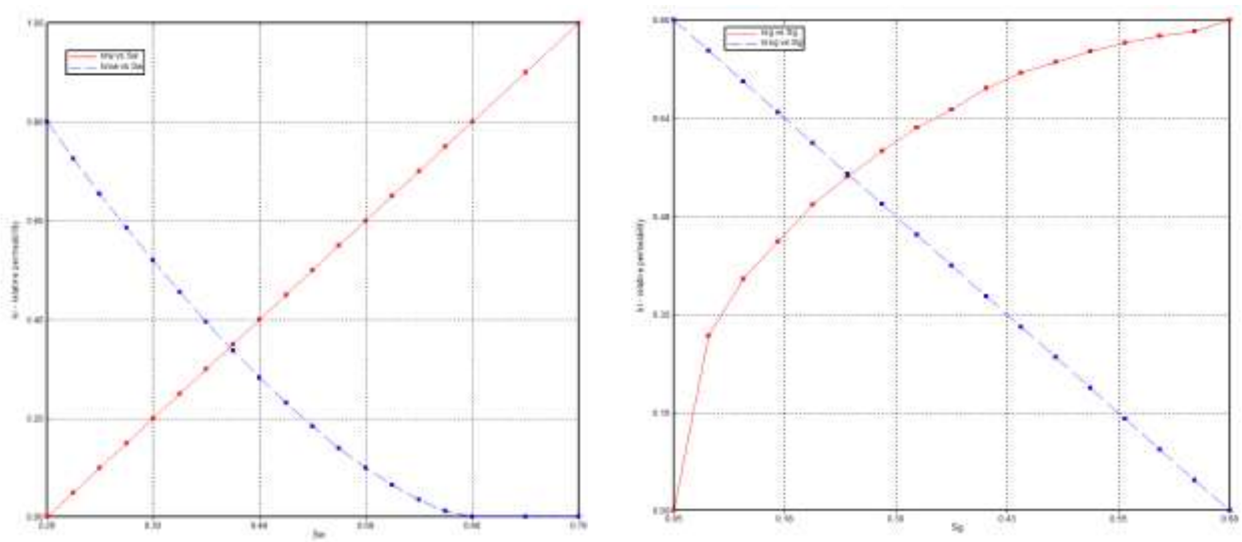

Figure 3.10. Relative permeability curves used in the model

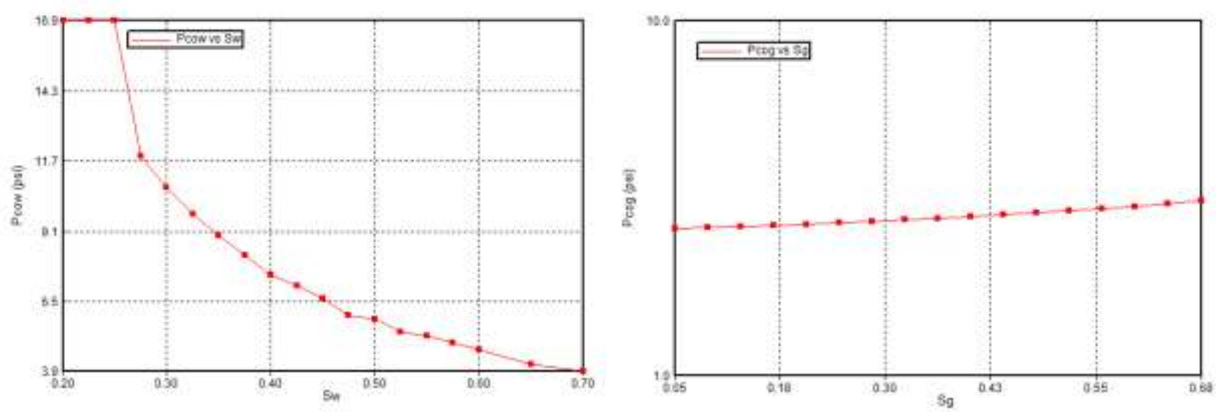

Figure 3.11. Oil-Water (Left) and Gas-Oil (Right) capillary pressure curves

3.a.6 Field and Completion History

Three main production periods can be defined for this reservoir. Primary recovery started in 1937 and continued to 1948. Through this time, 22 wells produced oil from the MPZ. Secondary water flood recovery began in 1948. Two wells were converted to gas cap re-injectors in 1948 and 1950, while 13 wells were converted into water injectors between 1964 and 1972. Legado provided the completion history for each of the wells in the Phase I area. Figure 3.12 shows the completion history and well schematic for well #163, as an example.

Most of the producers were originally completed through the GC and into the MPZ. Later, the completions were deepened through the entire MPZ for gas/water injection, and finally opened through the ROZ for CO_2 WAG-EOR in 2009. Individual well completion history was implemented in the reservoir model. Figure 3.13 shows a 3-D structure of the model and the location of the wells. Injection wells at Goldsmith are generally open in both the MPZ and ROZ, with some selective completions. The producers are completed throughout the MPZ and ROZ, as well as the Gas Cap (Figure 3.14).

Prior to 2008 (when Legado took over as operator of the property), no production or injection data was available for individual well histories. For the period of 1937 to 1958, the well count (more than 400 wells for the field) and the cumulative production values were available for the entire lease. A field production performance plot, provided by Legado, (Figure 3.15) was used to compute the average well oil, water and gas rate and to begin assembling individual well production histories for history matching.

From 1958 to 2007, monthly production rates were available for the entire GLSAU lease (not for individual wells). An average production per well was calculated using well/lease data. Since completion records were available from the operator, understanding which wells were operational and contributing to lease production enable this second period to be converted to individual well data.

A total of 25 active wells exist in the study area, with 16 injectors and 9 producers. Each of the injectors are converted production wells. Figure 3.16 displays the estimated and available production history in the Phase I modeled area During secondary production, two main recovery mechanisms were implemented in the field: gas cap re-injection from 1948 to 1971 and water flood from 1963 to 2008. No gas injection data was available. Hence, it was estimated using gas production data. An average value was calculated based on the cumulative gas production from 1948 to 1965 and monthly gas production from 1965 to 2007.

Field:	Goldsmith Landreth San Andres Unit
	Location:
Footage:	990' FSL & 330' FWL
Section:	29
Block:	44, T-1N
Survey:	T&P RR
County:	Ector
Lat:	
Long:	
	Elevations:
GL:	3184
KB:	3194
KB Calc:	10
ck w/log?	

Date	History
3/8/1937	Acidezed open hole 4166' - 4224' w/ 6000gals acid. IP 1552 BOPD.
4/18/1996	Set CIBP @ 4143'. TA'd well.
5/12/1997	DO CIBP @ 4143' Push to 4259'. Put well on production.
1/12/2001	Shut in.
11/17/2008	POOH with rods and pump. Attempt to pull tbg but TAC was stuck. Tbg pa
	while attempting to pull. Fished tbg and TAC. CO to 4272. Ran ESP & ret
	well to production.
12/28/2009	Deepened to 4365'. Logged and Retruned well to produciton.
4/8/10	ESP pump plugged with iron sulfide. Replaced pump, both seals, & gas se
	Hydro test tbg. All OK.
7/1/2010	Hole in tbg. Btm 6 jts of tbg had holes from outside corrosion. Replaced tb
	w/IPC. Pump tested OK. Replaced btm 950' of cable due to corrosion pits.
8/12/2010	Mix 200 bbl 2% KCl w/ 55 gals SRW-4804 & 5 glas RE-4574. Pump 100 b
	solution w/ 52 gals Magnatreat-M & flush w/ 100 bbl solution.
8/31/2010	Pull ESP & found hole in btm jt. Perf 4154' - 4166' w/ 4 SPF. RWTP.
11/3/2010	Pull ESP & found motor burnt w/ wtr & burnt oil in seal. Run new ESP & RV

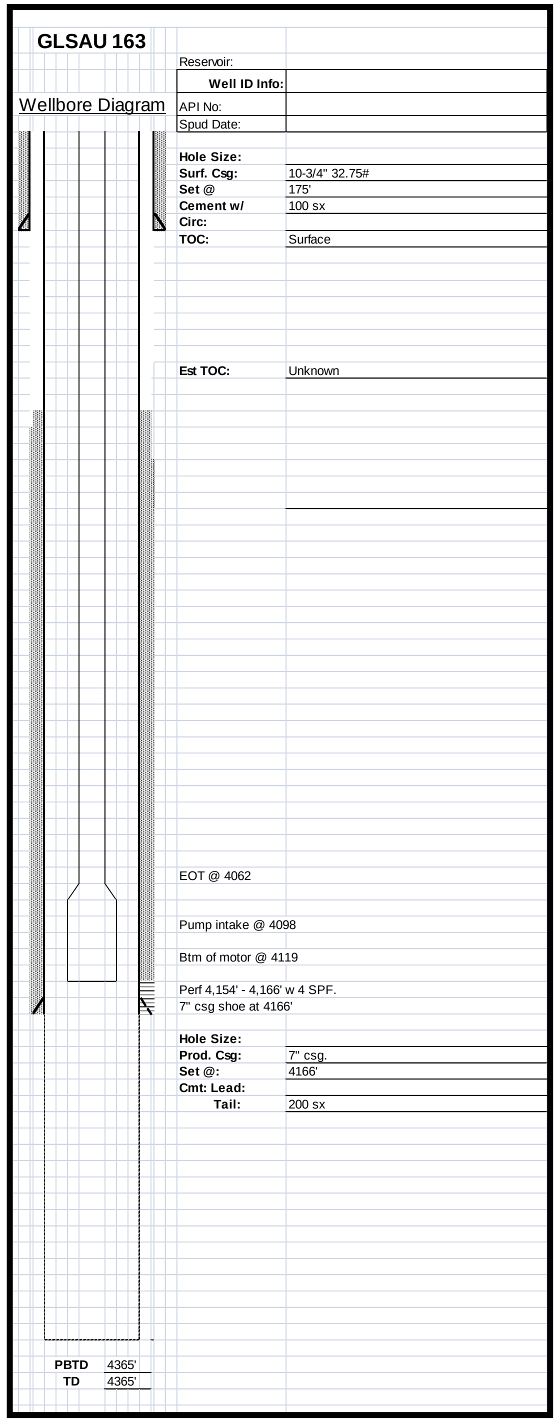

Figure 3.12. A sample of completion history and well schematic

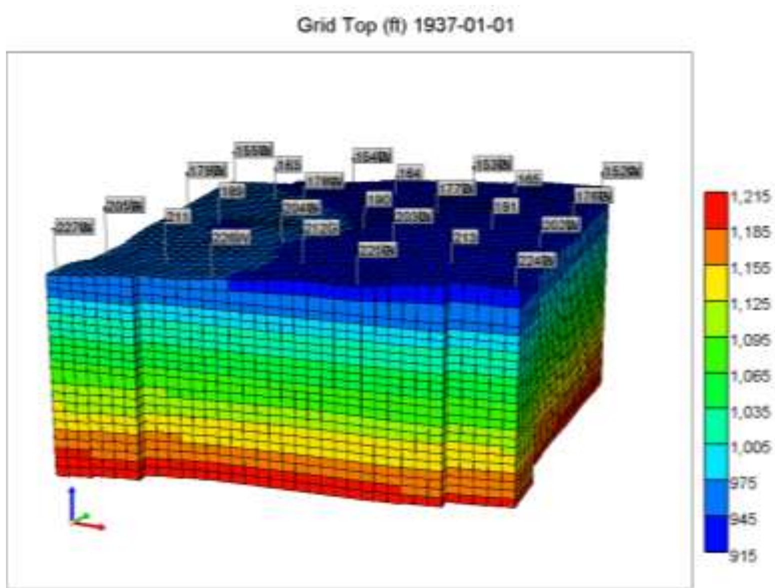

Figure 3.13. 3-D structure of the model and well locations

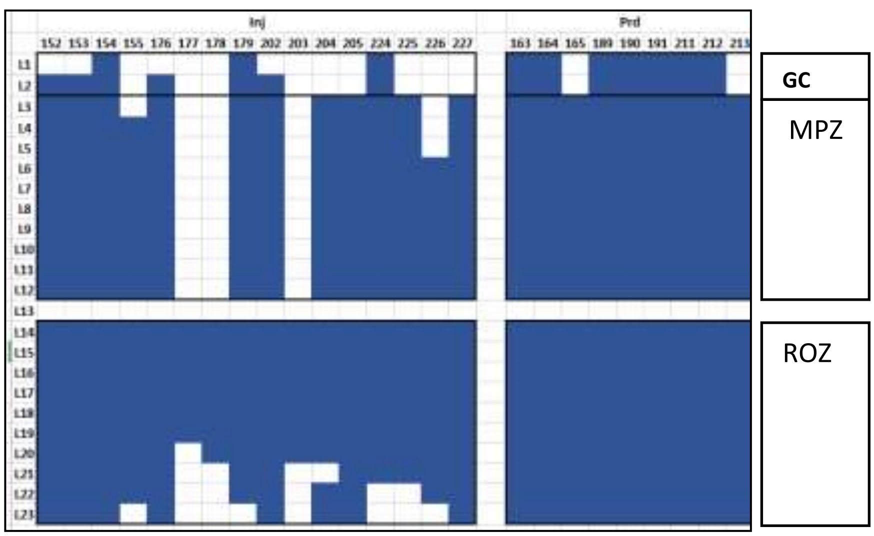

Figure 3.14. Current Well Completions at Goldsmith (columns represent wells and rows represent different layers)

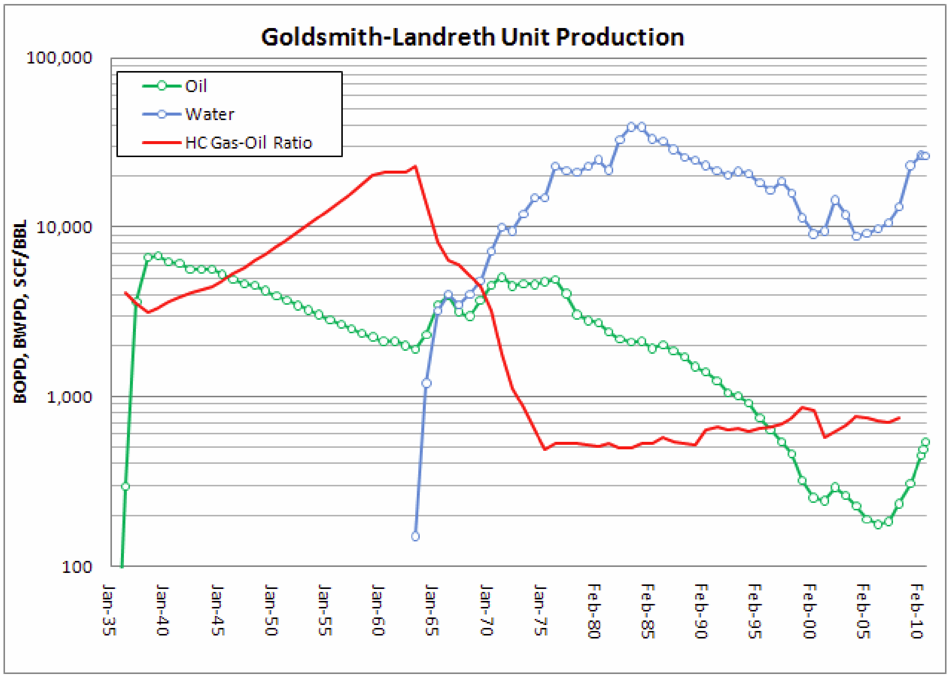

Figure 3.15. Field production performance plot

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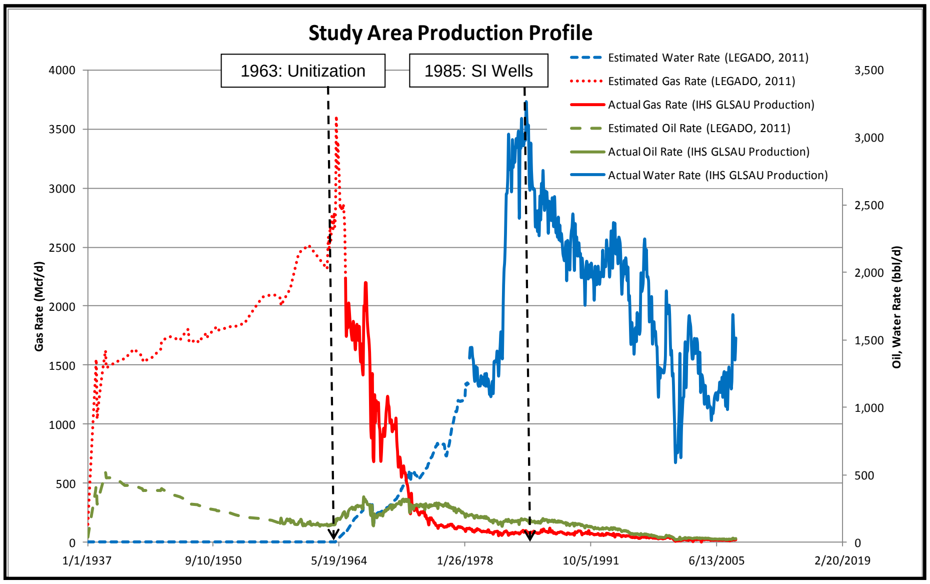

Figure 3.16. Phase I area production history

Water injection data was reported from 1983 to 2007. For the time from 1963 to 1983, injection rate was controlled by constraining the maximum bottom-hole pressure of 1,600 psia, and maximum water rate of 6,000 bbls/day for this time span. Date of starting and shutting the wells was honored in the model.

The pressure constraint for the injection wells prior to 2008 is set to be 90% of the initial reservoir pressure, which is approximately 1,600 psia. This value is based on standard practice and lease pressure limit on the Permian Basin ROZ project. Starting in 2008, the water injection data was available on a monthly basis for each individual well in the study area (Figure 3.17).

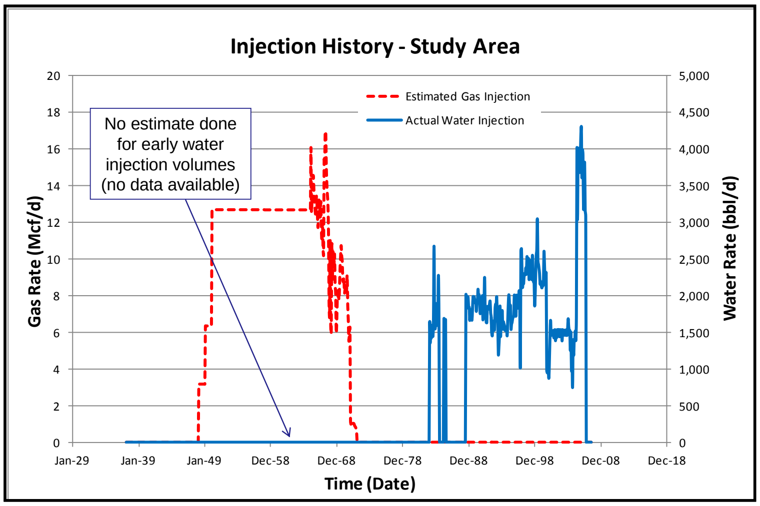

Figure 3.17. Estimated injection rate in the area of study prior to 2008

3.a.7 Reservoir Volumetrics

The original oil in place (OOIP) in the model area is determined volumetrically. Before the ROZ was swept by water movement, the OOIP in the study area (GC, MPZ and ROZ) is 47.3 million stock tank barrels (MmSTB), with 26 MmSTB located in the ROZ and 21 MmSTB in the MPZ. Prior to 1937, the ROZ is swept by water movement, resulting in a reduction to 13.8 MmSTB and 35.1 MmSTB for whole of the area.

3.a.8 History Matching

Numerical history matching of well performance in the Phase I area was carried out. The history matching was divided into two primary segments. The first piece was primary and secondary recovery to 2008 and the second was tertiary CO_2-EOR operations conducted by Legado thereafter.

Prior to 2008, production was controlled by oil rate and the injectors by gas rate. Producers operated at a minimum bottomhole pressure constraint of 250 psia and injectors a maximum pressure bottomhole pressure of 1,600 psia. During this period, production is from the MPZ and the GC. After 2008, production and injection wells are constrained by oil, gas, or water, respectively.

The base model went through multiple changes and modification with the intention of matching the historical production data. The gas production rate was one of the challenging parameters in the course of history matching.

It is important to note that the thickness of the GC, where the majority of the gas production is believed to originate, is much thinner in this portion of the field. As a result, the average gas production may have been largely overstated for the Phase I area.

Porosity and permeability alterations were made on a global basis in the model to achieve better performance matches. However, their impact was low in terms of improving the matches of oil, gas, and water production, indicating the starting values in the model were close to "actual". Relative permeability adjustments, however, greatly improved the ability to match gas production rates, in particular.

The relative permeability curves generated using the data in the literature were not providing adequate permeability for the gas to flow. Dramatically increasing the gas relative permeability was able to improve the gas production rate, post 2008 (Figure 3.18).

3.a.7 History Matching Results

The largest factor in achieving a history match related to the uncertainty in the actual production history of the model area. Due to the field and lease reported production/injection data, prior to 2008, assembling an accurate history for the Phase I area was impossible. Further, the estimated historical gas production rates nearly

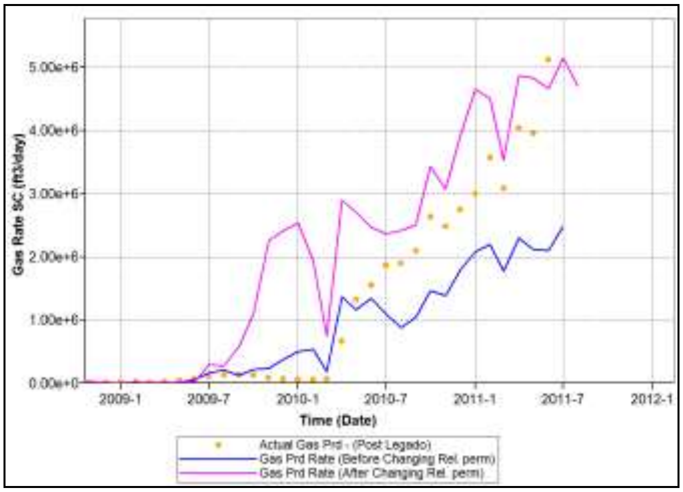

Figure 3.18. Effect of modifying relative permeability on gas production

exceeded the gas in place for the model. This was due to a general thinning of the GC in the Phase I area. So, the emphasis and priority for matching was carried forward as follows: oil rate, injection volumes, water rate, and gas rate. The results of history matching for the first period (1937 to 2008) are shown in Figure 3.19.

With discreet well production histories available for the Phase I wells after 2008, a high quality history match was achieved for the CO_2-EOR project. This match furthered our confidence that the match for the pre-2008 data was acceptable, since the same model was employed for each of these time periods. Figure 3.20 shows the history matching results for this the period.

Table 3.8 lists the produced oil volume from the wells in the model area. Out of these wells, nine have produced from both the MPZ and ROZ.

3.a.9 Oil in Place and Recovery Efficiency

From the numerical model, the original oil endowment for the Phase I area was calculated as 47.3 MmSTB, Table 3.9. The replication of the natural water flushing after the uplift of the Permian Basin shows that over 12 MmSTB, or 26% of the total oil in place (OIP), was displaced from the area, leaving 35 MmSTB at field discovery in 1937. Primary and secondary recovery operations produced another 4.6 MmSTB of oil from

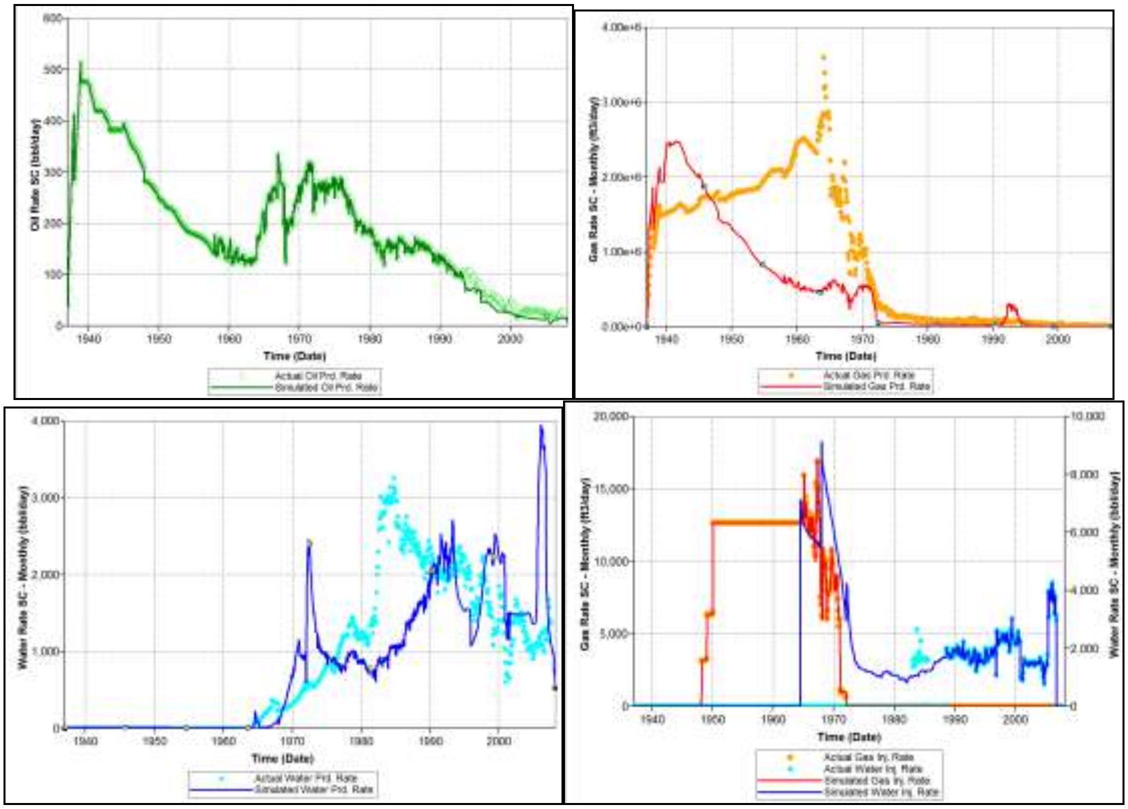

Figure 3.19. Oil, gas, water production rate and gas/water injection rate, pre-2008

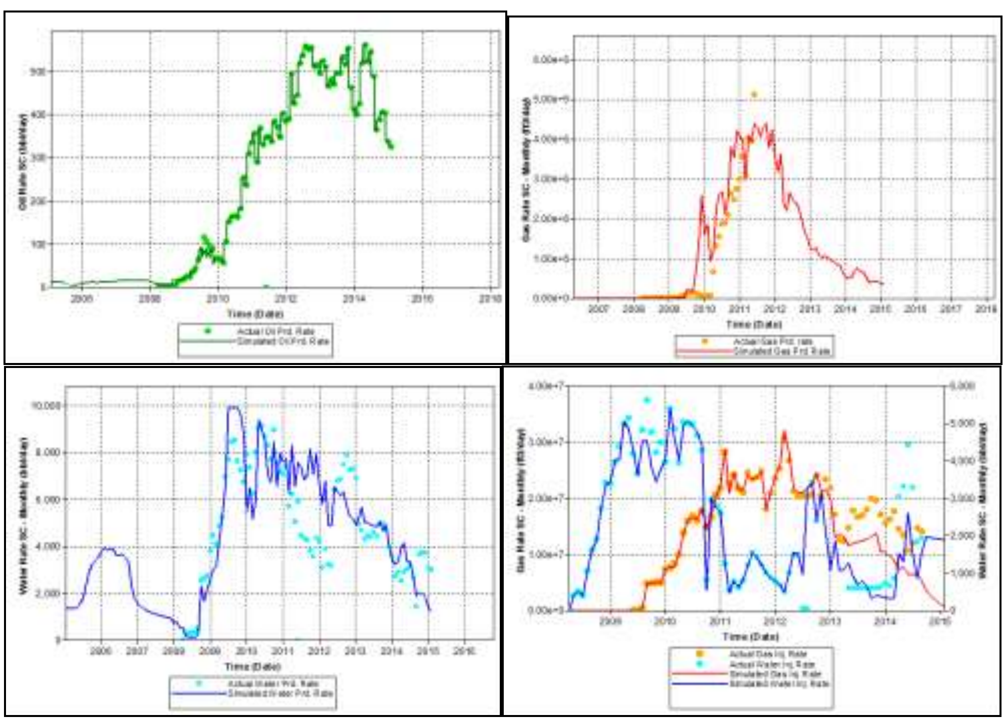

Figure 3.20. Oil, gas, water production rate and gas/water injection rate, post-2008

Table 3.20. Oil volumes produced from the wells in the Phase I area, pre and post-EOR

Cumulative Oil Production (Mbbls)					
Well	**MPZ only (Pre CO2 EOR)**	**MPZ and ROZ (Post CO2 EOR)**	**Well**	**MPZ only (Pre CO2 EOR)**	**MPZ and ROZ (Post CO2 EOR)**
152	25	0	**190**	172	165
153	97	0	**191**	348	83
154	86	0	**202**	160	0
155	81	0	**203**	275	0
163	423	91	**205**	96	0
164	379	104	**211**	691	66
165	179	61	**212**	87	38
176	115	0	**213**	171	77
177	145	0	**224**	67	0
179	93	0	**225**	91	0
189	938	63	**226**	178	0
Total	2,561	320	**Total**	2,338	430

Table 3.21. OOIP and recovery efficiency

Flow Unit	OOIP MMSTB	1937 OIP* MMSTB	Pre-EOR (2009) MMSTB	Current (2015) MMSTB	Total Recovery MMSTB
GC	-	-	3.8	4.3	(4.30)
MPZ	21.3	21.3	12.9	11.7	9.60
ROZ	26.0	13.8	13.8	12.8	1.00
Field	47.3	35.1	30.5	28.8	6.30
Recovery Efficiency		26%	13%	6%	18%
***Natural water flushing**					

the Phase I area, reducing the EOR target by 13% of OIP. Nearly 4 MmSTB of oil was displaced into the GC due to a rising gas-oil contact due to gas production.

EOR operations have brought the ROZ into play, but it is still in its early stages. Oil recovery has produced another 2 MMSTB of oil, bringing overall recovery to just over 6% of the 1937 OIP.

3.a.8 CO_2 Distribution

Comparing the vertical distribution of CO_2 and the vertical location of the remaining oil in-place in the MPZ and ROZ provides valuable insights on the effectiveness of the CO_2 flood. In the GLSAU "Study Area", 55 Bcf of CO_2 has been injected into 16 CO_2 injection wells, with 36 Bcf entering nine confined production patterns.

Table 3.22 tabulates the volume and distribution of the injected CO_2 for: (1) each of the nine production patterns in the GLSAU "Study Area" and (2) the distribution of the injected CO_2 into the MPZ and ROZ, based on the spinner data. The region of note is highlighted in red.

For comparison, layer-by-layer cumulative CO_2 injection in the model can be tied to spinner/tracer surveys (Table 3.23). Generally, there is good agreement between the data, despite the actual data carrying forward for another several months due to new data. The GC received 1.9 Bcf compared to 0.7 Bcf in the model. Ratios of Actual to simulated for the MPZ and ROZ were 10.8/8.1 Bcf and 21.2/21.4 Bcf, respectively. These results strengthen the quality of the simulation history match.

In addition to field injection of CO_2, gas production data can be reviewed as an indication of CO_2 break-through. Table 3.24 tabulates this value for well#190, showing that CO_2 is possibly moving the fastest through the ROZ – L1.

Table 3.22. Injected CO_2 in each layer- spinner/tracer survey

CO2 Injection	GLSAU "Study Area" CO2 Volume by Production Pattern (Bcf)									TOTAL (Bcf)
	#163	#164	#165	#189	#190	#191	#211	#212	#213	
2009	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.2	0.0	**0.7**
2010	0.3	0.6	0.3	0.6	1.3	0.7	0.4	0.9	0.5	**5.6**
2011	0.5	1.0	1.1	0.5	1.1	1.2	0.5	1.1	1.1	**8.2**
2012	0.6	1.0	1.1	0.7	1.2	1.3	0.6	1.3	1.0	**8.8**
2013	0.3	0.6	0.9	0.6	0.6	0.7	1.1	1.1	0.9	**6.8**
2014	0.4	0.4	0.5	0.6	0.7	0.6	0.9	0.7	0.7	**5.5**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**
Gas Cap	13%	10%	8%	4%	2%	5%	4%	3%	5%	**5%**
MPZ	34%	28%	31%	34%	13%	14%	67%	37%	26%	**30%**
ROZ	42%	58%	45%	58%	84%	68%	29%	60%	68%	**59%**
NonPay	11%	3%	17%	3%	0%	13%	0%	1%	2%	**5%**
Gas Cap Volume	0.3	0.4	0.3	0.1	0.1	0.2	0.1	0.1	0.2	**1.9**
MPZ Volume	0.7	1.0	1.2	1.1	0.7	0.6	2.5	1.9	1.1	**10.8**
ROZ Volume	0.9	2.1	1.7	1.9	4.4	3.2	1.1	3.1	2.8	**21.2**
NonPay Volume	0.2	0.1	0.6	0.1	0.0	0.6	0.0	0.0	0.1	**1.8**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**

Table 3.23. Simulated injected CO_2 distribution in different layers of the reservoir

Flow Unit/Layer	Cum CO2 Inj (BCF) @ 2015/2/1
GC	0.69
MPZ	8.1
Roz – L1	3.4
Roz – L2	1.8
Roz – L3	1.7
Roz – L4	1.7
Roz – L5	1.8
Roz – L6	1.8
Roz – L7	1.3
Roz – L8	3.1
Roz – L9	2.0
Roz – L10	2.7

Table 3.24. Simulated gas production from different layers -Well#190

Flow Unit/Layer	Cum Gas (BCF) @ 2015/2/1
MPZ-L1	0.27
MPZ-L2	0.09
MPZ-L3	0.01
MPZ-L4	0.01
MPZ-L5	0.01
MPZ-L6	0.01
MPZ-L7	0.00
MPZ-L8	0.00
MPZ-L9	0.00
MPZ-L10	0.00
Roz – L1	0.49
Roz – L2	0.04
Roz – L3	0.05
Roz – L4	0.04
Roz – L5	0.04
Roz – L6	0.03
Roz – L7	0.03
Roz – L8	0.11
Roz – L9	0.01
Roz – L10	0.00

3.a.10 Production Forecast

In order to assess the potential of the MPZ and ROZ reservoir sections under tertiary recovery, the model was executed in forecast mode to forward model the oil recovery of the Phase I area. The model was executed for a period of 20 additional years, operating at the same water-alternating-gas ratio. Overall recovery shows that 13.9 Mmbbls could be recovered from the Phase I area under status quo conditions. While some of the MPZ production is lost to the gas cap, net production shows an additional 1 Mmbbls of oil could be garnered from this horizon. The ROZ, however, contributes 7.7 Mmbbls of oil, indicating 6.7 Mmbbls of additional recovery could be achieved.

These estimates bring overall recovery to 40% of the 1937 OIP, exclusive of the 4.3 Mmbbls of oil lost to the gas cap. MPZ recovery is 49% of OIP and ROZ recovery is 56% of OIP. When ROZ recovery is normalized to the pre-flushed OOIP, recovery is

30% of OOIP. Overall, there is still a great deal of oil to be garnered from the project, particularly in the ROZ.

3.a.11 Well #190 Pattern History Match

To investigate the ROZ section in more detail, a new model was built for the #190 pattern, which has a wealth of flood diagnostic information available for review. This pattern will be studied in detail in Section 4 of this report. However, this section offers a comparison of the 3-dimensional, fully compositional model to that of the scoping level streamtube model.

Model Construction

In order to build this 5-spot pattern model, the well coordinates were extracted from the Phase I base model, and modified to make a symmetrical pattern (Figure 3.21). The modeled area covers 40 acres. There are 11 grid blocks in each X and Y direction. Each grid block has a lateral dimension of 120 ft. A constant value of 1,090 ft has been considered as the top of the structure. Well#190 (producer) is surrounded by four injectors.

A focused geologic investigation was made for this pattern area and is detailed in Section 4 of this report.

Since the focus of the pattern model is on the ROZ section, the model has only 4 layers for ease of comparison to the streamtube model. Pressure values were distributed in each ROZ layer based on the pressure gradient of 0.416 psi/ft. The initial oil in place in ROZ is equal to 854 Mstb based on these reservoir properties.

History Matching

Modeling begins in August of 2008, which is when Well #190 is perforated in ROZ. Four offset injection wells create the five-spot pattern. While there are some instances of completion and injection into the MPZ within this pattern, it is short lived at best. As such, this was an excellent pattern to explore the efficacy of CO_2-EOR within the ROZ.

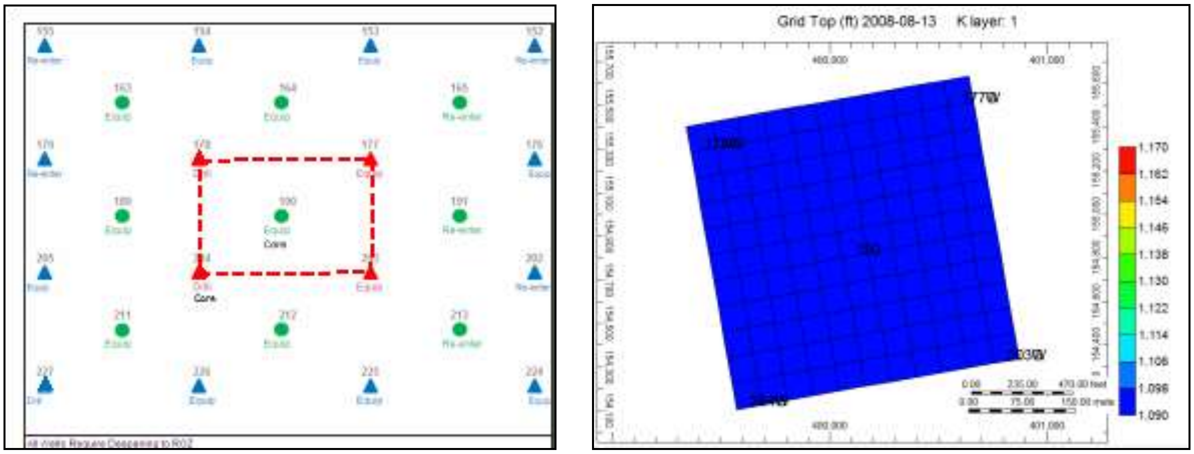

Figure 3.21. Location of the wells and #190 pattern in the study area (Left), the top structure of the pattern model (Right)

Recorded bottom-hole pressure for Well#190 were made available by the operator and span August 2008 to June 2011. This data has been set as the constraint for the producer. The production and injection rates for each well are available on a monthly basis after 2008. Since production and injection is happening in MPZ and ROZ, the modest amount of MPZ production has been removed from consideration during the matching process.

Overall, 21 Bcf of CO_2 has been injected into the four injection wells located in the GLSAU CO_2-EOR Phase I area. Based on the spinner/tracer data out of this volume:

- 5.25 Bcf entered Pattern #190 with the remaining CO_2 (15.75 Bcf) entering the 8 patterns surrounding the model area.
- Out of the 5.25 Bcf of CO_2 entering Pattern #190, 4.42 Bcf (84.2%) entered the ROZ, because of the “ROZ” only completions used in the four CO_2 injection wells surrounding Pattern #190.
- The remainder of the CO_2, approximately 0.83 Bcf (15.8%), entered the MPZ, with essentially all of this volume from the “dual MPZ/ROZ” completion in Well #204.

Since the injection profile logs were available, permeability was tuned to achieve similar injection profiles into this study pattern. The resultant porosity, permeability and relative permeability data were modified as shown in Table 3.13 and Figure 3.22. The permeability is isotropic. Horizontal and vertical permeability are equal in each layer. A trapped oil saturation (Sorm) of 10% is used in the model.

Table 3.13. Reservoir properties in the #190 pattern model

Layer	Porosity %	Perm. (mD)
ROZ-1	9.06	22
ROZ-2	11.32	28
ROZ-3	8.21	19
ROZ-4	12.72	80

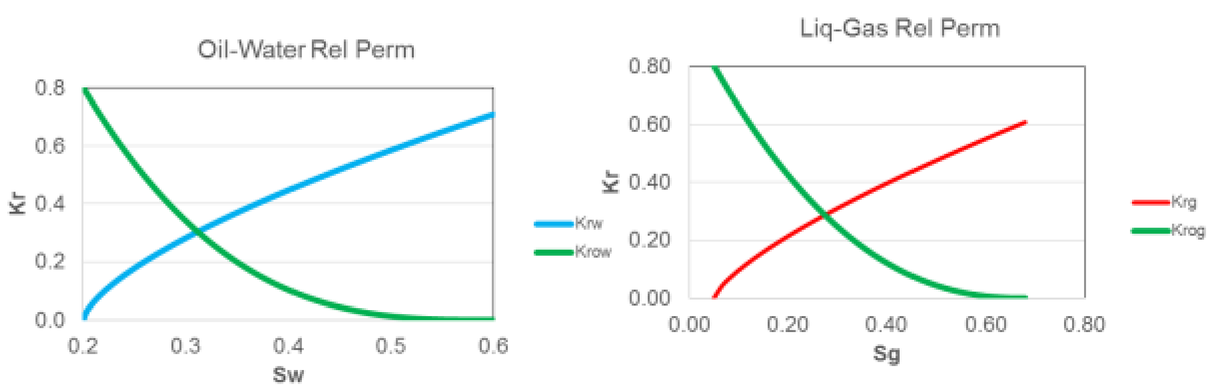

Figure 3.22. Water-oil and liquid-gas relative permeability curves

The resultant production and injection history matching results for the history matched pattern model are shown in Figures 3.23 through 3.25.

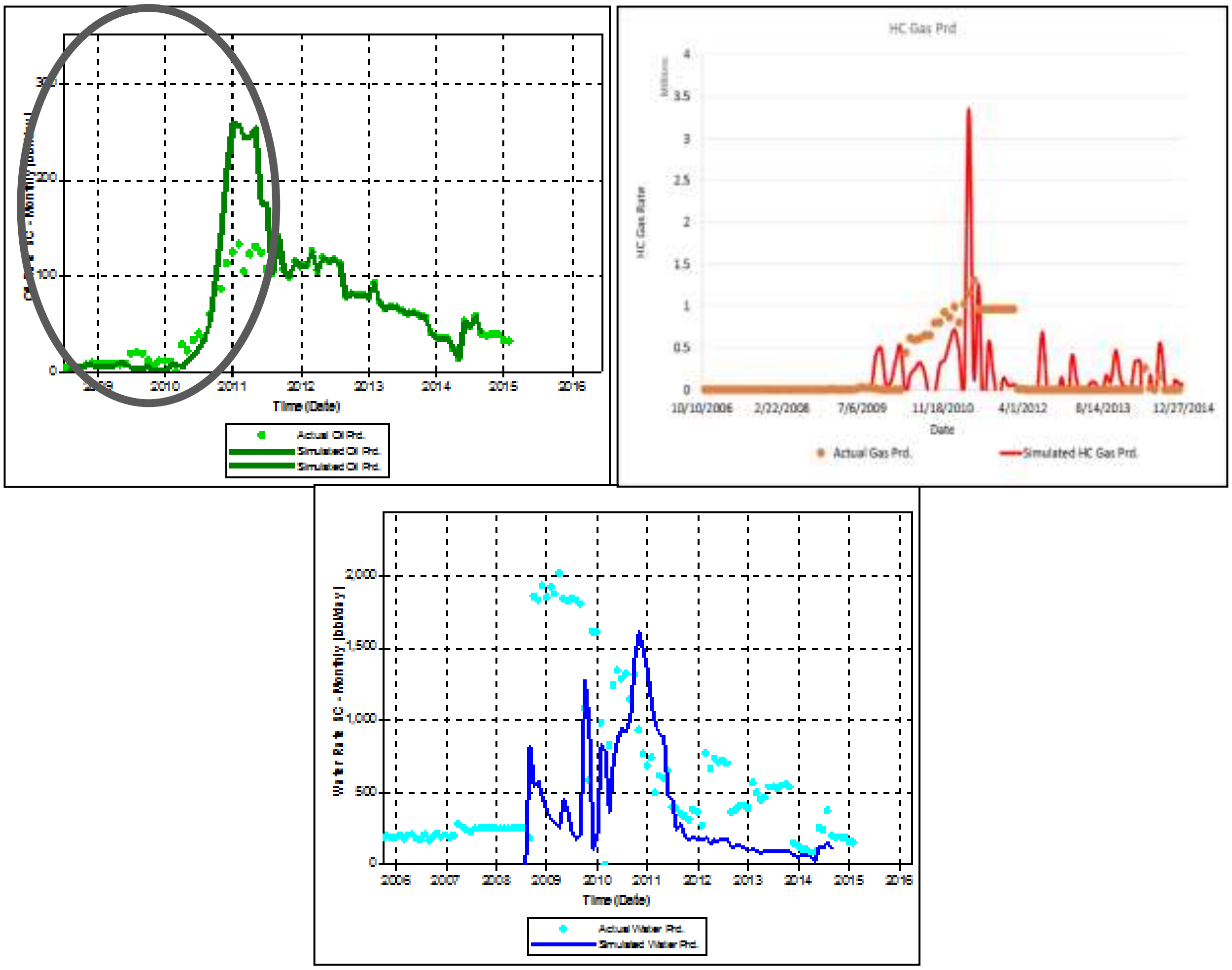

Figure 3.23.Oil, HC gas and water production in the ROZ for the #190 pattern (highlighting ramp up in oil production).

Figure 3.26 shows the amount of cumulative CO_2 injected in each ROZ layer. Layer 2 takes the biggest portion of the injected gas, while the lowest amount is injected in the bottom layer. The values obtained from tracer/spinner survey are in good agreement with the simulated injection values (Table 14). During almost 6 years of ROZ operation, it has produced about 140 Mbbls of oil which accounts for approximately 16% of OOIP in the ROZ section.

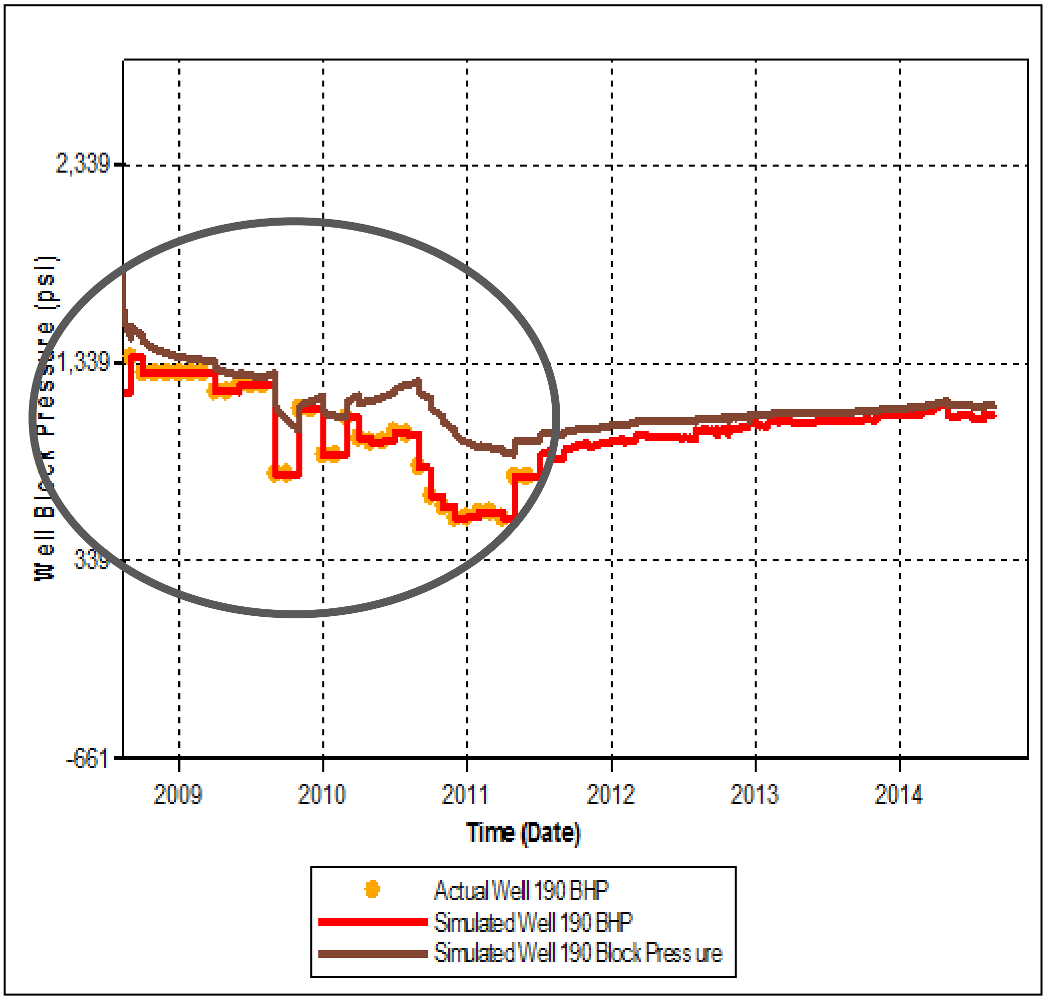

Figure 3.24. BHP and block pressure in well#190 (The circle highlights BHP control)

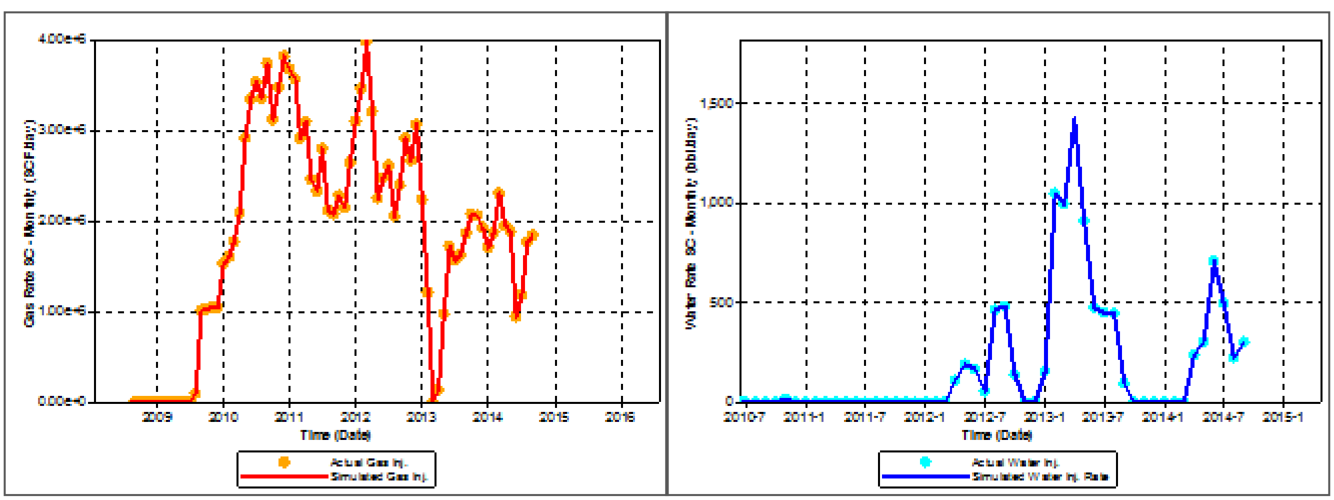

Figure 3.25. CO_2 and water injection in ROZ for the #190 pattern

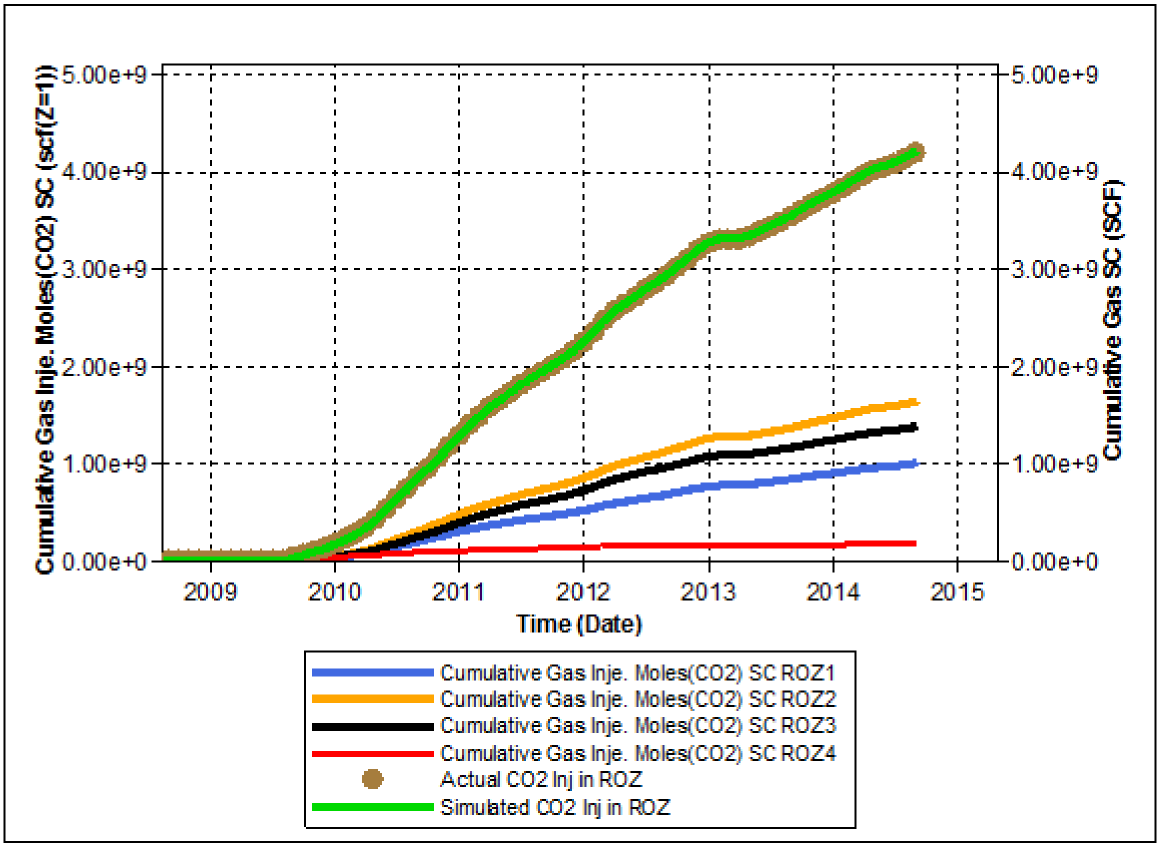

Figure 3.26. CO_2 injection per ROZ layer, #190 pattern

Table 3.14. Injection per layer - Spinner vs. Simulation

	Spinner Data		Simulation Results	
ROZ Interval	Volume CO2 Injection (MMcf)	% of Total Inj in Each Layer	Volume CO2 Injection (MMcf)	% of Total Injection in Each Layer
Top 20	1,110	25%	1,010	24%
Next 20	1,900	43%	1,637	39%
Next 40/50	1,170	26%	1,381	33%
Base 30	240	5%	186	4%
TOTAL	4,420		4,215	

Forecast Modeling

Following the history matching process, optimization scenarios were reviewed to understand the potential of the ROZ in this pattern. These scenarios include one waterflooding case, which assumes the pattern is mature and acts to displace the current EOR front to the production well and two water-alternating-gas (WAG) cases, which look at the potential upside of this pattern.

Similarly to the history matching effort, the forecast results for the streamtube model compared very favorably with those generated by the fully compositional model. The following highlights the results of these cases.

3.a.12 Case 1 – Water Flush

In this scenario, it is assumed that CO_2 operations are mature, with nearly one hydrocarbon pore volume (HCPV) of CO_2 injection having occurred. A 0.5 HCPV water flush is modeled to displace the injected CO_2 and oil to the production well, which then concludes injection operations. CO_2 and water Injection profiles are illustrated in Figure 3.26.

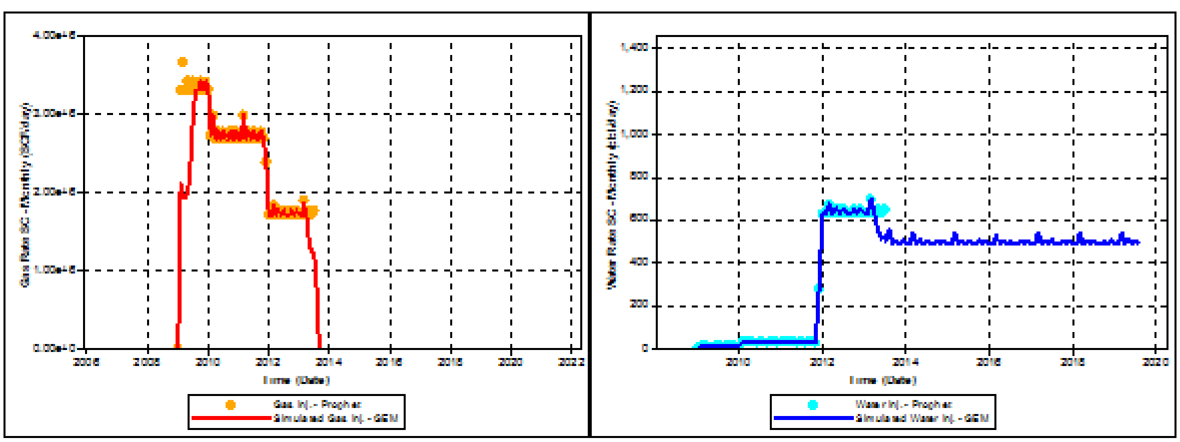

Figure 3.27. Gas injection (Left) and water injection (Right) profiles

Oil recovery forecast an additional 50 Mmbbls of oil production, bringing the total oil recovery to 202 MmBbls. This represents a recovery of nearly 24% of ROZ OOIP, which is comparable to the recoveries garnered in the Phase I model area. The total production obtained from the streamtube model was 182 Mmbls, which is within 10%.

3.a.13 Case 2 – Targeted Upper/Lower ROZ Development

This scenario is an idealized case with more consistent CO_2 injection and greater volumes of water injection. The upper three layers of the ROZ are flooded with 1 HCPV of CO_2. Once complete, the upper layers will be abandoned and the bottom layer will be opened and flooded. As shown in Figure 3.27, the first and second phase of this scenario take almost 4 and 5 years correspondingly, with the break in gas injection indicating the water flush for the upper portion of the ROZ. The producer minimum BHP is 900 psia.

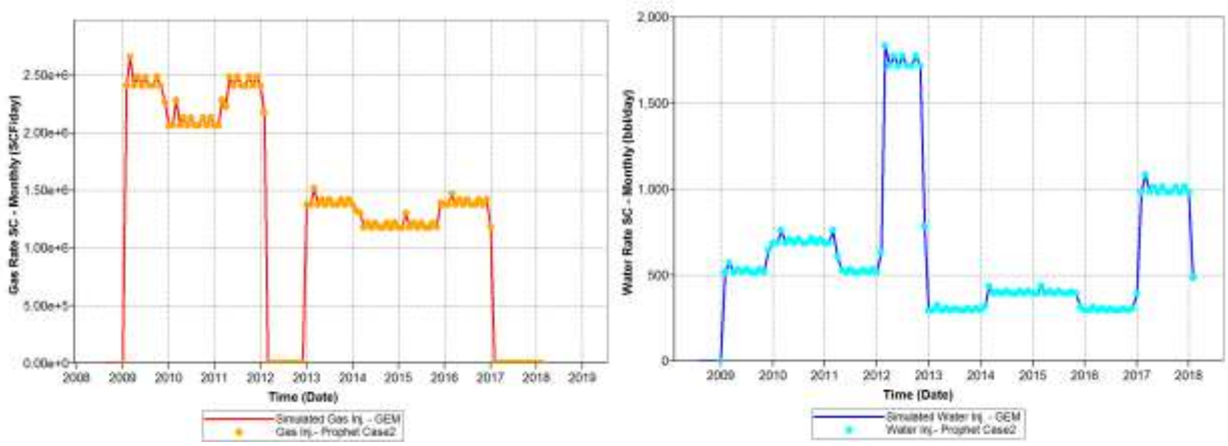

Figure 3.28.Gas (Left) and water injection (Right) profiles

The oil, water and total gas production rates are compare favorably, Figure 3.28. The cumulative oil production out of upper ROZ based on the compositional model and streamtube models was 288 MMbls and 278 Mbbls, respectively.

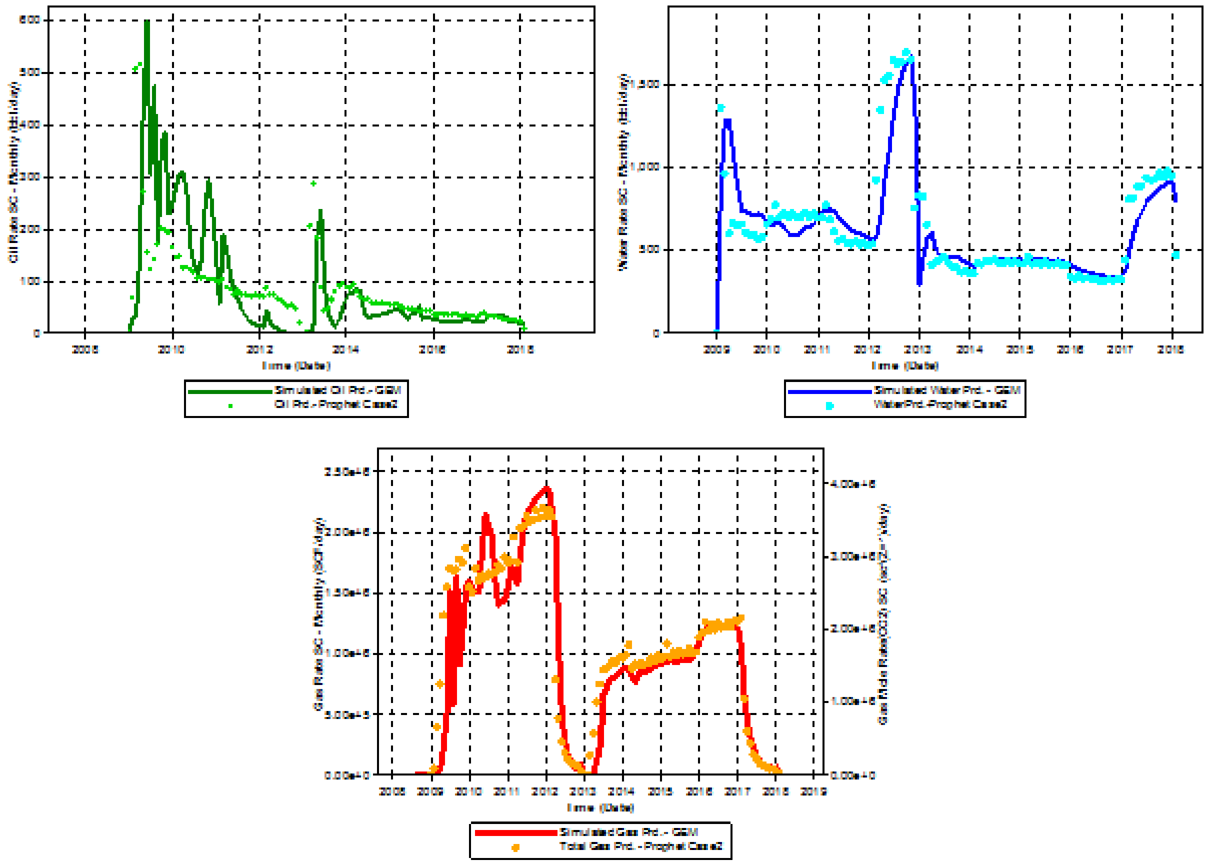

Figure 3.29. Oil (Top Left), water (Top Right), and total gas production (Bottom)

3.a.14 Case 3 – Injection in Full ROZ Pay Zone

While the previous scenarios explored variations on the existing field history, this scenario looks at injecting across the full ROZ horizon to explore how the upper ROZ would have responded to CO_2-EOR operations from the onset of development. As a result, all four layers are open to receive injection based on their petrophysical properties. Gas and water injection profiles are consistent as shown in Figure 3.30.

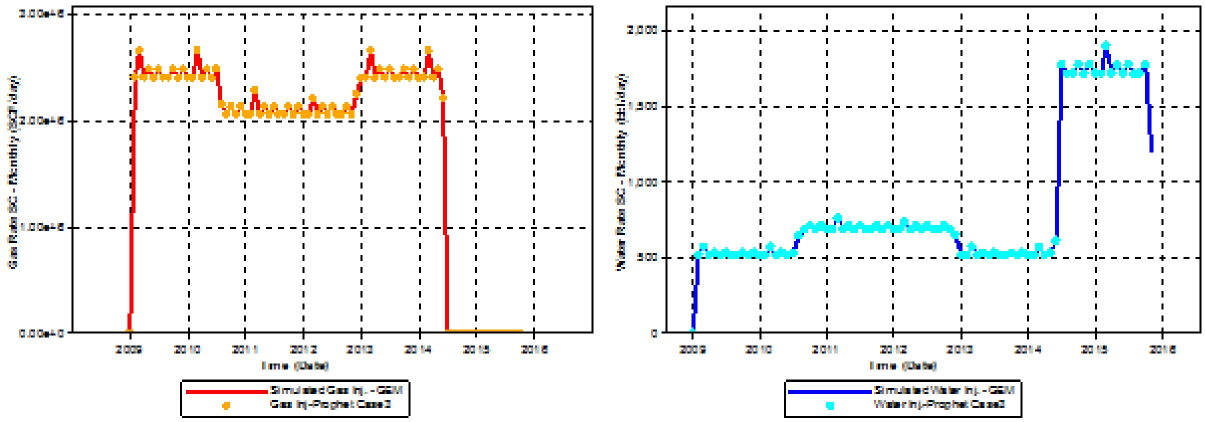

Figure 3.30. Gas (Left) and water injection (Right) in the upper ROZ

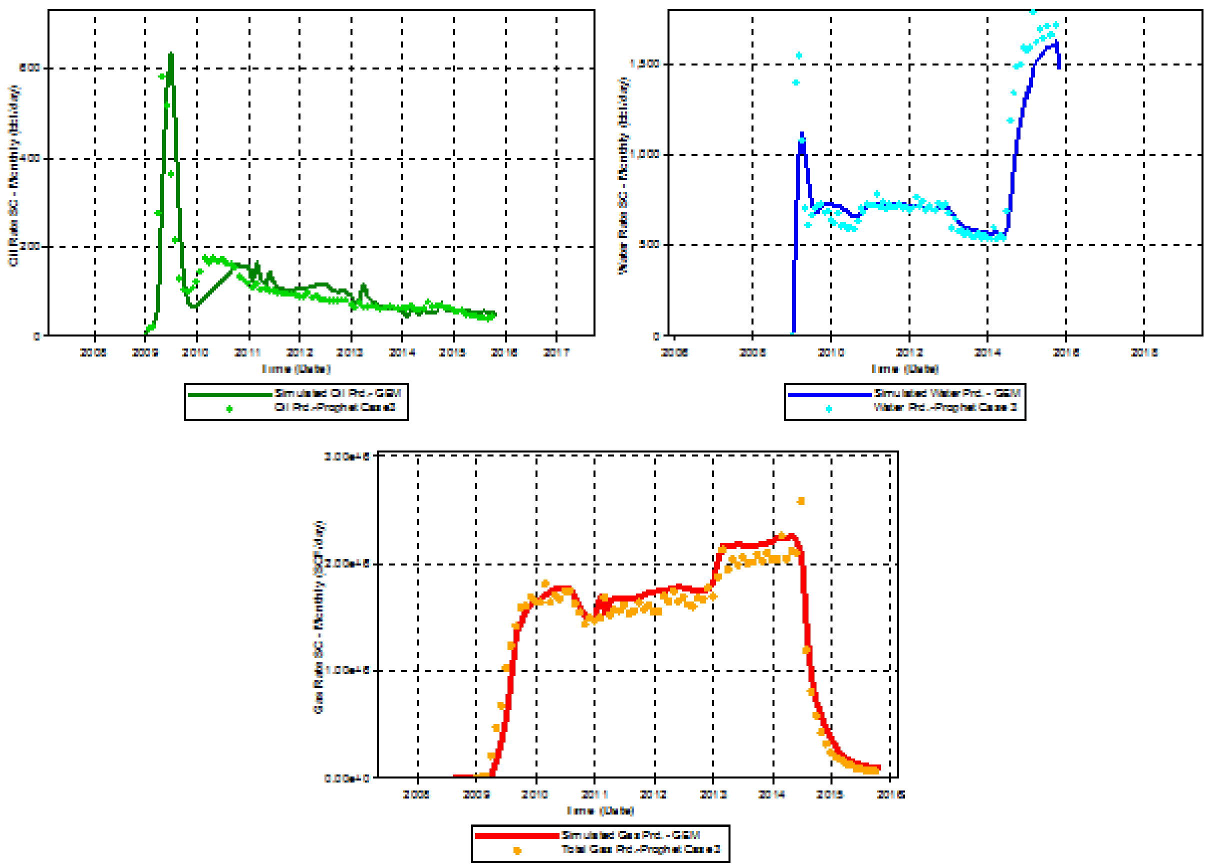

Figure 3.31. Oil (Top Left), water (Top Right), and total gas production (Bottom)

Figure 3.31 compares the oil, water, and gas production results of the streamtube and compositional models. Injecting 2,083 Mmbbls of water and 4,539 Mmcf of CO_2 results in 277 (33% of ROZ OOIP) Mbbls of oil production in the compositional model. The streamtube model compared favorably by producing 262 Mbbls of oil.

References – Section 3

Berry, A.; Trentham, B.; Stoudt, E, 2011, “Goldsmith Field Goldsmith Field: GLSAU Geology & Volumetrics” ,., Legado resources

Cantwell, D. 2011, “GLSAU MPZ and ROZ Development update –, SPE ROZ Symposium Midland, TX

Section 4 (Task 4) - Apply Next Generation Feedback and Control Technology to Optimize the CO_2 Flood

The use of CO_2 for Enhanced Oil Recovery was first applied at large scale in the 1970s but it was not until the mid-80s that a statistically meaningful number of CO_2 projects were underway to allow development of the first best practices on how to implement and operate a CO_2 flood. Since that time, many CO_2 production and operations techniques have evolved to become commonplace but it would be widely recognized that improvements are still being made and are needed to keep projects profitable especially in times of low oil prices. The U.S. Department of Energy recognizes that need, offers help in the way of public funding, and this project was identified as one they chose with great potential to advance the technologies of CO_2 flooding and, collaterally, carbon capture and storage.

The scope of this particular project was envisioned to tackle an exciting new development in CO_2 flooding.   The extension of CO_2 EOR to zones below the oil/water contact was just beginning and was encountering new challenges. This project attempted to tackle the new conditions in ROZ CO_2 flooding that had only been addressed in a fleeting fashion to date.

Initially, the specific techniques to investigate in the research were several. As the research project got underway, the selection of the next generation technologies had to go through a multi-dimensional screening process. The production and operational issues of producing the ROZ was new and unknown at first, the reservoir response of oil to CO_2 injection was unknown, had to be observed, and the peculiarities of the GLSAU surface and reservoir issues amply considered in the selection.

The challenges of producing the large volumes of water were one focus, the differing chemistry of the water in the ROZ as compared to the main pay zones (MPZs) was another, and the issues of conformance of injecting fluids with both the ROZ and MPZs open was clearly another. In order to tackle field issues such as these, the concerns and operational priorities of the industry partner, Legado Resources, were necessary to consider and their cooperation in the work was an absolute imperative. The project is indebted to Legado as a result, not only for their assistance in the project but for their help in identification of the priority challenges they were facing, especially early in the pilot and Phase I operations.

The second year of the research work identified a new artificial lift under development at a nearby CO_2 flood in a shallow, clastic reservoir that might have great promise to be useful in the deeper carbonate reservoir setting at GLSAU. The challenge of utilizing the new gas lift technique at GLSAU were many, not the least of which would be the differing water chemistries and depths of wellbores. Could the mechanisms of delivery of CO_2 to the producing wellbores allow less expensive conformance monitoring and/or be extended to delivery of scale inhibitors?

During the third year of the research the injection and reservoir response of the commingled ROZ and MPZ sections were offering challenges to the operator. Profile logs were required to assess conformance of injectant and, with the advantages of the new gas lift system, it was possible to profile log even the producing wells allowing them to be evaluated for fluid entry. Permission to acquire a large series of profiles logs were obtained and the project received access to the logs in order to assess effectiveness of injection into and production of oil from both the ROZ and MPZ intervals. The results of these two individual projects are reported herein in Section 4.b.

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Section 4.a: CO_2 Gas Lift Description and Designs

Task 4.a. Design and Implementation of a Next-Generation Lift System for a ROZ CO_2 Flood

CO_2 flooding is most generally commenced near the end of the water flood life of an oil recovery project. In this situation, the reservoir is being re-pressured from the depleted pressure conditions of the primary phase of production. As the water flood does its work and re-pressures the formation over many years or decades, it helps make for an easy transition from water as the injectant to CO_2. But unlike water used in the water flood, the CO_2 will mix with the oil, make it mobile and less likely to be bypassed like much of it was during the water flood. If the oil and pressures are right and the CO_2 flood is in a miscible condition, another 10-20% of the original oil in place can be produced.

CO_2 is often referred to as an energized fluid in the sense that it is dense like a liquid at reservoir conditions but has an extraordinary capacity for expansion as it converts to a gaseous state in the wellbore and as it approaches the surface. That specific attribute of CO_2 can allow a well to flow in contrast to the heavy, gas-less column required to be lifted in the wells during the water flood phase of production.

A flowing well offers savings in capital and operating costs that come from the avoidance of installations of a submersible or beam pump at each producing well, The only incremental cost is the CO_2 distribution line to the producing well and the energy attributable for compressing the small volume split-stream of CO_2 required for lifting the fluid column.

There are several methods of conveyance for delivery of the CO_2 to the producing well. In conventional gas lift as in an offshore well, casinghead gas is utilized as the lifting fluid and is delivered to the fluid column in the tubing from the annular volume by means of one of several mandrels (one way valves) emplaced on the tubing string. It requires pressuring up on the casing annulus and the gas is in contact with the internal surface of the casing. In the new CO_2 gas lift system described herein, the lifting fluid is sent below a packer near the bottom of the well via a capillary string and through a port in the packer assembly. The capillary string used to convey the CO_2 is strapped to the tubing string as it is installed in the well at the time of well completion. The use of the cap string is possible because of the dense nature of the CO_2 and necessity to isolate the CO_2 from the casing where corrosive carbonic acid could create casing integrity issues given a long term exposure to the casing.

4.a.1 CO_2 Gas Lift Description

Utilizing CO_2 as the lifting fluid is a new concept. Its fluid properties differ from the conventional hydrocarbon gas lift systems. In conventional gas lift, hydrocarbon gas will be delivered and produced all in a gaseous state. In the CO_2 gas lift system, the CO_2 is delivered to the well and to the bottom hole at a pressure above the critical pressure and temperature (supercritical state). As the lifting occurs, the CO_2 will change to a gaseous phase in the tubing string as the pressure falls and converts the CO_2 to a gaseous phase. As mentioned above the design of the CO_2 lift system takes advantage of the denser stage of pressurized CO_2 and the large expansion resulting from the conversion to gas phase.

The early experimentation with that critical property of CO_2 was accomplished at the Goldsmith-Landreth San Andres Unit (GLSAU) after its initial and successful testing at the North Ward Estes (NWE) project in Ward County[3] just to the West of GLSAU. The NWE gas lift application was a shallower reservoir and in a sandstone with greater permeability than the deeper San Andres carbonate reservoir at GLSAU. If the success

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[3] Payne, E (2012); "Chemical Treating and Gas Lift Simultaneously in Producing CO_2 Flood Wells (North Ward Estes), 2012 CO_2 Flooding Conference, Dec 2012, Midland, Texas. http://www.co2conference.net/wp-content/uploads/2012/12/04C-Payne_Whiting-CO2-Gas-Lift-12-6-12.pdf

achieved at NWE could be replicated at GLSAU, it could lead to a dramatically larger application in the larger numbers of San Andres Carbonate floods throughout west Texas and, perhaps, to deeper floods around the world.

One of the periodic expenses involved in a CO_2 flood has historically been the necessity of changing the artificial lift system for producing wells during the course of the CO_2 flood. Transition to a CO_2 flood from a water flood presents a whole different set of conditions to consider when artificially lifting the producing fluids. For one, it is a heavier water and oil column in a water flood. History shows that most operators will have chosen a submersible or beam pump artificial lift system in that phase of production. Occasionally progressive cavity pumps are used but their application has historically been limited to shallow conditions and they utilize a stainless steel rod design insert into an elastomer sheath. Adaptation to CO_2 flooding has not been successful owed to the tendency of CO_2 to penetrate into the elastomer and create swelling and causing failure of the lift system.

Hydraulic pumping systems have also been used in primary phases of production but can get complicated and require additional infrastructure. As a result, their application in both water floods and CO_2 floods have been rare.

Plunger lift systems are also used in the oilfield in primary production situations where gas is being produced with small volumes of liquid production. Their application in water flooding is rare due to the typically low volumes of gas and high liquid lift requirements. In a CO_2 flooding phase of production there is gas production present, but the episodic flow in plunger lift systems result in cycles of high instantaneous gas rates then no flow. In a CO_2 flood, the variable gas rates will provide complications for managing and metering the flow volumes.

Most often, at the start of a CO_2 EOR project, the active producing wells will be configured with either a submersible or beam pump. The conventional practice has been to adapt that existing lift system to the new CO_2 phase of production. Some downhole metallurgy and/or elastomer replacement may be accommodated via a well workover but the lift system left in place.

When CO_2 begins to be produced with the oil in a CO_2 flood at some point after converting to CO_2 injection, the beam or submersible pump will see more gas entry causing a tendency for 'gas locking' of the pump. This may require the downhole configuration of the pump to have to be changed, often several times, creating the expense of multiple workover operations.

The installation of a CO_2 lift system at the onset of the CO_2 flood can avoid the necessity of the pump changes and remedial workovers. Once installed, it can immediately provide the necessary lift to create a flowing well, even prior to CO_2 being produced with the oil. The lightening of the column with the injected, energized CO_2 with its volumetric expansion, allows the well to flow. Later on in the project and as the produced fluids include CO_2, the fluid column gets lighter and the well can begin to flow on its own. The capillary gas lift volumes can be turned off at that point. The result of providing CO_2 gas lift at the onset of the flood will be that the producing well workovers, so common to the submersible and beam pump installations, can be almost completely avoided.

A second auxiliary benefit of adopting a CO_2 gas lift system that has proven immensely valuable has been the ability to use a second capillary string to deliver chemical treatments downhole to inhibit scale deposition or corrosion developing in the tubing string. As it has evolved, the CO_2 gas lift system solution has come along at the perfect time as many floods have begun to deepen the productive interval into the ROZ. In the Permian Basin, the ROZ possesses more sulfate rich waters in contrast to the MPZ with its chloride rich waters. The greater downhole gas expansion and cooling that accompanies CO_2 breakthrough to the producing wellbores (Joule–Thomson effect) can aggravate the tendency for scaling. The combination of the variable and sulfate rich water along with the wellbore cooling is a recipe for downhole scaling. It can also aggravate and asphaltene deposition but the scaling issue has been the predominate one and occurs in many of the wells. In the early phases of the GLSAU project, the operator encountered scaling up of the tubing strings in many producing wells necessitating a relook at the artificial lift design and encouragement to develop a capillary tube delivery system for both lifting the fluids and delivery of scale inhibitors.

4.a.2 CO_2 Gas Lift Design and Economics

The initial trials of a CO_2 Gas Lift system were at the North Ward Estes (NWE) field and were developed for a shallower configuration and a clastic reservoir. The project's challenge was to extrapolate the design to GLSAU while taking advantage of the lessons learned at NWE but allowing for some significant differences (e.g., depth, lithology, etc) that had to be considered.

Table 4.1 provides key design parameters used at both the GLSAU and NWE floods for the CO_2 lift system while highlighting the changes in the two differing reservoir characteristics. Note that the depths of deployment had to be extended to 4100' at GLSAU and to the carbonate environment so frequently CO_2 flooded in the Permian Basin. One of the exciting developments was to determine that the capacity to lift as much as 2000 barrels of liquid per day was possible even when utilizing the 2 3/8th inch tubing strings that were the common carryover from the water flood.

One key design consideration involved sizing the production tubing as closely as possible to expected produced liquid volumes to achieve the optimal efficiency. A steady flow to the surface is always preferable to cyclic flow as liquid fall back can occur otherwise.

TABLE 4.a.1 - CO_2 Gas Lift Design and Reservoir Characteristics

	GLSAU	NWE	Units
Depth of Formation	4100	2500	feet below surface
Formation Lithology	Carbonate	Sandstone	
Average Reservoir Porosity	12	16	Percent
Average Reservoir Permeability	32	37	Millidarcies
Reservoir Temperature	95	83	Degrees F
Typical Liquid Production/Well	~ 200	~ 250	blpd
Maximum Liquid Production/Well	~ 1000	~ 2000	blpd
Average Produced Gas CO_2 Composition	85	95	Percent
Avg H_2S Concentration	~1500	~1500	PPM
Oil Gravity	35	~37	Degrees API
Oil Viscosity	1.3	1.6	Centipoise
Water Spcific Gravity Range	1.05-1.15	1.05–1.14	gpcc
Active Gas Injectors (Producing Wells)	25	150	
Average Gas Lift Volume to Producer Well	40	40	mcfpd
Typical Startup Gas Lift Ratio	500	500	mcf/bbl (gas/liquid Ratio)
Ave. CO_2 Surface Distribution System Pressure	1800	1400	psi
Ave. Bottomhole Delivery Pressure	3300	2100	psi
Percent of Wells no Longer Needing CO_2 Lift	0	70	Percent
Minimum Casing or Liner Size	4	4	Inches
Typical Tubing Size	2 5/8	2 3/8	Inches

One of the convenient features of the CO_2 gas lift is that the lifting volume sent downhole can be controlled with the use of surface chokes. Using too little gas has the obvious issue of not providing the lift energy for the produced fluid column and using too much lift gas can possibly reduce reservoir fluid production by over displacing the production tubing with CO_2 instead of the desired reservoir fluids. By carefully monitoring well production, one can quickly find the range of optimal CO_2 injection volumes.

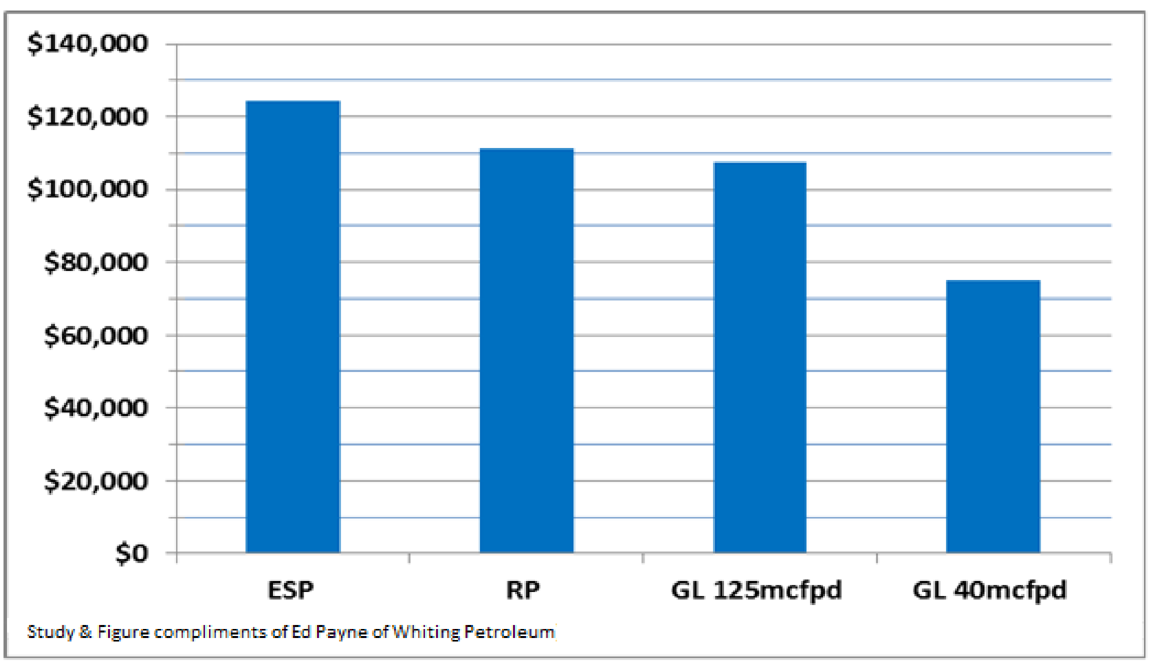
Experimentation with the capillary tubing composition has seen an evolution to the current preferred scheme of 3/8ths or 5/8ths inch (outer diameter) stainless (2205 duplex) steel tubing coil tubing strapped externally to the 2 3/8ths or 2 5/8ths (outer diameter) inch tubing strings. Each of the conveying compositions/modes is discussed below with the challenges and shortcomings mentioned for each.

1. Utilization of 3/8" Stainless Steel Coil Tubing (2205 Duplex) via a commercial coil tubing rig to drive the capillary string concentrically *inside* the production tubing. This approach led to capillary tubing failures due to the coil rig drive and sand damage in the NWE application (see Fig, 4.3).
2. A second approach used 5/8" thermal polymer plastic coil tubing with a pump truck and swab cup mandrel to pump the capillary string concentrically inside the production tubing. This less stable tubing saw occasional capillary tubing collapse failures due to cyclic flow conditions
3. A third approach utilized 5/8" thermal polymer plastic capillary string installed with a "home-made" rig with 1 ¼" weight bars to gravitate the capillary string concentrically down inside the production tubing. This approach observed scale and asphaltene build-up around the capillary tubing strings.
4. Finally, the fourth and chosen approach that evolved utilizes banding of 5/8" or 3/8" 2205 duplex to the outside of the production tubing for the gas lift. A specially designed packer assembly with the capillary string ports was required. This configuration allows for a second or even third capillary tube that can be installed simultaneously for chemical treating (scale, paraffin, asphaltenes).

Capital and operating costs always drive artificial lift decisions in the oilfield. Figure 4.1 illustrates the capital well cost comparisons for a condition of 250 barrels of liquid production for an electric submersible pump (ESP), a typical rod pump (RP) configuration, the fourth gas lift design above requiring 125 mcf per day of CO_2 (GL 125mcfpd), and a second gas lift design requiring the more typical 40 mcfpd (GL 40mcfpd).

Operating costs are also critical and the experience to date has shown that the well failure rates of ESP and rod pumps in the CO_2 flood conditions are typically 0.5 failures per well per year while the CO_2 gas lift (and flowing wells due to gas lift) are less than half (0.2 failures/well/year). While these numbers are representative and are used herein, it is important to remember that costs and failure rates can vary significantly with well and surface equipment age and when well control issues are acute. One should remember that there are conditions that can lead to even greater operational and capital savings when using CO_2 lift system. They are operating the lifts in high gas to liquid ratio wells where corrosion and other chemical treating conditions are necessary, where

Figure 4.1 – Lift System Capital Cost Comparisons



voltage fluctuations in the field are common leading to submersible pump or surface pumping unit failures, and when the producing fluids create precipitates, sand, scale, or asphaltene that can interfere with downhole pumps.

Figures 4.2– 4.4 provide photographs of the CO_2 lift system to familiarize the reader with its design and deployment.

Figure 4.2 - Concentrically Installed Gas Lift – Methods 1-3

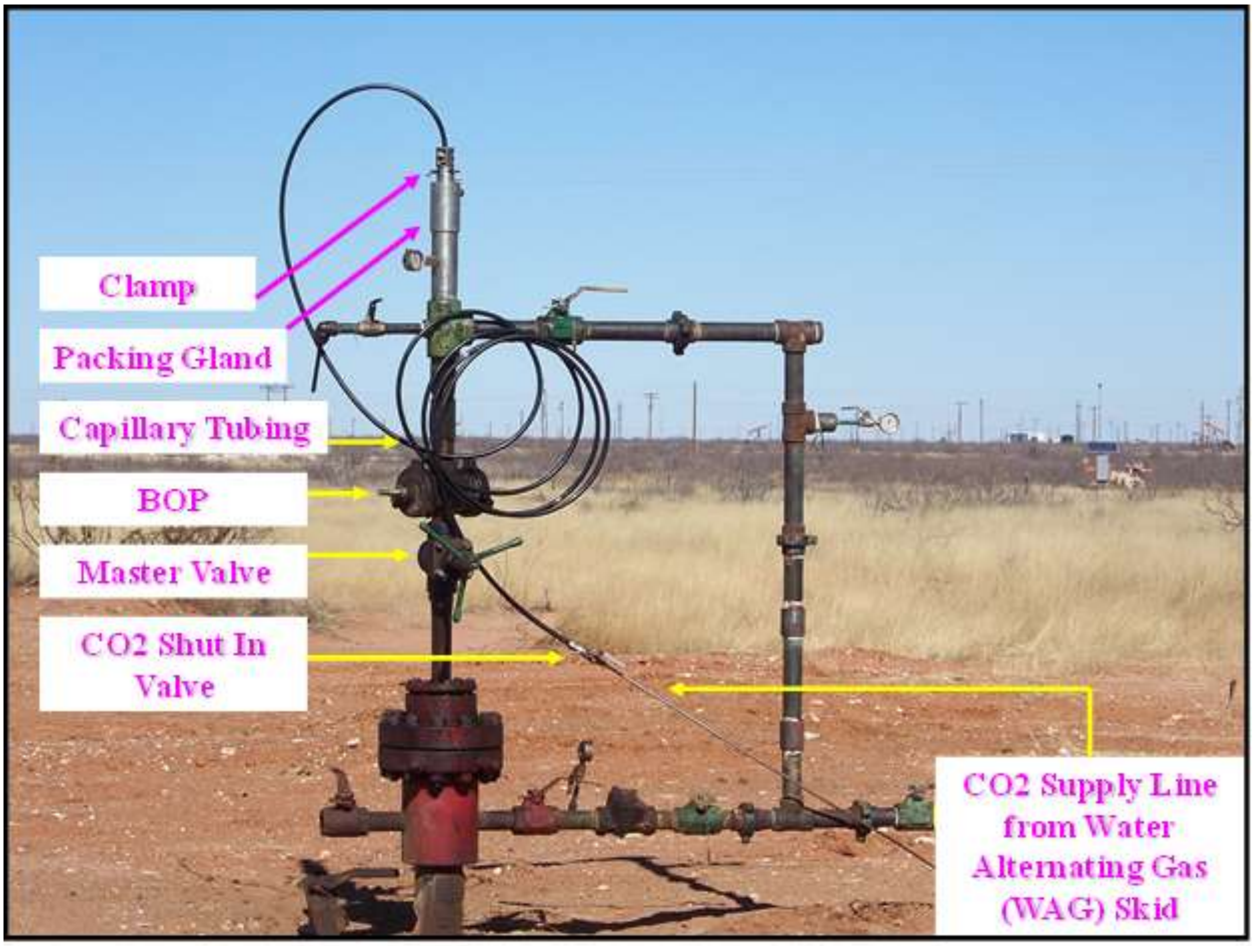
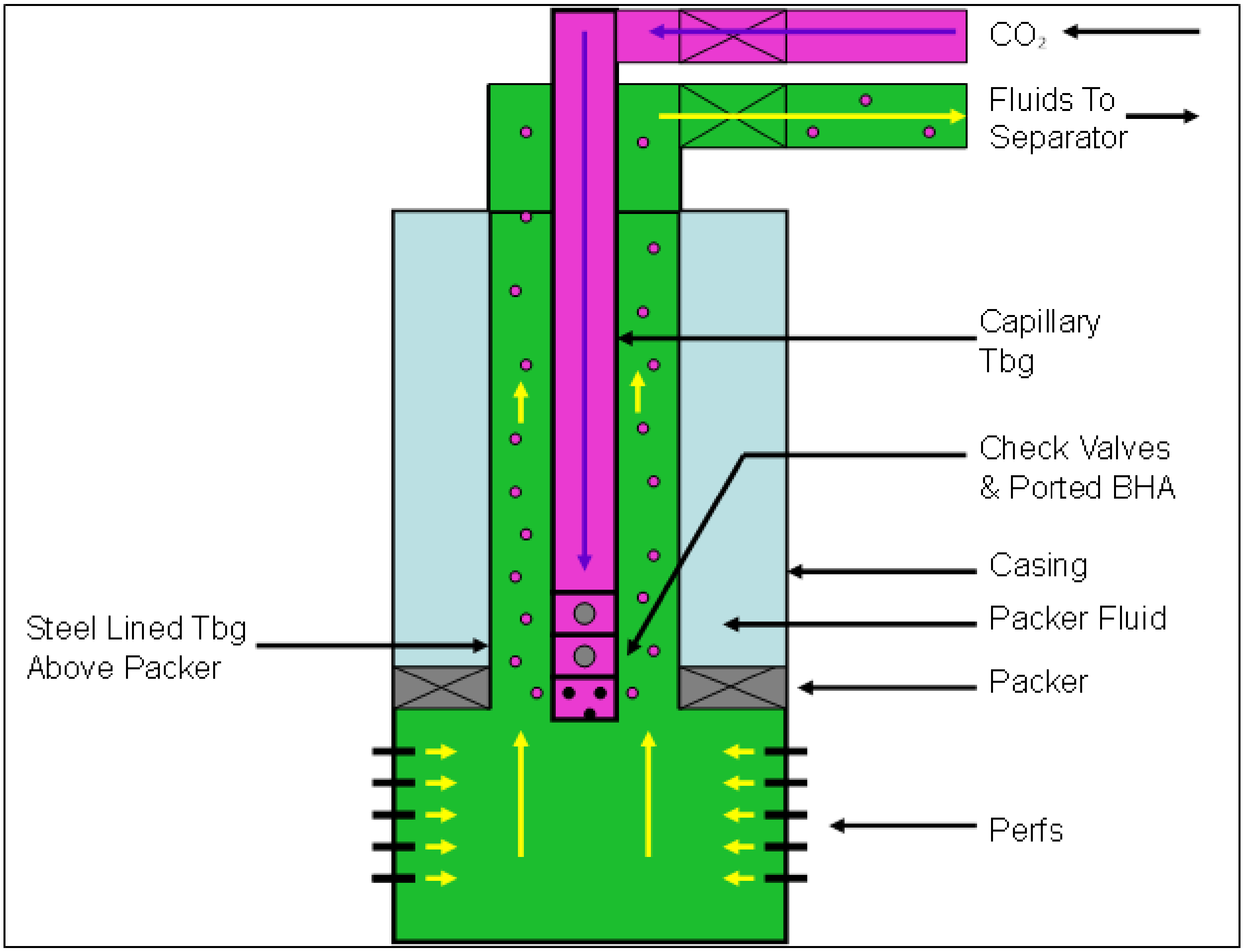


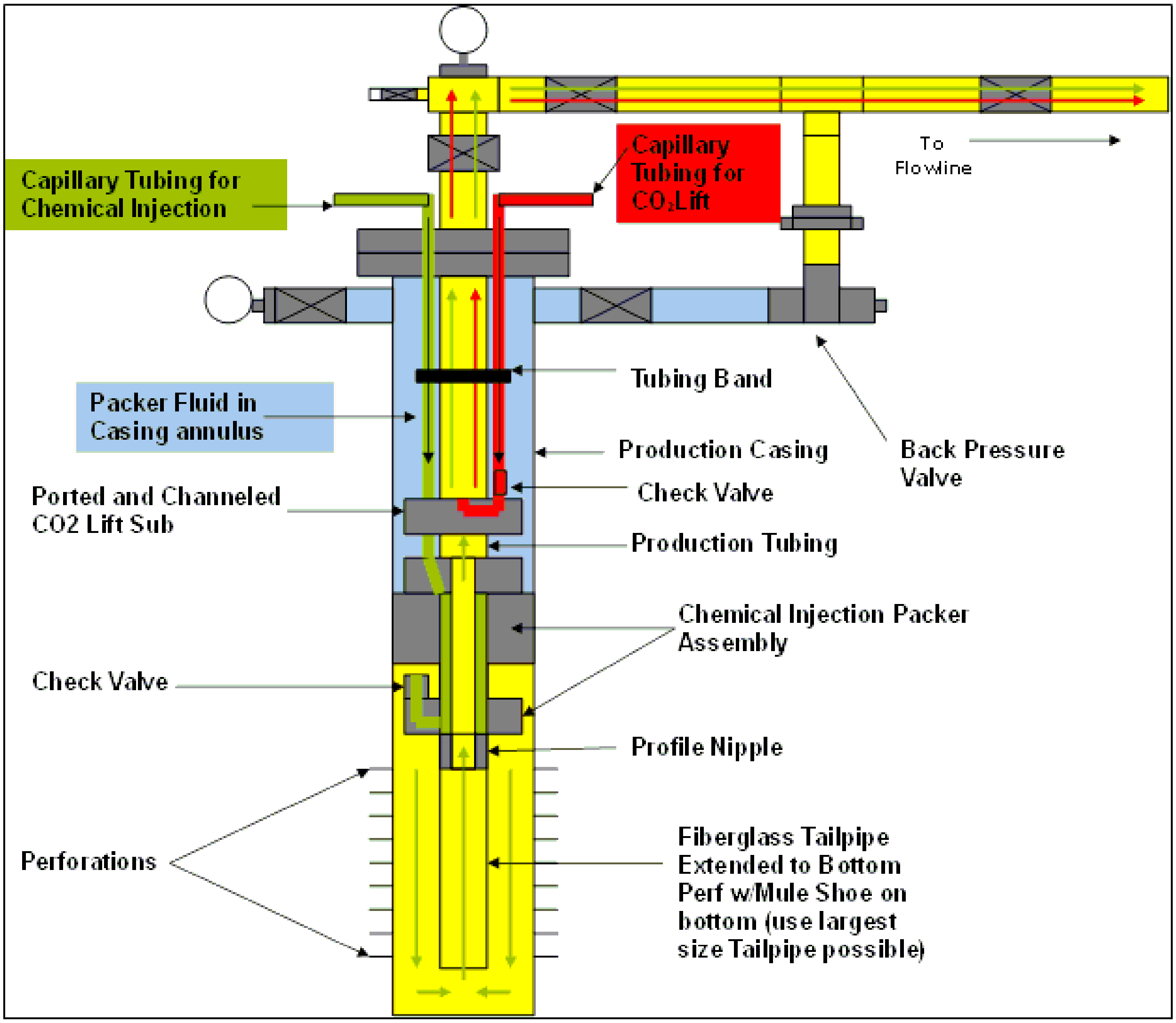
Photo Courtesy of Ed Payne, Whiting Petroleum

Figure 4.3 - Flowing Well with Concentric Gas Lift Installed



Drawing Compliments of Ed Payne of Whiting Petroleum

Figure 4.4a - Exterior Banded Capillary Tube System – Selected Method



Drawing Compliments of Ed Payne, Whiting Petroleum

Figure 4.4b - Exterior Banded Capillary Tube System – Selected Method

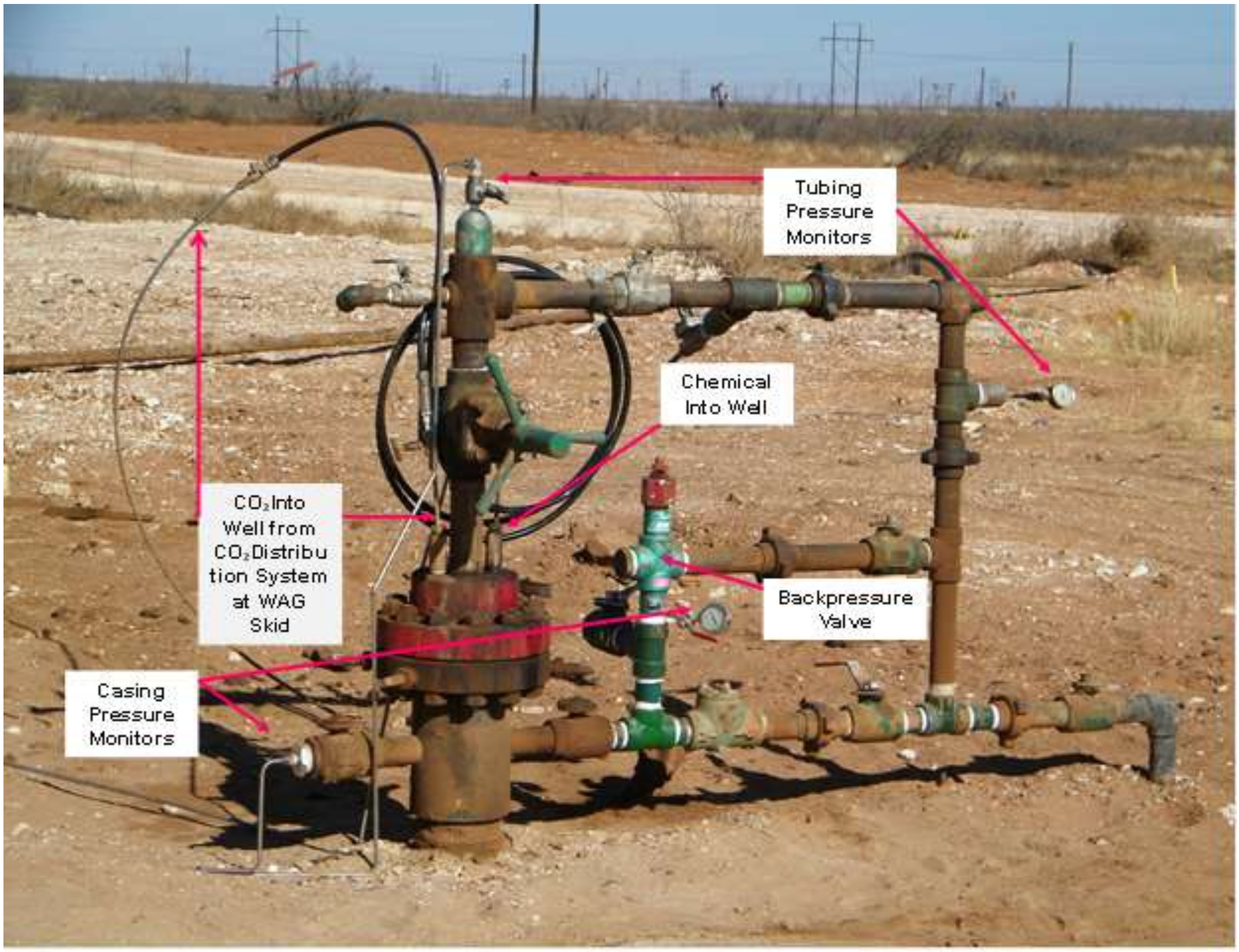


Photo Courtesy of Ed Payne, Whiting Petroleum

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Payne, E (2012); "Chemical Treating and Gas Lift Simultaneously in Producing CO_2 Flood Wells (North Ward Estes), 2012 CO_2 Flooding Conference, Dec 2012, Midland, Texas. http://www.co2conference.net/wp-content/uploads/2012/12/04C-Payne_Whiting-CO2-Gas-Lift-12-6-12.pdf

Section 4b: Profile Logs and Modeling Effort

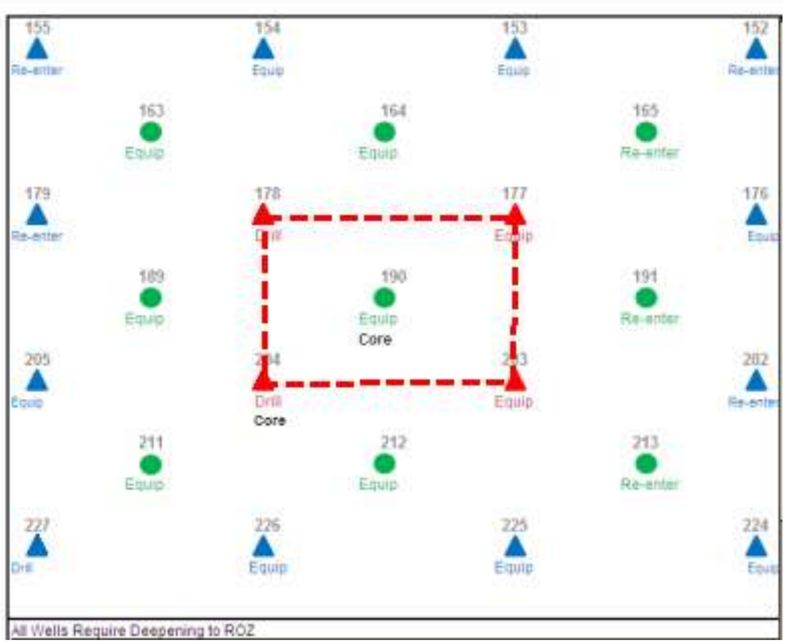
Task 4b. Monitoring and Surveillance of the ROZ/MPZ CO_2 Flood at the Goldsmith-Landreth San Andres Unit, Ector County, Texas

4.b.1. Summary

4.b.1.1 Introduction. In the GLSAU "Study Area", 55 Bcf of CO_2 has been injected into 16 CO_2 injection wells, with 36 Bcf entering nine confined production patterns, Figure 4.5. The primary concern is: "To what extent is the CO_2 being injected into the formation processing the high resource concentration intervals of the reservoir?"

Comparing the vertical distribution of CO_2 and the vertical location of the remaining oil in-place in the MPZ and ROZ would provide valuable insights with which to address this concern as well as the effectiveness of the CO_2 flood.

Figure 4.5. GLSAU ROZ "Study Area"



Source: Legado Resources, 2010.

4.b.1.2 Key Research Questions. A series of CO_2 injection profiles were conducted in the GLSAU "Study Area" to address this concern as well as the following research questions:

What portion of the injecting CO_2 is entering and flooding the MPZ, the ROZ and/or other (unproductive) reservoir intervals?

How does the choice of well completion practices - - (1) open-hole, (2) partially cased and perforated plus open-hole, (3) cased/perforated dual interval, and (4) cased/perforated single interval completions - - impact the placement and profile of injected CO_2?

What is the actual vertical profile of the injected CO_2 within the MPZ and within the ROZ? Are there significant intervals of net pay in the MPZ or the ROZ not being efficiently contacted by CO_2?

To what extent does the CO_2 and its contact within the MPZ and ROZ profile change with time?

4.b.1.3 GLSAU's Interest in Simultaneous MPZ/ROZ Development. The GLSAU project has considerable interest in determining whether simultaneous injection of CO_2 into both the MPZ and the ROZ would prove to be feasible:

> The Goldsmith-Landreth project is a little different from other quaternary efforts because Legado is, from the onset of CO_2 flooding, simultaneously injecting into both the MPZ and the deeper ROZ in an attempt to produce both at the same time, points out Tom Thurmond, Engineering Manager.
>
> "I believe we are the first to develop the ROZ contemporaneously with the MPZ. It is an opportunity to do something that, on one hand, has not been done before, but on the other hand, is an extension of technology that has been around for 30 years. We have made that our niche, doing something that is a little bit new by taking existing technology and expanding its application."
>
> Source: **American Oil & Gas Reporter December 29, 2011**

4.b.1.4 Viability of Simultaneous MPZ/ROZ CO_2-EOR Development. For purpose of operational ease and lower costs, a CO_2-EOR project would prefer to conduct a joint MPZ/ROZ CO_2 flood, using a single CO_2 injection well dually completed in both the MPZ and ROZ, as opposed to using individually dedicated MPZ and ROZ CO_2 injection wells (or completion designs). Additional cost savings would accrue if an operator could continue to use existing open-hole well completions rather than having to rework the wells to provide a more controlled setting for CO_2 injection using casing and perforations.

One of the main purposes of the CO_2 injection profile surveys was to examine the influence of well completion practices on CO_2 injection and flow for a joint MPZ/ROZ CO_2 flood. In addition to helping understand the impact of well completion practices on the distribution of CO_2 among the MPZ, the ROZ and other reservoir intervals, the CO_2 tracer surveys can be used to understand how the injected CO_2 is distributed within the MPZ and within the ROZ.

4.b.1.5 The CO_2 Tracer Program. As part of the reservoir surveillance and monitoring research program, 42 CO_2 injection profile surveys were conducted in the 16 CO2 injection well, 9 production pattern GLSAU "Study Area."

Each of the 16 CO_2 injection wells received at least one CO_2 profile survey (consisting of tracers placed into the injected CO_2 stream), with most wells receiving multiple CO_2 surveys, including:

CO_2 profile surveys before and after well remediation,
CO_2 profile surveys before and after changes in well completion, and
Time-lapse CO_2 profile surveys to track changes in the entry and location of CO_2 with time.

4.b.1.6 Impact of Well Completion Practices on CO_2 Distribution. With four distinct well completion practices applied in the 16 CO_2 injection wells, the GLSAU "Study Area" provides a rich data set for examining the impact of well completion practices on CO_2 injection and reservoir contact:

Seven wells with open-hole (OH) completions in both MPZ and ROZ,
Three wells partially perforated in the MPZ, with rest of the MPZ and ROZ OH,
Two wells cased and perforated in both the MPZ and ROZ, and
Seven wells cased and perforated in ROZ only.

Figure 4.6. CO_2 Tracer Profiles in Open Hole MPZ and ROZ CO_2 Injection Well Completions

(A) Well #202W | (B) Well #205W

Tracer Survey #1: Mar. 31, 2010 | Tracer Survey #3: Dec. 6, 2012

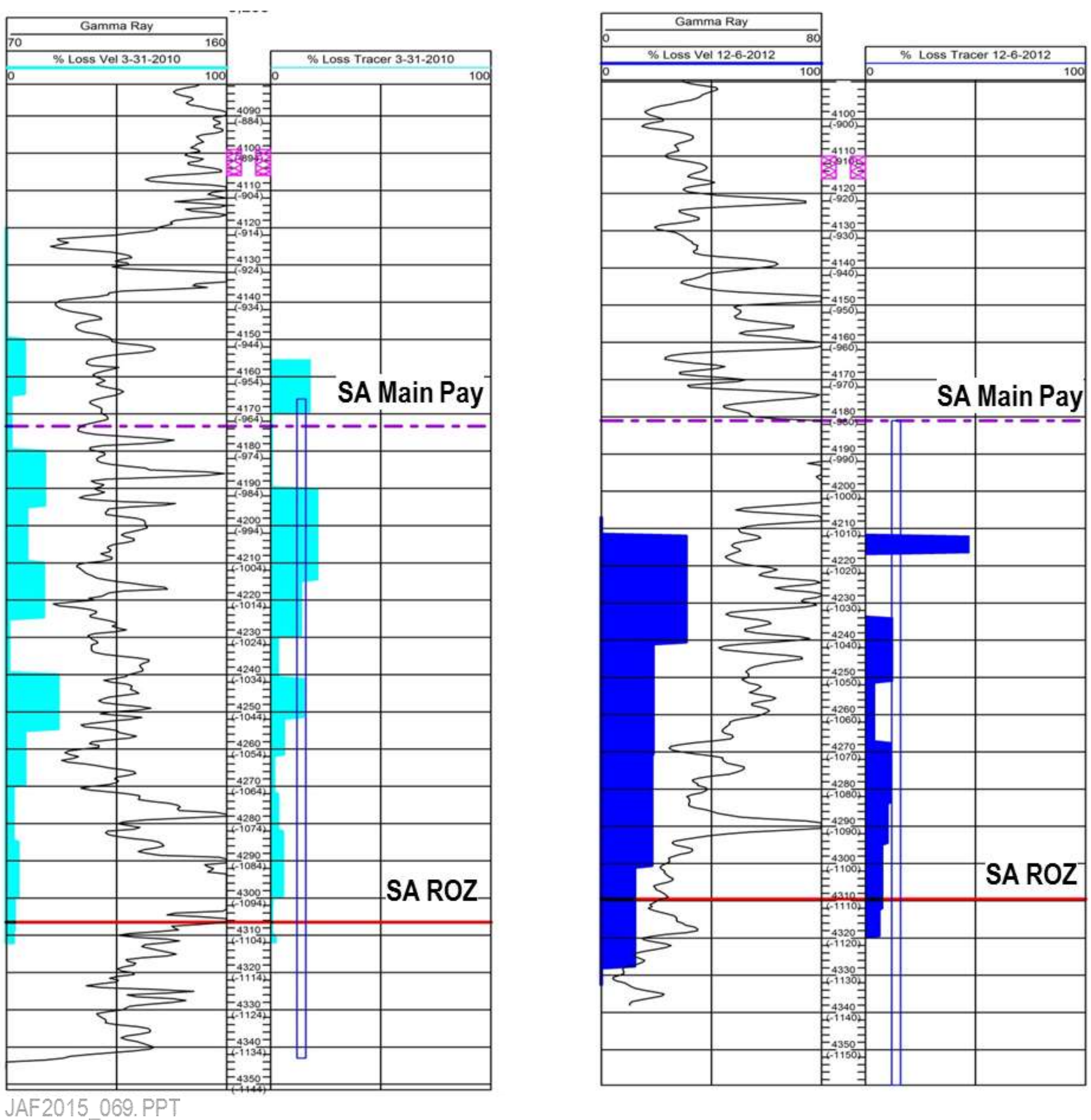


Table 4.2. Impact of Well Completion Practices on CO_2 Distribution.

Reservoir Interval	Type of CO_2 Injection Well Completion			
	OH	Partial Perf Plus OH	Dual MPZ/ROZ	ROZ Only
	(% CO_2)	(% CO_2)	(% CO_2)	(% CO_2)
Gas Cap	7%	25%	6%	0%
MPZ	72%	48%	77%	1%
ROZ	19%	20%	17%	99%
Other	2%	7%	0%	0%

The two figures (Figure 4.6A and 4.6B) illustrate the CO_2 injection profiles for two open hole wells - - Well #202W and Well #205W.

In Well #202W, the injected CO_2 is concentrated in the MPZ with very little entering the ROZ.
In Well #205W, the injected CO_2 is concentrated in the middle and lower portions of the MPZ, with some CO_2 entering the top of the ROZ.

The CO_2 profile surveys at GLSAU show that without direct control over the entry points of CO_2 injection, such as by using a "ROZ only" well completion, the great bulk of the injected CO_2 will enter and process the MPZ, Table 4.2.

4.b.1.7 CO_2 Injection into the GLSAU "Study Area". Table 4.3 below, tabulates the volume of injected CO_2 and the distribution of the injected CO_2 for: (1) each of the nine production patterns in the GLSAU "Study Area" and (2) the distribution of the injected CO_2 into the MPZ and ROZ. Tables 4.4 and 4.5 provides the detailed CO_2 injection and flow profiles for the four CO_2 injection wells in the ROZ "Pilot Test" (Pattern #190).

Table 4.3. CO_2 Injection into the GLSAU "Study Area"

CO2 Injection	GLSAU "Study Area": CO2 Volume by Production Pattern (Bcf)									TOTAL (Bcf)
	#163	#164	#165	#189	"Pilot Test" #190	#191	#211	#212	#213	
2009	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.2	0.0	**0.7**
2010	0.3	0.6	0.3	0.6	1.3	0.7	0.4	0.9	0.5	**5.6**
2011	0.5	1.0	1.1	0.5	1.1	1.2	0.5	1.1	1.1	**8.2**
2012	0.6	1.0	1.1	0.7	1.2	1.3	0.6	1.3	1.0	**8.8**
2013	0.3	0.6	0.9	0.6	0.6	0.7	1.1	1.1	0.9	**6.8**
2014	0.4	0.4	0.5	0.6	0.7	0.6	0.9	0.7	0.7	**5.5**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**
Gas Cap	13%	10%	8%	4%	2%	5%	4%	3%	5%	**5%**
MPZ	34%	28%	31%	34%	13%	14%	67%	37%	26%	**30%**
ROZ	42%	58%	45%	58%	84%	68%	29%	60%	68%	**59%**
NonPay	11%	3%	17%	3%	0%	13%	0%	1%	2%	**5%**
Gas Cap Volume	0.3	0.4	0.3	0.1	0.1	0.2	0.1	0.1	0.2	**1.9**
MPZ Volume	0.7	1.0	1.2	1.1	0.7	0.6	2.5	1.9	1.1	**10.8**
ROZ Volume	0.9	2.1	1.7	1.9	4.4	3.2	1.1	3.1	2.8	**21.2**
NonPay Volume	0.2	0.1	0.6	0.1	0.0	0.6	0.0	0.0	0.1	**1.8**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**

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Table 4.4. CO_2 Injection and Flow Profile: ROZ “Pilot Test” (Pattern #190)

CO2 Injection Profile for Production Pattern #190									
Injector Well 177				**Injector Well 178**				**Injector Well 203**	
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
Gas Cap	0%	0%	0%	Gas Cap	0%	0%	0%	Gas Cap	0%
MPZ	0%	16%	8%	MPZ	2%	0%	1%	MPZ	0%
ROZ	100%	84%	92%	ROZ	98%	100%	99%	ROZ	100%
NonPay	0%	0%	0%	NonPay	0%	0%	0%	NonPay	0%
Gas Cap Interv	4144-4174			Gas Cap Interval	4146-4176			Gas Cap Interval	4140-4180
(ft from top)				(ft from top)				(ft from top)	
10	0%	0%	0%	10	0%	0%	0%	10	0%
20	0%	0%	0%	20	0%	0%	0%	20	0%
30	0%	0%	0%	30	0%	0%	0%	30	0%
40	0%	0%	0%	40	0%	0%	0%	40	0%
MPZ Interval	4174-4285			MPZ Interval	4176-4285			MPZ Interval	4180-4295
MPZ				MPZ				MPZ	
(ft from top)				(ft from top)				(ft from top)	
10	0%	0%	0%	10	0%	0%	0%	10	0%
20	0%	0%	0%	20	0%	0%	0%	20	0%
30	0%	0%	0%	30	0%	0%	0%	30	0%
40	0%	0%	0%	40	0%	0%	0%	40	0%
50	0%	16%	8%	50	0%	0%	0%	50	0%
60	0%	0%	0%	60	0%	0%	0%	60	0%
70	0%	0%	0%	70	0%	0%	0%	70	0%
80	0%	0%	0%	80	0%	0%	0%	80	0%
90	0%	0%	0%	90	0%	0%	0%	90	0%
100	0%	0%	0%	100	0%	0%	0%	100	0%
110	0%	0%	0%	110	2%	0%	0%	110	0%
120	0%	0%	0%	120	0%	0%	1%	120	0%
130	0%	0%	0%	130	0%	0%	3%	130	0%
Injector Well 177				**Injector Well 178**				**Injector Well 203**	
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
ROZ Interval	4285-4400			ROZ Interval	4285-4400			ROZ Interval	4295-4407
ROZ				ROZ				ROZ	
(ft from top)				(ft from top)				(ft from top)	
10	11%	0%	6%	10	6%	0%	3%	10	16%
20	23%	69%	46%	20	6%	15%	11%	20	6%
30	66%	15%	40%	30	22%	15%	19%	30	23%
40	0%	0%	0%	40	14%	10%	12%	40	36%
50	0%	0%	0%	50	16%	18%	17%	50	5%
60	0%	0%	0%	60	15%	12%	13%	60	3%
70	0%	0%	0%	70	0%	5%	2%	70	1%
80	0%	0%	0%	80	7%	11%	9%	80	10%
90	0%	0%	0%	90	12%	13%	13%	90	0%
100	0%	0%	0%	100	0%	0%	0%	100	0%
110	0%	0%	0%	110	0%	0%	0%	110	0%

Table 4.5. CO_2 Injection and Flow Profile: ROZ "Pilot Test" (Pattern #190)

CO2 Injection Profile for Production Pattern #190							June 30, 3015
Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
Gas Cap	0%	0%	0%	19%	4%	11%	
MPZ	0%	0%	0%	47%	61%	54%	
ROZ	100%	100%	100%	34%	35%	35%	
NonPay	0%	0%	0%	0%	0%	0%	
Gas Cap Interval	4152-4181						**Gas Cap**
(ft from top)							**Avg**
10	0%	0%	0%	0%	0%	0%	**0%**
20	0%	0%	0%	0%	0%	0%	**0%**
30	0%	0%	0%	7%	0%	4%	**1%**
40	0%	0%	0%	12%	4%	8%	**2%**
MPZ Interval	4181-4291		Period			Period	**MPZ**
MPZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)							
10	0%	0%	0%	9%	7%	8%	**2%**
20	0%	0%	0%	7%	7%	7%	**2%**
30	0%	0%	0%	2%	16%	9%	**2%**
40	0%	0%	0%	2%	15%	8%	**2%**
50	0%	0%	0%	2%	6%	4%	**3%**
60	0%	0%	0%	13%	2%	8%	**2%**
70	0%	0%	0%	9%	2%	6%	**1%**
80	0%	0%	0%	3%	2%	3%	**1%**
90	0%	0%	0%	1%	2%	1%	**0%**
100	0%	0%	0%	0%	1%	0%	**0%**
110	0%	0%	0%	0%	0%	0%	**0%**
120	0%	0%	0%	0%	0%	0%	**0%**
130	0%	0%	0%	0%	0%	0%	**1%**
Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
ROZ Interval	4291-4410		Period			Period	**ROZ**
ROZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)							
10	0%	0%	0%	0%	0%	0%	**6%**
20	5%	0%	3%	0%	2%	1%	**16%**
30	14%	2%	8%	0%	6%	3%	**21%**
40	10%	11%	11%	16%	6%	11%	**15%**
50	8%	13%	10%	18%	21%	19%	**10%**
60	22%	19%	20%	0%	0%	0%	**4%**
70	13%	16%	15%	0%	0%	0%	**1%**
80	10%	15%	13%	0%	0%	0%	**5%**
90	17%	16%	16%	0%	0%	0%	**3%**
100	0%	8%	4%	0%	0%	0%	**0%**
110	0%	0%	0%	0%	0%	0%	**0%**

4.b.1.8 Assessment of CO_2-EOR Performance and Opportunities for Optimization: GLSAU ROZ "Pilot Test" and "Study Area". With the benefit of CO_2 profile surveys, plus core and log data, it is possible to undertake an assessment of performance (for years 2009-2014) for the ROZ "Pilot Test" and MPZ/ROZ "Study Area" at GLSAU by undertaking the following steps.

First, use core and log data to establish the oil in-place in each of the MPZ/ROZ intervals and "flow units" in the ROZ "Pilot Test" and "Study Area".

Second, use core/log data to establish the main reservoir "flow units" for the MPZ/ROZ, including the volumes of remaining oil in-place within each "flow unit".

Third, use the CO_2 tracer surveys to establish how much CO2 entered each "flow unit".

Compare the volume of CO_2 placed into each "flow unit" with the volume of oil in-place and oil recovery in each "flow unit" to assess the efficiency of CO_2 injection into the GLSAU ROZ "Pilot Test" and "Study Area".

Finally, examine options for optimizing the CO_2 flood in the GLSAU ROZ "Pilot Test" and "Study Area".

This sequence of analysis will be discussed in the training sections of this report.

4.b.2 CO_2 Tracer Surveys: GLSAU "Study Area"

4.b.2.1 Key Research Questions. The CO_2 tracer surveys conducted in the GLSAU "Study Area" address the following questions:

What portion of the injecting CO_2 is entering and flooding the MPZ, the ROZ, and/or other (unproductive) reservoir intervals?

How does the choice of well completion practices - - (1) open-hole, (2) partially cased and perforated plus open-hole, (3) cased/perforated dual interval, and (4) cased/perforated single interval well completions - - impact the placement and profile of injected CO_2?

What is the actual vertical profile of the injected CO_2 within the MPZ and within the ROZ? Are there significant intervals of net pay in the MPZ or the ROZ not being efficiently contacted by CO_2?

To what extent does the CO_2 and its contact within the MPZ and ROZ profile change with time?

4.b.2.2 The CO_2 Tracer Program. As part of the comprehensive reservoir surveillance and monitoring research program, 42 CO_2 injection profile surveys were conducted in the 16 CO_2 injection well, 9 production pattern GLSAU "Study Area," Table 4.6. Each of the 16 CO_2 injection wells, Figure 4.6, received at least one CO_2 profile survey (consisting of tracers placed into the injected CO_2 stream), with the majority of the wells receiving multiple CO_2 surveys, including:

CO_2 profile surveys before and after well remediation,

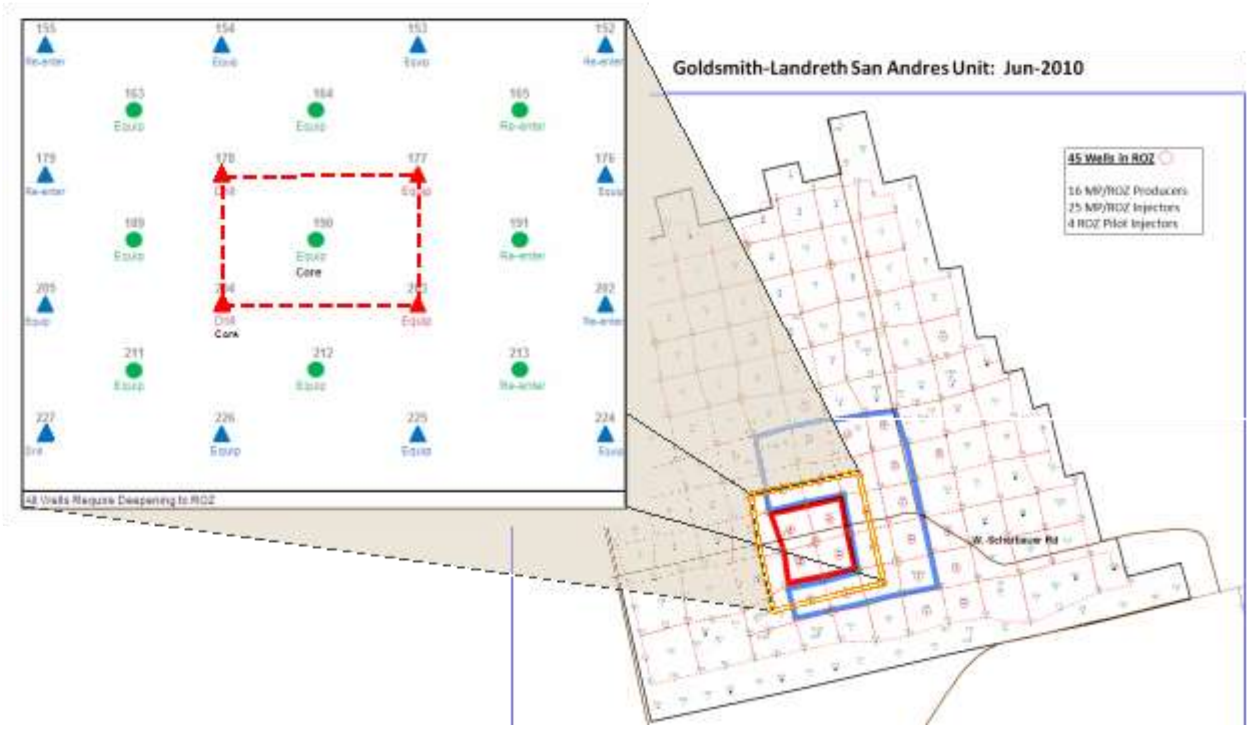
CO_2 profile surveys before and after changes in well completion, and

Time-lapse CO_2 profile surveys to track changes in CO_2 entry with time.

Table 4.6. Record of CO_2 Tracer Surveys: GLSAU "Study Area"

CO_2 Injection Well	Dates of CO_2 Tracer Survey				
	Survey #1	Survey #2	Survey #3	Survey #4	Survey #5
#152W	3/3/2011				
#153	2/25/2011	9/12/2012	12/3/2012		
#154	2/28/2011	11/8/2011	7/6/2011		
#155W	9/26/2011	10/18/2012			
#176W	4/22/2010	3/8/2011	9/13/2012	10/4/2012	
#177	9/21/2011	12/1/2012			
#178R	8/25/2011	9/10/2012			
#179W	9/23/2011	10/20/2012			
#202W	3/31/2010	2/18/2011	5/22/2012		
#203	9/19/2011				
#204R	8/24/2009	8/24/2009	2/26/2011	7/16/2012	
#205W	5/7/2010	12/9/2011	12/6/2012		
#224W	6/29/2011	8/31/2012			
#225W	2/17/2011	6/28/2011	7/10/2012	9/4/2012	11/30/2012
#226W	6/20/2011	8/27/2012	12/6/2012		
#227R	10/3/2011				

Figure 4.7. GLSAU ROZ "Study Area" and Pilot Test Facility



Source: Legado Resources, 2010.

4.b.2.3 Benefits of CO_2 Tracer Program. The CO_2 tracer profiles available at GLSAU provide a treasure trove of information on CO_2 injection performance, information that is rarely publically available from oil field projects. This information (as discussed further in the following slides) can enable an operator to:

1. Identify existing problems with well completions, particularly casing failures and other problems that lead to loss of CO_2 to non-productive horizons.

2. Better understand how alternative well completion methods and targeted CO_2 injection strategies determine where the injected CO_2 enters and floods the MPZ and the ROZ.

3. Define the vertical distribution (profile) of the injected CO_2 within the MPZ and ROZ to provide sound information for undertaking a targeted reservoir conformance program.

4. Understand how the vertical distribution of CO_2 (in the ROZ and MPZ) may change with time and continued injection of CO_2.

4.b.2.4 Identifying Non-Productive Injection of CO_2. One of the benefits of undertaking a wellbore surveillance and monitoring program is early identification of the location and volumes of CO_2 that enter non-productive reservoir intervals, enabling an operator to promptly remedy these problems.

The injection of CO_2 with tracers at the GLSAU study area identified the entry of CO_2 into unproductive reservoir intervals in five CO_2 injection wells that were then subsequently remediated, Table 4.7.

Table 4.7. Identifying and Remediating Unproductive Injection of CO_2

CO2 Injection Well	Pre-Remediation CO2 Tracer Tests				Post-Remediation CO2 Tracer Tests	
	Date(s)	Total CO2 Injected	Unproductive CO2 Injected		Date	Unproductive CO2 Injected
		(Mcf)	(%)	(Mcf)		(%)
#153	2/2011	1,046	11%	115	1/2012	0%
#154	2/2011 & 11/2011	1,482	23%	341	6/2012	2%
#205W	5/2014 & 12/2011	91	9%	9	12/2012	0%
#224W	2/2011	749	11%	82	1/2012	0%
#225W	2/2011	471	37%	174	4/2011	0%
Total		**3,839**		**721**		

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Unproductive CO_2 entry was also identified in three additional wells - - #155, #176 and #179. However, we do not have access to more recent CO_2 profile survey data that would confirm the remediation of these three wells.

The volumes of CO_2 entering unproductive reservoir intervals in the five CO_2 injection wells ranged from 9% in well #205 to 37% in well #225, averaging 19% on a volume weighted basis (before remediation). After remediation, the loss of CO_2 to unproductive reservoir intervals was reduced to less than 1%.

The loss of CO_2 to unproductive reservoir intervals (pre-remediation), totaled 721 Mmcf in the five CO_2 injection wells. Assuming a value for CO_2 of $2/Mcf, this is equal to about $1.44 million.

Without identification of unproductive injection of CO_2 and assuming CO_2 injection would have continued without remediation through 2014, the volume of unproductive injected CO_2 in these five wells would have totaled about 3.5 Bcf, equal to about $7 million.

4.b.2.5 Impact of Well Completion on CO_2 Distribution. With four distinct well completion practices applied in the 16 CO_2 injection wells, the GLSAU "Study Area" provides a rich data set for examining the impact of well completion practices on CO_2 injection and flow. The four well completion practices at GLSAU consist of:

Seven wells with open-hole (OH) completions in both the MPZ and ROZ,
Three wells partially perforated in the MPZ, with rest of the MPZ and ROZ OH,
Two wells cased and perforated in both the MPZ and ROZ, and
Seven wells cased and perforated in the ROZ only.

Five of the CO_2 injection wells, namely wells #158, #176, #204, #224 and #225, have utilized more than one completion design, providing additional information on understanding the influence of well completion practices on CO_2 injection and location.

4.b.2.5.1 Open-Hole Well Completions. Seven of the sixteen CO_2 injection wells have open-hole (OH) completions through the entire MPZ and ROZ - - wells #152, #153A, #154, #202, #205 , #225A and #226. (Because wells #153 and #225 have changed their completion design since the start of CO_2 injection, the time period when these two wells were OH is designated by #153A and #225A.)

The CO_2 tracer based injection profiles, calculated after well remediation, show that in an OH well completion (and with prior fluid and pressure depletion of the MPZ), the great bulk of the injected CO_2 (72%) entered the MPZ (oil) with a relatively modest volumes of CO_2 entering the ROZ (19%), the Gas Cap (7%) and other reservoir intervals (2%), Table 4.8.

Table 4.8. CO_2 Injection Profile for OH Well Completions

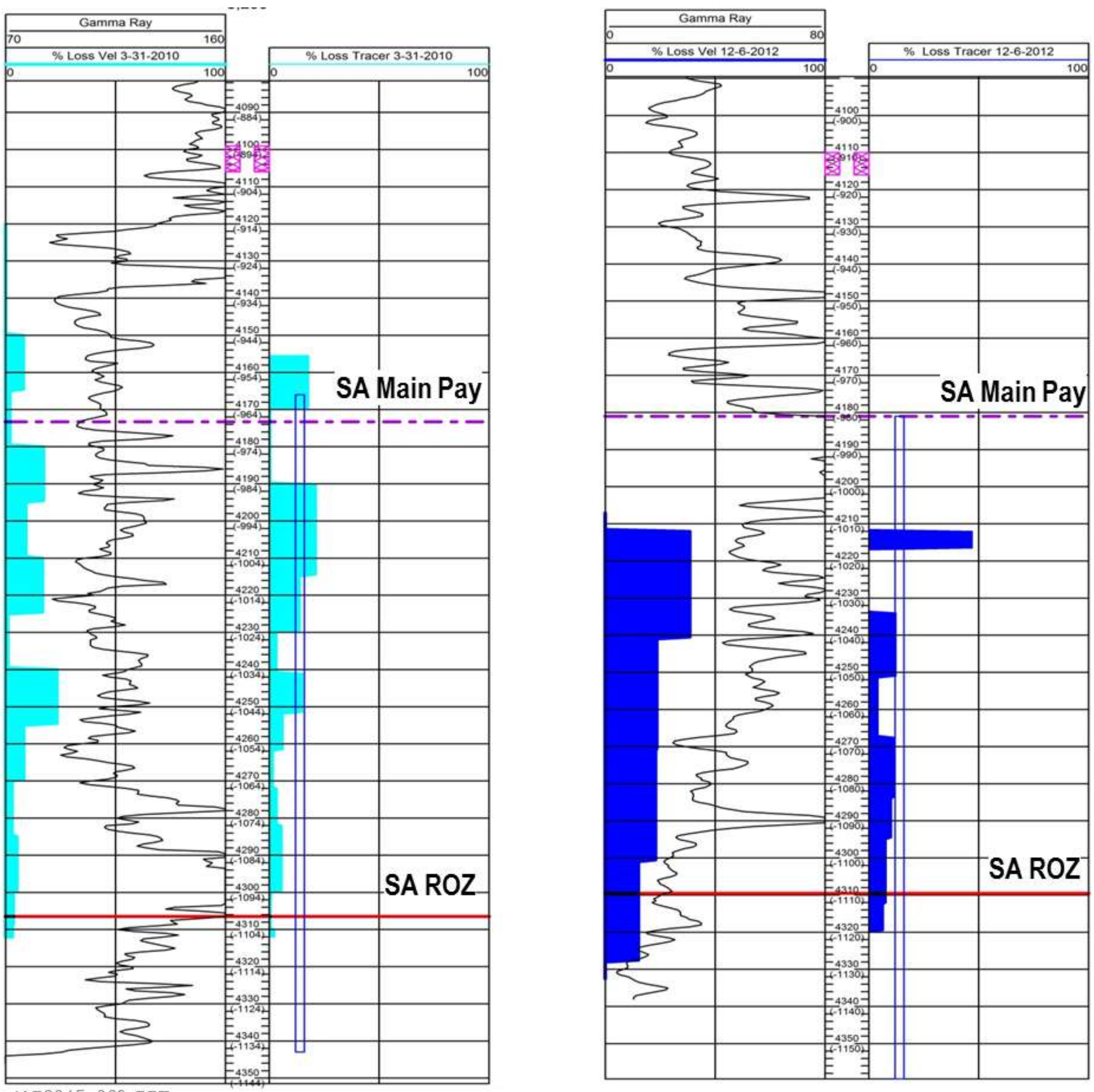
Interval	% of Injected CO_2
Gas Cap	7%
MPZ (oil)	72%
ROZ	19%
Other	2%

Figure 4.8 illustrate the CO_2 injection profiles for two open hole wells - - Well #202W and Well #205W. In Well #202W, the injected CO_2 is distributed relatively uniformly in the MPZ with very little entering the ROZ. In Well #205W, the injected CO_2 is concentrated in the middle and lower portions of the MPZ, with only modest volumes of CO_2 entering the top of the ROZ.

Figure 4.8. CO_2 Tracer Profiles in Open Hole MPZ and ROZ CO_2 Injection Well Completions

(A) Well #202W | (B) Well #205W

Tracer Survey #1: Mar. 31, 2010 | Tracer Survey #3: Dec. 6, 2012



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A more in-depth look at the CO_2 injection profile in OH CO_2 injection wells shows:

Within the MPZ the CO_2 profile is relatively uniform, with higher concentration of CO_2 in the top 40 feet of the MPZ (32% of injected CO_2), less CO_2 concentration in the bottom 40 feet of the MPZ (13% of injected CO_2), and moderate CO_2 concentration (37% of injected CO_2) in the middle 60 feet of the MPZ.

Within the ROZ the CO_2 profile is concentrated in the top 40 feet of the ROZ (11% of injected CO_2), with 5% of injected CO_2 in the middle 40 feet of the ROZ, and no CO_2 in the bottom 30 feet of the ROZ.

Table 4.9 provides more detailed, well by well, data on the CO_2 profiles for the seven OH completed CO_2 injection wells in the GLSAU "Study Area."

4.b.2.5.2 Partially Cased/Perforated Plus OH Well Completions. Three of the sixteen CO_2 injection wells have partial perforations in the MPZ, typically 10 to 15 feet in the upper portion of the MPZ, and an OH completion for the remainder of the MPZ interval and in the ROZ - - wells #153B, #176A and #224A.

The CO_2 tracer based injection profiles, calculated after well remediation (except for well #224A that changed its well completion design), show that for this type of CO_2 injection well completion (and prior fluid and pressure depletion of the MPZ), the majority of the injected CO_2 (48%) entered the MPZ (oil), with 20% entering the ROZ, 25% entering the Gas Cap and 7% entering the other reservoir intervals, Table 4.10

An in-depth look at the CO_2 injection profile in partially perforated wells shows:

Within the MPZ, the CO_2 profile is concentrated in the top 20 feet of the MPZ interval (23%) and then is relatively uniform for the next 60 feet of the MPZ interval (42%). Very little CO_2 has entered the bottom 60 feet of the MPZ (4%).

Within the ROZ, essentially no CO_2 entered the top 20 feet and only 2% of the CO_2 entered the next 20 feet of the ROZ. (The CO_2 entering the ROZ was only from one of the three CO_2 injection wells, #176A.)

Table 4.9. Open-Hole CO_2 Injection Wells: GLSAU Study Area

Well #	#152	#153A	#154	#202	#226	#205	#225A	% of Injected CO2
Zone (s)	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	
Open-Hole Interval (ft):	4157-4402	4164-4415	4162-4401	4166-4404	4210-4424	4181-4430	4176-4380	
Gas Cap								
Feet from Top								
1-20	0%	0%	9%	8%	0%	0%	0%	2%
21-30/40	3%	0%	15%	13%	1%	0%	0%	5%
MPZ								
Feet from Top								
1-20	13%	9%	27%	5%	31%	0%	54%	20%
21-40	5%	12%	14%	7%	7%	47%	14%	15%
41-60	13%	6%	33%	9%	17%	4%	7%	13%
61-80	25%	6%	0%	13%	19%	10%	6%	11%
81-100	15%	0%	0%	9%	9%	11%	9%	8%
101-120	3%	16%	0%	11%	4%	8%	0%	6%
121-140	0%	0%	0%	0%	0%	0%	0%	0%
ROZ								
Feet from Top								
1-20	8%	6%	0%	20%	7%	11%	11%	9%
21-40	13%	12%	0%	6%	0%	8%	0%	6%
41-60	3%	12%	0%	0%	4%	0%	0%	3%
61-80	0%	10%	0%	0%	0%	0%	0%	1%
81-100	0%	0%	0%	0%	0%	0%	0%	0%
101-120	0%	0%	0%	0%	0%	0%	0%	0%
121-140	0%	0%	0%	0%	0%	0%	0%	0%
Gas Cap	3%	0%	24%	21%	1%	0%	0%	7%
MPZ	73%	49%	74%	53%	87%	81%	89%	72%
ROZ	25%	40%	0%	26%	11%	19%	11%	19%
NonPay	0%	11%	2%	0%	0%	0%	0%	2%

Table 4.10. CO_2 Injection Profile for Partially Perfed Plus OH Well Completions

Interval	% of Injected CO2
Gas Cap	25%
MPZ (Oil)	48%
ROZ	20%
Other	7%

Table 4.11 provides more detailed, well by well, data on the CO_2 profiles for the three partially perforated MPZ plus OH MPZ/ROZ completed CO_2 injection wells in the GLSAU "Study Area."

4.b.2.5.3 "Dual MPZ and ROZ" Well Completions. Two of the sixteen CO_2 injection wells are cased across the MPZ and ROZ intervals and have perforations in both the MPZ and ROZ - - wells #204B and #227. (Well #204B was initially perforated in the ROZ and subsequently also perforated in the MPZ; the CO_2 profile for this well is for the time period this well was a dual MPZ/ROZ completion.)

The CO_2 tracer based injection profile shows that for "dual MPZ and ROZ" cased and perforated CO_2 injection wells (and with prior fluid and pressure depletion of the MPZ), the majority of the injected CO_2 (77%) entered the MPZ with only a modest volumes entering the ROZ (17%) and the Gas Cap (6%), Table 4.b.2-7.

Two tracer surveys (Figure 4.9) illustrated the CO_2 profile for a "ROZ only" and a "dual MPZ/ROZ" well completion.

In the "ROZ only" well completion, the CO_2 is relatively uniformly distributed in the upper 80 feet of the ROZ.

In the "dual MPZ/ROZ" well completion, the great majority of the CO_2 enters the Gas Cap and upper MPZ in the upper portion of the reservoir with an only modest volume entering the ROZ.

Table 4.11. Partially Perforated Plus Open Hole CO_2 Injection Wells: GLSAU Study Area

Well #	#153B	#176A	#224A	% of Injected CO2
Zone (s)	MPZ/ROZ	MPZ/ROZ	MPZ/ROZ	
Perforated Interval (ft)	4142-4152	4150-4164	4163-4173	
Gas Cap				
Feet from Top				
1-20	49%	9%	9%	23%
21-30/40	0%	4%	4%	2%
MPZ				
Feet from Top				
1-20	30%	0%	19%	16%
21-40	15%	2%	8%	8%
41-60	6%	4%	35%	15%
61-80	0%	3%	14%	6%
81-100	0%	5%	0%	2%
101-120	0%	2%	0%	1%
121-140	0%	0%	0%	0%
ROZ				
Feet from Top				
1-20	0%	1%	0%	0%
21-40	0%	6%	0%	2%
41-60	0%	20%	0%	7%
61-80	0%	13%	0%	4%
81-100	0%	7%	0%	2%
101-120	0%	6%	0%	2%
121-140	0%	6%	0%	2%
Gas Cap	49%	13%	13%	25%
MPZ	51%	16%	76%	47%
ROZ	0%	60%	0%	20%
NonPay	0%	11%	11%	7%

Table 4.12. CO_2 Injection Profile for Cased and Perforated "Dual MPZ and ROZ" Well Completions

Interval	% of Injected CO2
Gas Cap	6%
MPZ (Oil)	77%
ROZ	17%

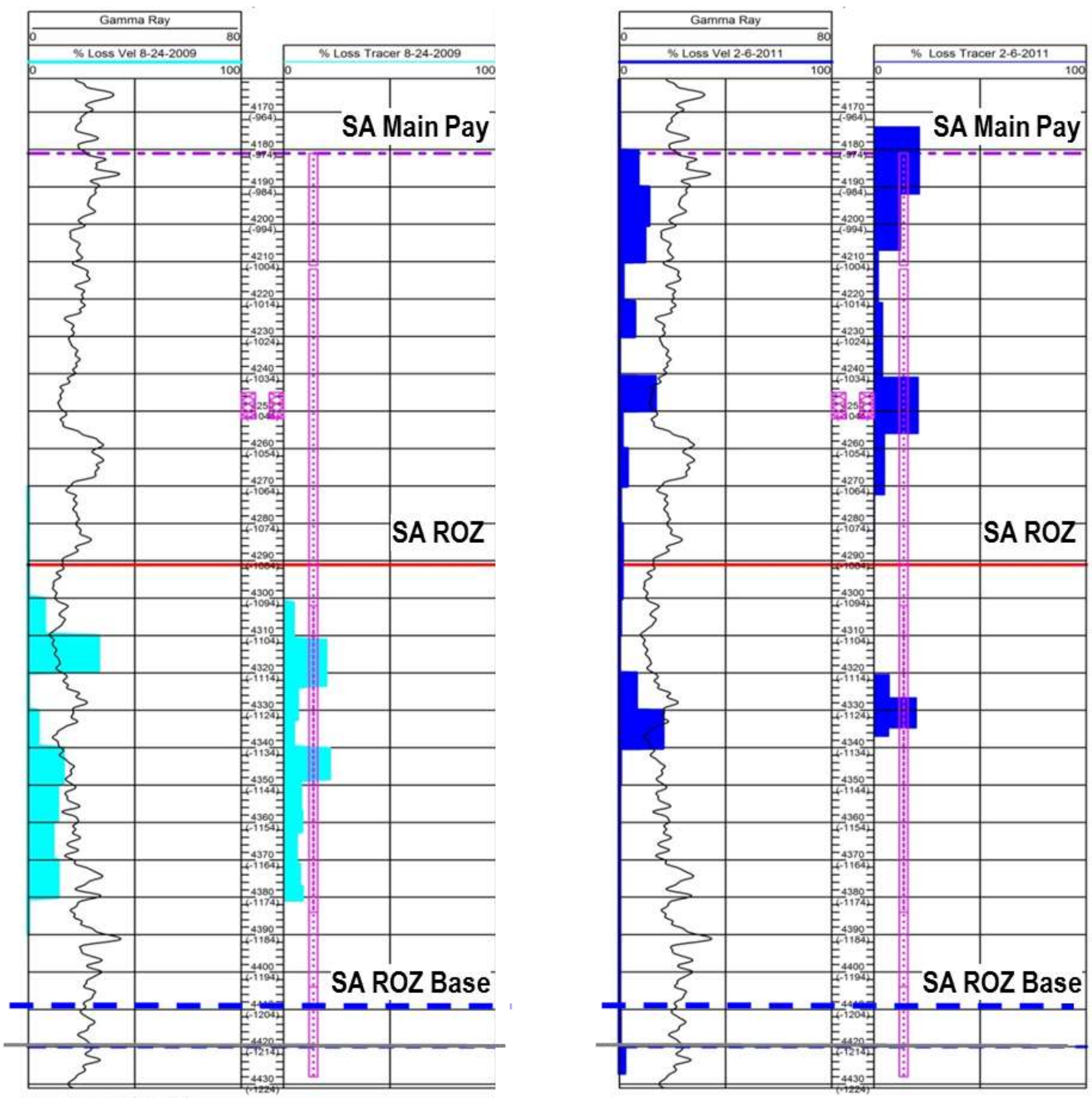
Figure 4.9. CO_2 Tracer Profiles in Open Hole MPZ and ROZ CO_2 Injection Well Completions

(A) Well #204R "ROZ Only" Completion

(B) Well # 204R "Dual MPZ/ROZ" Completion

Tracer Survey #1: Aug. 24, 2009

Tracer Survey#2 : Feb. 6, 2011



JAF2015_069.PPT

A more in-depth look at the CO_2 injection profile in cased plus dually perforated (in the MPZ and ROZ) CO_2 injection wells shows:

Within the MPZ, the CO_2 profile is concentrated in the top 40 feet of the MPZ interval (63%), with only modest volumes of CO_2 in the next 40 feet (18%) and very little CO_2 (3%) entering the lower portion of the MPZ. In one of the wells - - #227 - - essentially all (98%) of the CO_2 entered the top 40 feet of the MPZ.

Within the ROZ, the CO_2 profile is concentration in the top 40 feet of the ROZ interval (17%), with no discernable CO_2 entering the remainder of the ROZ interval.

Table 4.13 provides more detailed, well by well, data on the CO_2 profiles for the two cased and perforated "dual MPZ and ROZ" completed CO_2 injection wells in the GLSAU "Study Area."

4.b.2.5.4 "ROZ Only" Well Completions. Seven of the sixteen CO_2 injection wells are cased and perforated only in the ROZ. (One of these wells - - #176B - - has perforations placed below the base of the commercial ROZ and has not been included in the assessment). (Well #204A was initially completed in the "ROZ only" and subsequently also perforated in the MPZ; the CO_2 profile for this well is for the time period this well was a "ROZ only" completion.) The six wells included in this CO_2 profile assessment are - - #177, #178, #203, #204A, #224A, and #225B.

The CO_2 tracer based injection profile shows that for this type of well completion, essentially all of the injected CO_2 (99%) entered the ROZ with a small volume of (1%) entering the MPZ, Table 4.14.

An in-depth look at the CO_2 injection profile in cased and perforated "ROZ only" CO_2 injection wells shows:

The bulk of the CO_2 (70%) is concentrated in the top 40 feet of the ROZ interval.

The middle 40 to 50 feet of the ROZ interval receives 25% of the CO_2.

The bottom 30 feet of the ROZ interval receives 3% of the CO_2, with 2% entering the MPZ (above the ROZ).

Table 4.15 provides more detailed, well by well, information on the CO_2 profiles for the six cased and perforated "ROZ only" CO_2 injection wells in the GLSAU study area.

Table 4.13. Cased and Perforated "Dual MPZ and ROZ" Well Completions

Well #	#204B	#227	% of Injected CO2
Zone (s)	MPZ/ROZ	MPZ/ROZ	
Perforated Interval (ft)	4181-4404	4184-4428	
Gas Cap			
Feet from Top			
1-20	0%	0%	0%
21-30/40	11%	0%	6%
MPZ			
Feet from Top			
1-20	15%	47%	31%
21-40	17%	51%	34%
41-60	12%	2%	7%
61-80	8%	0%	4%
81-100	2%	0%	1%
101-120	0%	0%	0%
121-140	0%	0%	0%
ROZ			
Feet from Top			
1-20	1%	0%	1%
21-40	14%	0%	7%
41-60	19%	0%	10%
61-80	0%	0%	0%
81-100	0%	0%	0%
101-120	0%	0%	0%
121-140	0%	0%	0%
Gas Cap	11%	0%	6%
MPZ	54%	100%	77%
ROZ	35%	0%	17%
NonPay	0%	0%	0%

Table 4.14. CO_2 Injection Profile for Cased and Perforated "ROZ Only" Well

Interval	% of Injected CO_2
Gas Cap	-
MPZ	1%
ROZ	99%

4.b.2.5.5 Summary. The CO_2 tracer surveys at GLSAU, Table 4.16, show that without direct control over the entry points of CO_2 injection, such as by using a "ROZ only" well completion, the great bulk of the injected CO_2 will enter and process the MPZ.

4.b.2.6 Time-Lapse CO_2 Injection Profiles. Time-lapse CO_2 tracer surveys can provide data on how changes in well completion practices or continued CO_2 injection of CO_2 can influence the CO_2 profile.

Figure 4.10 shows the three CO_2 injection profiles for Well #204R overlain on its log suite.

4.b.2.6.1 Change in CO_2 Profile from Change in Well Completions. Change in the CO2 profile due to change in well completion is illustrated by two time-lapse CO_2 tracer surveys in the Well #204R, Figure 4.11.

The first profile survey (Tracer #1) was conducted in August 2009 when the #204R well was completed only in the ROZ. It shows a relatively uniform distribution of the injected CO_2 in the upper and middle portions of the ROZ. (A repeat tracer survey confirmed the CO_2 profile in ROZ.)

The second profile survey (Tracer #2) was conducted in February 2011 after the #204R well was recompleted into the MPZ. It shows that the majority of the injected CO_2 entered the MPZ (preferentially its upper interval), with the portion of the CO_2 entering the ROZ confined to a 20 foot interval in the ROZ.

This set of time-lapse CO_2 tracer surveys (Figure 4.11) illustrated the change in the CO_2 profile before and after adding perforations into the MPZ of Well #204. After recompletion, essentially all of the CO_2 enters the MPZ, particularly its upper 30 feet. The portion of the CO_2 in the ROZ is limited to a 20 foot interval from 4,520' to 4,340'.

Table 4.15. Cased and Perforated "ROZ Only" CO_2 Injection Well Completions

Well #	#177	#178	#203	#204A	#224B	#225B	% of Injected CO2
Zone (s)	ROZ	ROZ	ROZ	ROZ	ROZ	ROZ	
Perforated Interval (ft)	4290-4386	4300-4380	4297-4365	4302-4384 4404-4428	4300-4340 4360-4400	4195-4320 4340-4390	
Gas Cap							
Feet from Top							
1-20	0%	0%	0%	0%	0%	0%	0%
21-30/40	0%	0%	0%	0%	0%	0%	0%
MPZ							
Feet from Top							
1-20	0%	0%	0%	0%	0%	0%	0%
21-40	0%	0%	0%	0%	0%	0%	0%
41-60	8%	0%	0%	0%	0%	0%	1%
61-80	0%	0%	0%	0%	0%	0%	0%
81-100	0%	0%	0%	0%	0%	0%	0%
101-120	0%	1%	0%	0%	0%	0%	0%
121-140	0%	0%	0%	0%	0%	0%	0%
ROZ							
Feet from Top							
1-20	52%	14%	22%	3%	14%	100%	34%
21-40	40%	31%	59%	19%	24%	0%	29%
41-60	0%	30%	8%	31%	17%	0%	14%
61-80	0%	11%	11%	27%	9%	0%	10%
81-100	0%	13%	0%	20%	35%	0%	11%
101-120	0%	0%	0%	0%	0%	0%	0%
121-140	0%	0%	0%	0%	0%	0%	0%
Gas Cap	0%	0%	0%	0%	0%	0%	0%
MPZ	8%	1%	0%	0%	0%	0%	1%
ROZ	92%	99%	100%	100%	100%	100%	99%
NonPay	0%	0%	0%	0%	0%	0%	0%

Table 4.16. Impact of Well Completion Design on CO_2 Profile

Reservoir Interval	Type of CO2 Injection Well Completion			
	OH	Partial Perf Plus OH	Dual MPZ/ROZ	ROZ Only
	(% CO_2)	(% CO_2)	(% CO_2)	(% CO_2)
Gas Cap	7%	25%	6%	0%
MPZ	72%	48%	77%	1%
ROZ	19%	20%	17%	99%
Other	2%	7%	0%	0%

4.b.2.6.2 Change in CO_2 Profile from Continue Injection of CO_2. The change in the CO_2 profile due to continued injection of CO_2 is illustrated by two time-lapse surveys in the GLSAU #204R well, Figures 4.12.

The first time-lapse survey (Tracer #2) in well #204R (conducted after well recompletion in February 2011), shows three concentrated intervals of CO_2:

- From 4,174' to 4,192' (18 feet) and from 4,242' to 4,256' (14 feet) in the 110 foot MPZ interval, and
- From 4,320' to 4,337' (17 feet) in the 120 foot ROZ interval.

The second time-lapse tracer survey (Tracer #3) in well #204R, conducted in July 2012 (after seventeen months of CO2 injection), shows a much broader distribution of the injected CO_2: from 4,184' to 4,228' (44 feet) in the upper portion of the 110 foot MPZ interval and from 4,306' to 4,340' (34 feet) in the upper portion of the 120 foot ROZ interval.

Very little CO_2 has entered the bottom, low permeability interval of the MPZ as well as the middle and lower portions of the ROZ.

Figure 4.10. Time-Lapse CO_2 Injection Profiles for GLSAU #204R

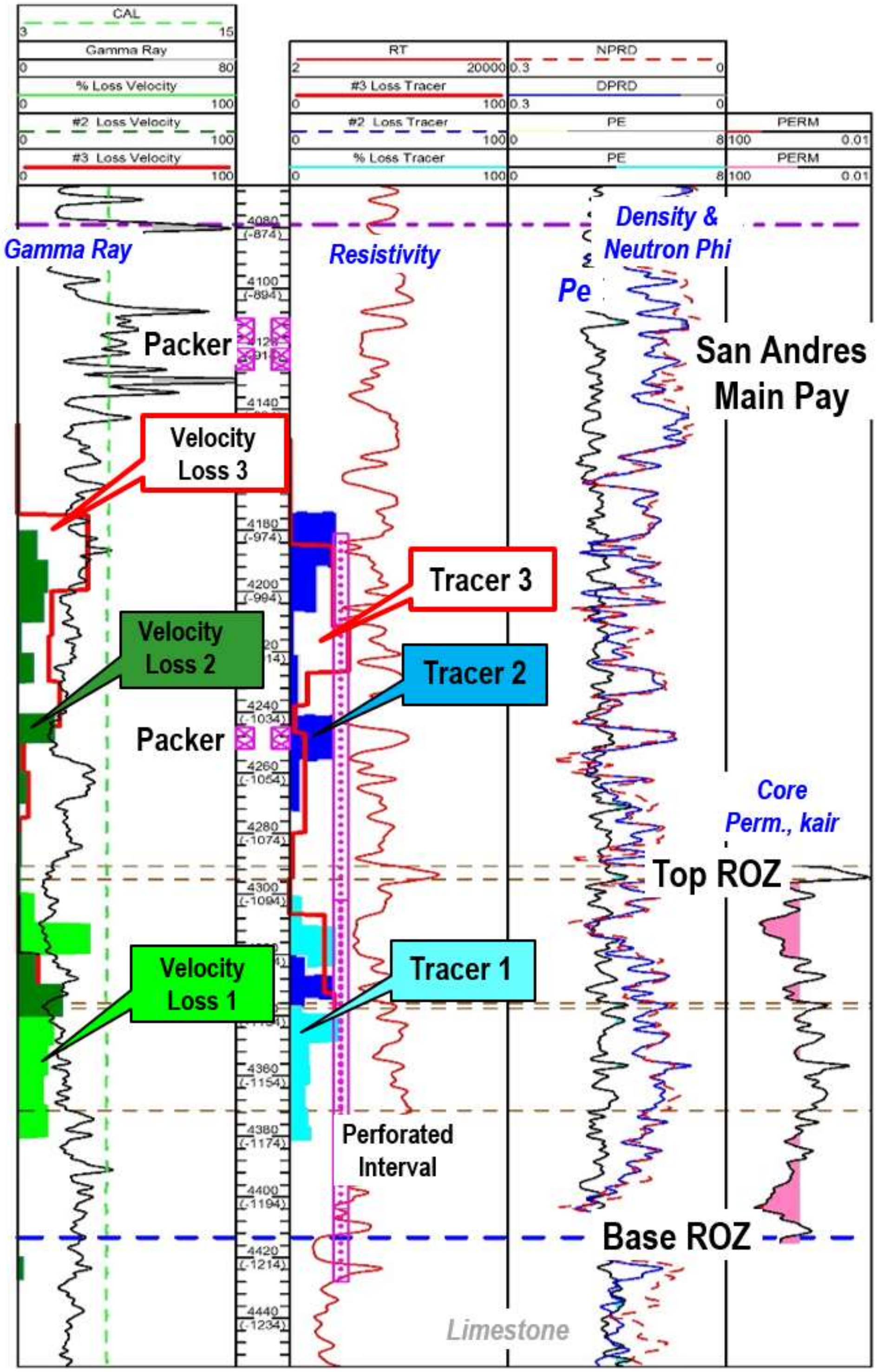


Figure 4.11. Time-Lapse CO_2 Injection Profiles: GLSAU Well #204

(A) Well #204R — Tracer Survey #1: Aug. 24, 2009

(B) Well #204R — Tracer Survey#2 : Feb. 6, 2011

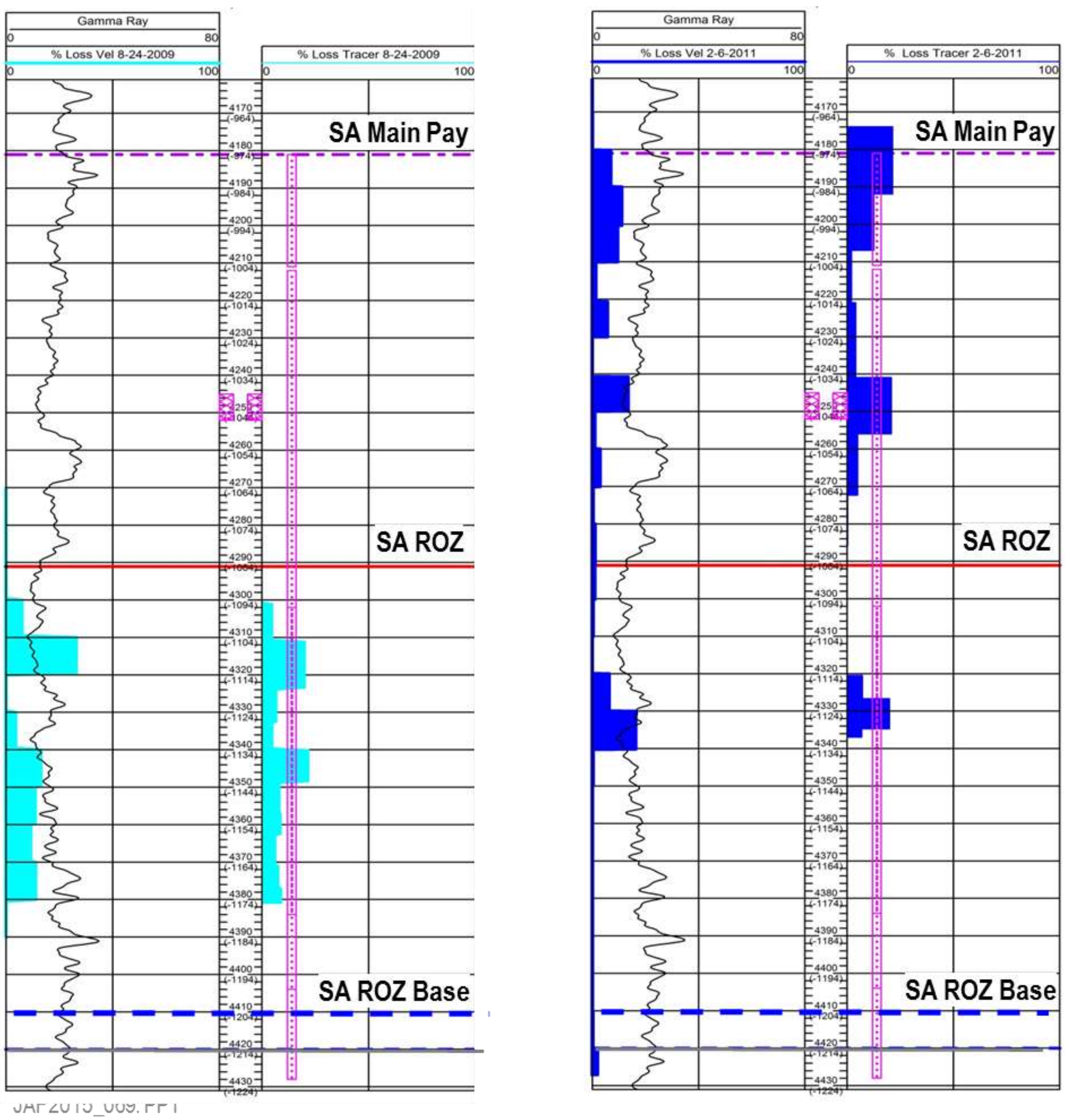
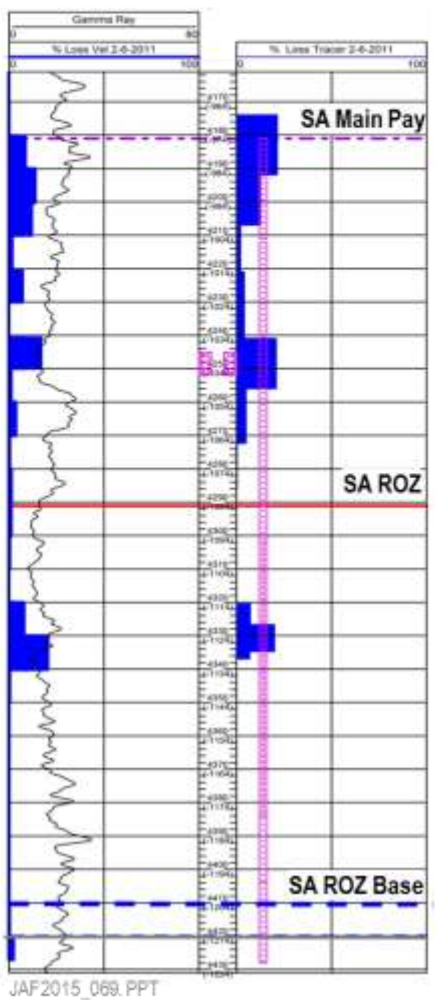


Figure 4.12. Time-Lapse CO_2 Injection Profiles: GLSAU Well #204R

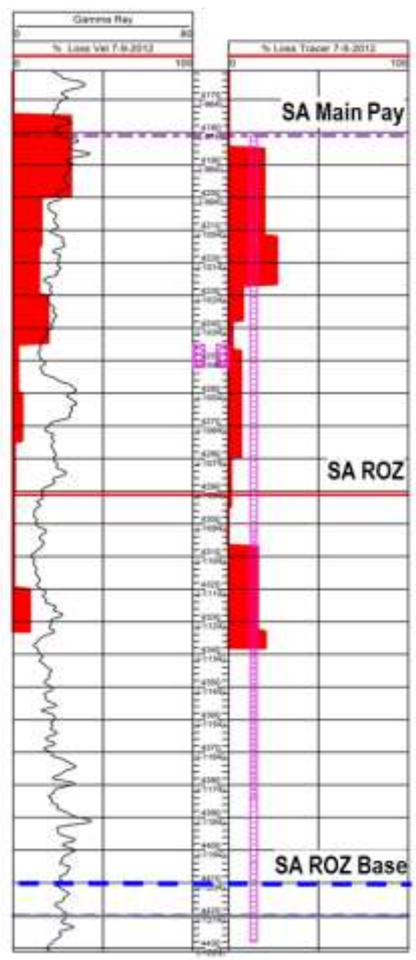
(A) Well #204R

Tracer Survey#2: Feb. 6, 2011



Well #204R

Tracer Survey#3: Jul. 9, 2012



This set of time-lapse CO_2 tracer surveys Figure 4.12) illustrated the change in the CO_2 profile after 17 months of continued CO_2 injection into the dually completed (MPZ/ROZ) Well #204R.

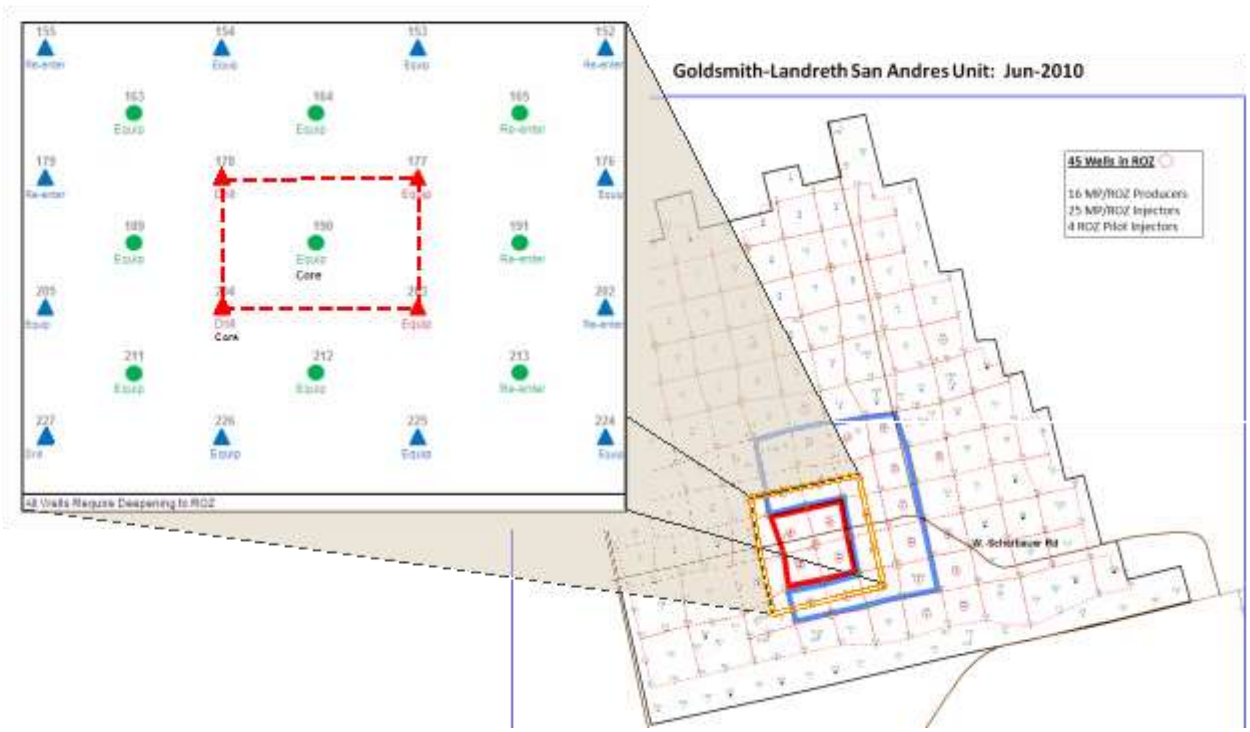
Tracer Survey #2 shows three concentrated intervals of CO_2 entry and flow.
Tracer Survey #3 shows a much broader distribution of the CO_2 in the MPZ and ROZ.

4.b.3. CO_2 Injection Profiles: GLSAU ROZ "Pilot Test" (Pattern #190)

4.b.3.1 CO_2 Injection Into Pattern #190.

An estimated 21 Bcf of CO_2 has been injected into the four injection wells surrounding production Pattern #190 (end of 2014), Figure 4.13.

Figure 4.13. GLSAU ROZ "Study Area" and Pilot Test Facility



Source: Legado Resources, 2010.

Assuming that one-quarter of the CO_2 injected into each of the four CO_2 injection wells has entered Pattern #190, this 40 acre pattern has received about 5.25 Bcf of injected CO_2, Table 4.17.

Table 4.17. CO_2 Injection Into Pattern #190

CO_2 Injection Well	Volume of CO_2 Injected	Volume of CO_2 Allocated to Pattern #190
	(Mmcf)	(Mmcf)
#177	4,873	1,220
#178	3,631	910
#203	6,079	1,520
#204A*	2,024	510
#204B*	4,370	1,090
Total	**20,977**	**5,250**

*The designation of well #204 by A and B is to separate the volumes of CO2 injected when the well was a "ROZ only" completion (#204A) and when the well was a "dual MPZ/ROZ" completion (#204B).

4.b.3.2 CO_2 Injection and Distribution in Pattern #190.

Even with the recompletion of CO_2 injection well #204 into a "dual MPZ and ROZ" CO_2 injector in early 2011, but with wells #177, #178 and #203 remaining as ROZ only injectors, the great bulk (4.42 Bcf) of the CO_2 in Pattern #190 has entered the ROZ, Table 4.18.

4.b.3.2.1 CO_2 Profile for Pattern #190 During "ROZ Only" Well Completion. The CO_2 profile surveys for the four CO_2 injection wells (#177, #178, #203 and #204A) provide a valuable set of information on the distribution of CO_2 within the ROZ interval in Pattern #190, Table 4.19. (This CO_2 profile is for the time period when Well #204A was a "ROZ only" completion.)

Table 4.18. CO_2 Injection and Distribution in Pattern #190

Injection Well	CO_2 Allocated to Pattern #190 (Mmcf)	CO_2 In ROZ (Mmcf)	CO_2 In MPZ (Mmcf)
#177	1,220	1,120	100
#178	910	900	10
#203	1,520	1,520	-
#204A*	510	510	-
#204B*	1,090	370	720
Total	**5,250**	**4,420**	**830**

*The designation of well #204 by A and B is to separately determine the volumes of CO2 injected when the well was a ROZ only completion (#204A) and when it was a joint MPZ/ROZ completion (#204B).

Given the placement of the perforations into the upper 60 to 80 feet in the ROZ, it is not surprising that very little CO_2 entered the Lower ROZ interval (from 4,380' to 4,410').

4.b.3.2.2 CO_2 Profile of Well #204 Before and After Perforation of MPZ. Well #204, that had been a "ROZ only" completion, was also perforated in the MPZ (from 4,180'-4,300') in early 2011. This provides valuable comparative information on the CO_2 profile for: (1) a "ROZ only" completion and (2) a "dual ROZ and MPZ" completion in the same geological setting, Table 4.20. (The perforation of the MPZ in Well #204 occurred after about 2 Bcf of CO_2 had been injected by Well #204 into the ROZ).

Table 4.19. CO_2 Profile for Pattern #190 During "ROZ Only" Well Completion

ROZ Interval	Well #177 Perfs: (4,290'-4,350') (1,220 MMcf)		Well #178 Perfs: (4,300'-4,380') (910 MMcf)		Well #203 Perfs: (4,300'-4,370') (1,520 MMcf)		Well #204A Perfs: (4,300'-4,380') (510 MMcf)		Pattern #190 (4,160 MMcf)	
(Feet From Top)	(%)	(MMcf)	(%)	(MMcf)	(%)	(MMcf)	(%)	(MMcf)	(%)	(MMcf)
0-20	52%	630		120	22%	330	11%	50	31%	1,130
20-40	40%	490		280	59%	880	21%	110	42%	1,760
40-60	-			280	8%	120	35%	180	11%	580
60-80	-			100	11%	160	29%	150	12%	410
80+	-			120		30	4%	20	1%	170
MPZ	8%	100		10	-	-	-		3%	110
Totals		**1,220**		**910**		**1,520**		**510**		**4,160**

JAF2015_028.XLS

Table 4.20. CO_2 Profile of Well #204 Before and After Perforation of MPZ

Interval	"ROZ Only" Perfs: 4,300'-4,380' (4,404'-4,428')		"Dual ROZ and MPZ" Perfs: 4,180'-4,300' 4,300'-4,380' (4,404'-4,428')	
	(%)	(MMcf)	(%)	(MMcf)
MPZ	-	-	66%	720
ROZ (feet from top)				
0-20	11%	50	4%	40
20-40	21%	110	30%	330
40-60	35%	180	-	-
60-80	29%	150	-	-
80+	4%	20	-	-
Total	**100%**	**510**	**100%**	**1,090**

JAF2015_028.XLS

After perforation of the MPZ in Well #204: (1) the majority of the CO_2 (66%) entered the MPZ, with 34% of the CO_2 that entering the ROZ.

4.b.3.2.3 CO_2 Profile and Injection Volumes for Pattern #190. The 5.25 Bcf of CO_2 entering Pattern #190 and its distribution to the MPZ and the four main reservoir flow units are provided in Table 4.21:

4.42 Bcf (84.2%) of the injection of CO_2 entered the ROZ
0.83 Bcf (15.9%) of the injected CO_2 entered the MPZ

Table 4.21. CO_2 Profile and Injection Volumes for Pattern #190

Interval	"ROZ Only" Completion (Four CO2 Inj. Wells)		"Dual ROZ and MPZ" Completion in Well #204R		Total CO2 Injection (Four CO2 Inj. Wells)	
	(%)	(MMcf)	(%)	(MMcf)	(%)	(MMcf)
MPZ	**3%**	**110**	**66%**	**720**	**16%**	**830**
ROZ (Ft from Top)	**97%**	**4,050**	**34%**	**370**	**84%**	**4,420**
Top 20		1,130		40		1,170
Next 20		1,760		330		2,090
Next 40/50		1,160		-		1,160
Base 30		-		-		-
Totals		**4,160**		**1,090**		**5,250**

JAF2015_028.XLS

Figures 4.13 through 4.16 contain the wellbore diagram for the four CO_2 injection wells surrounding Pattern #190.

4.4 Effectiveness of CO_2 Injection: ROZ "Pilot Test".

Overall, 21 Bcf of CO_2 has been injected into the four CO_2 injection wells located in the GLSAU CO_2-EOR Pilot, Table 4.22. Of this volume:

5.25 Bcf entered Pattern #190 with the remaining CO_2 15.75 Bcf entering the 8 patterns surrounding the Pilot area.
Of the 5.25 Bcf of CO_2 entering Pattern #190, 4.42 Bcf (84.2%) entered the ROZ, because of the "ROZ" only completions used in the four CO_2 injection wells surrounding Pattern #190.
The remainder of the CO_2, approximately 0.83 Bcf (15.8%) entered the MPZ, with essentially all of this volume from the "dual MPZ/ROZ" completion in Well #204.

Figure 4.14. CO_2 Injection Wellbore Diagrams: Pattern #190

Field: Goldsmith Landreth San Andres Unit

GLSAU 177W

Reservoir:

Well ID Info:	
API No:	
Spud Date:	

	Location:
Footage:	330' FSL & 2310' FWL
Section:	29
Block:	44, T-1N
Survey:	T&P RR
County:	Ector
Lat:	
Long:	
	Elevations:
GL:	3190
KB:	3199
KB Calc:	9
ck w/log?	

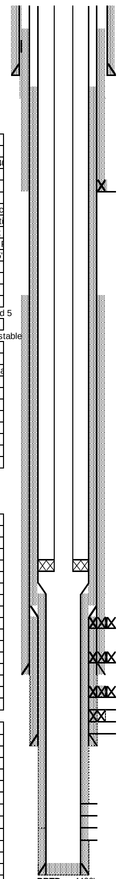
Date	History
7/1/1937	Acidized open hole 4170' to 4220' w/ 3500 gals acid.
8/6/1956	Ran 5-1/2" liner 4145' to 4223'. DO and deepen well to 4240'. Acidized w/4(
	gals 15% HCL acid.
10/29/1956	Plug back to 4216' w/ cement. Perf 4208-4215 w/4 JSPF and acidized
	w/10,000 gals 15% HCL acid.
5/18/1967	DO and deepen to 4274'. Acidized new open hole w/3000 gals 15% HCL ac
	Perf 4153', 4167',& 4194' and acidized w/1600 gals 15% acid. Put on injecti
5/3/1973	Plug back to 4230' w/sand & Hydromite. Sqz perfs 4153' to 4215' w/275 sx
	Found hole in csg @ 1506'. Sqz hole @ 1506'. DO cmt and CO to 4274'.
	4210', 4215', & 4220' w/1 JSPF. Perf OH 4235', 4245', 4255', 4260', & 4265'
	Acidzed w/2000 gals 15% HCL acid.
4/16/1985	Acidized down coil tbg w/4000 gals 15% HCl and circ clean w/ N2.
7/20/1988	Pulled to check for hole in tbg. Found hole in pkr mandrel.
11/12/2003	Pulled to check for hole in tbg. Found hole in pkr mandrel.
5/6/2009	Pulled to check for hole in tbg. Found pkr seals leaking. Scan of tbg found 5
	bad jts. Replaced bad tbg and ran new packer.
6/4/2009	Raised pkr 1 jt and tightend well head to eliminate small leak. Able to get stable
	pressure test on chart.
12/2/09	Deepened well to 4450'. Ran 4" FJ and 4-1/2" Liner and cemented
	Perf ROZ from 4290' to 4350' and acidized w/3000 gals 90/10 HCL & rock sa
7/12/10	Change out tbg w/ CLS FG lined tbg w/ AB modified collars

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
129	2-3/8" 4.7# J-55 tbg FG lined w/ AB modified c	4,017.00	4,017.00
1	Weatherford T-2 on/off tool w/1.50" profile nipp	2.00	4,019.00
1	4-1/2" X 2-3/8" Arrowset 1X pkr (nickel plated)	6.00	4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00
			4,025.00

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00

Pumping Unit: Injector
Updated: 7/15/2010 MCB

Wellbore Diagram



Surf. Csg: 10-3/4"
Set @ 230'
Cement w/ 100 sx
Circ:
TOC:

Sqzd csg leak @ 1506' w/500 sx Class H (did not circ to surface)
Ran Temp srvy TOC @ 77'

Calc TOC behind 7" is 2184'

Packer Set @ 4017'

Top of 4" Flush Joint Liner @ 4024'

Top of 5-1/2" liner @ 4145'
Squeezed Perf @ 4153 & 4167'
Hole Size:
Prod. Csg: 7"
Set @: 4180'
Cmt: Lead:
Tail: 250 sx
Squeezed Perf @ 4194'
Perf 4210' 1JSPF
Squeezed Perfs 4208-4215 (4 JSPF)
Perf 4215' & 4220' 1 JSPF
Prod. Liner 5-1/2" Liner
TOL@ 4145'
Btm of Liner @ 4223'
Cement: 75 sx

ROZ perfs 4290' to 4350 4 JSPF (240 holes)

PBTD 4406'
TD 4450'

Hole Size: 4-3/4"
Prod. Liner 4" Flush Joint Liner
TOL@ 4024'
Btm of Liner @ 4448'
Cement: 315 sx 50/50 Poz cmt

Field: Goldsmith Landreth San Andres Unit

GLSAU 178R W

Reservoir: San Andres

Well ID Info:	
API No:	42-135-40095
Spud Date:	11/30/2009

	Location:
Footage:	233' FSL & 924' FWL
Section:	29
Block:	44, T-1-N
Survey:	T&P RR Co.
County:	Ector
Lat:	31 deg 59'05.598"
Long:	102 deg 39'48.518"
	Elevations:
GL:	3190
KB:	3201
KB Calc:	11
ck w/log?	Yes

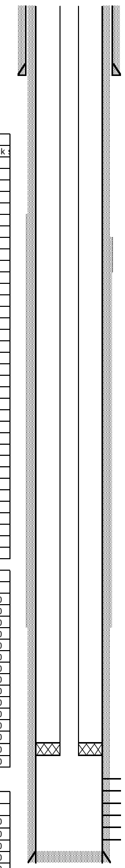
Date	History
12/14/2009	Perf 4300' to 4380' w/4 JSPF and acidize w/3900 gals 90/10 Acidtol w/rock s
10/8/2010	Change out tbg w/ CLS FG lined tbg w/ AB modified collars

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
131	2-7/8" 6.5# J-55 CLS lined tbg w/AB mod cplg	4,245.00	4,245.00
1	T-2 on/off tool w/1.81" profile (nickel coated)	2.00	4,247.00
1	5-1/2" x 2-7/8" Arrowset 1X nickel coated pkr	7.00	4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00
			4,254.00

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00

Pumping Unit: Injector
Updated: 12/18/09 SDY

Wellbore Diagram



Hole Size: 12-1/4"
Surf. Csg: 8-5/8" 24#
Set @ 1513'
Cement w/ 700 sx
Circ: Yes
TOC: Surface

Est TOC: Surface, circ 15 sx

Pkr Set @ 4245'

ROZ perfs 4300 to 4380 4 JSPF (320 holes)

PBTD 4442'
TD 4485'

Hole Size: 7-7/8"
Prod. Csg: 5-1/2" 15.5# J-55
Set @: 4484'
Cmt: Lead: 325 sx Class C 50/50 poz 10% gel
Tail: 100 sx Class C 50/50 poz, 2% gel

Figure 4.15. CO_2 Injection Wellbore Diagrams: Pattern #190

Field: Goldsmith Landreth San Andres Unit

GLSAU 203

Wellbore Diagram

	Location:
Footage:	990' FNL & 330' FEL
Section:	32
Block:	44, T-1N
Survey:	T&P RR
County:	Ector
Lat:	
Long:	
	Elevations:
GL:	3197
KB:	3205
KB Calc:	8
ck w/log?	

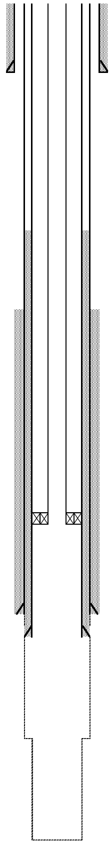
Reservoir:

Well ID Info:	
API No:	
Spud Date:	

Date	History
4/5/1937	Acidized open hole 4167 - 4225' w/5000 gals acid.
4/1/1948	Pull tbg and mill pakcer. Deepen well 27' to 4252'. Plug back to 4205' w/ gr
	sqz gas cap w/350 gals plastic. CO to TD & acidize w/1000 gals 15% HCL.
2/29/1972	Deepend well from 4252' to 4285'. Perf 4156 7 4179 1 JSPF, Perf 4186 -419
	2 JSPF & acidze perfs & OH w/6000 gals 15% HCL. Converted well to injec
5/23/1983	Pull to locate csg leak. Unable to get pkr loos. Fish pkr and ck csg OK. R
7/18/1986	Isolate csg leak from 1440' to 2243', 803' bad csg. Set CIBP @ 4100'.
2/3/1987	DO CIBP @4100' and run 5" liner. Set @ 4181'. Cment w/270 sx. Left wt
	in hole. Test annulus between 7" and 5" to 1500 psi held OK.
6/8/2009	Deepen well to 4416'. Acidized w/2000 gals 85/15 & 6000 gals 90/10 Acidto
6/18/2009	Pooh and install on/off tool.

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
127	2-3/8" 4.7# J-55 IPC SC 850 tbg.	4,122.00	4,122.00
1	Weatherford T-2 on/off tool w/1.50" profile nipp	2.00	4,124.00
1	5" X 2-3/8" Arrowset 1X pkr (nickel plated)	7.00	4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00
			4,131.00

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00



Hole Size:
Surf. Csg: 10-3/4"
Set @ 175'
Cement w/ 100 sx
Circ:
TOC:

7" csg leaks from 1440' to 2243'

TOC between 7" and 5" liner is at 2650' from temp survey

Packer @ 4124'

Prod. Csg: 7"
Set @: 4167'
Cmt: Lead:
Tail: 250 sx

Prod. Liner: 5" 15# K-55
Set @: 4181'
Cmt: Lead: 270 sx class C cmt.
Tail:

Original 6-1/8" open hole to 4285'

New 4-1/8" open hole 4285' to 4416'

PBTD 4416'
TD 4416'

Pumping Unit: Injection Well
Updated: 6/19/2009 SDY

Field: Goldsmith Landreth San Andres Unit

GLSAU 203

Wellbore Diagram

	Location:
Footage:	990' FNL & 330' FEL
Section:	32
Block:	44, T-1N
Survey:	T&P RR
County:	Ector
Lat:	
Long:	
	Elevations:
GL:	3197
KB:	3205
KB Calc:	8
ck w/log?	

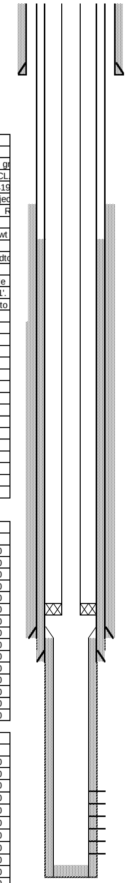
Reservoir:

Well ID Info:	
API No:	
Spud Date:	

Date	History
4/5/1937	Acidized open hole 4167 - 4225' w/5000 gals acid.
4/1/1948	Pull tbg and mill pakcer. Deepen well 27' to 4252'. Plug back to 4205' w/ gr
	sqz gas cap w/350 gals plastic. CO to TD & acidize w/1000 gals 15% HCL.
2/29/1972	Deepend well from 4252' to 4285'. Perf 4156 7 4179 1 JSPF, Perf 4186 -419
	2 JSPF & acidze perfs & OH w/6000 gals 15% HCL. Converted well to injec
5/23/1983	Pull to locate csg leak. Unable to get pkr loos. Fish pkr and ck csg OK. R
7/18/1986	Isolate csg leak from 1440' to 2243', 803' bad csg. Set CIBP @ 4100'.
2/3/1987	DO CIBP @4100' and run 5" liner. Set @ 4181'. Cment w/270 sx. Left wt
	in hole. Test annulus between 7" and 5" to 1500 psi held OK.
6/8/2009	Deepen well to 4416'. Acidized w/2000 gals 85/15 & 6000 gals 90/10 Acidto
6/18/2009	Pooh and install on/off tool.
10/9/2009	Attempt to squeeze off zone 4385' to 4416'. Cement circ around open hole
	pkr and stuck tbg. Fished tbg and milled out tbg to btm of 5" liner at 4181'.
	Sidetracked around cemented tbg in open hole and drilled new open hole to
	4380'. Ran 2-7/8" liner and cemented. CO liner to 4374'. Perf liner 4297'
	to 4365' w/4 JSPF. Acidized w/3500 gals 15% HCL 90/10 Acidtol.
10/8/2010	Change out tbg w/ CLS FG lined tbg w/ AB modified collars

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
129	2-3/8" 4.7# J-55 CLS lined tbg w/AB mod cplg	4,051.00	4,051.00
1	Weatherford T-2 on/off tool w/1.50" profile nipp	2.00	4,053.00
1	7" X 2-3/8" Arrowset 1X pkr (nickel plated)	6.00	4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00
			4,059.00

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00



Hole Size:
Surf. Csg: 10-3/4"
Set @ 175'
Cement w/ 100 sx
Circ:
TOC:

7" csg leaks from 1440' to 2243'

TOC behind 7' calculated to be 2172'

TOC between 7" and 5" liner is at 2650' from temp survey

Arrowset 1X pkr @ 4059'

Prod. Csg: 7"
Set @: 4167'
Cmt: Lead:
Tail: 250 sx

Liner: 5" 15# K-55
Set @: 4181'
Cmt: Lead: 270 sx class C cmt.
Tail:

Sidetracked around cemented tbg and drilled 4-1/4" hole to 4380'.

ROZ Perfs 4297' to 4265' 4 JSPF (272 holes)

Liner: 2-7/8" 6.5# J-55
Top of Liner 4111'
Set @: 4380'
Cmt: Lead: 35 sx class C cmt.
Tail:

PBTD 4374'
TD 4380'

Pumping Unit: Injection Well
Updated: 10/8/2010 MCB

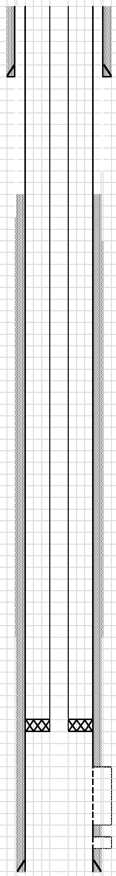
Figure 4.16. CO_2 Injection Wellbore Diagrams: Pattern #190

Field: **Goldsmith Landreth San Andres Unit** — **GLSAU 204R W**

Reservoir: San Andres

	Location:
Footage:	949' FNL & 940' FWL
Section:	32
Block:	44, T-1-N
Survey:	T&P RR Co.
County:	Ector
Lat:	31 deg 58'54.063"
Long:	102 deg 39'45.956"
	Elevations:
GL:	3195
KB:	3206
KB Calc:	11
ck w/log?	Yes

Wellbore Diagram



Well ID Info:	
API No:	42-135-39830
Spud Date:	4/9/2009

Hole Size:	
Surf. Csg:	8-5/8" 24#
Set @	1515'
Cement w/	700 sx
Circ:	Yes
TOC:	Surface
Est TOC:	2600' Bond log

Date	History
5/11/2009	Perf 4404 - 4428' and 4302-4384' w/4 JSPF. Acidized w/5000 gals 15% HCl
	200 bs & 2100# rock salt. Ran inj tbg and pkr. Set pkr @ 4254'.
5/19/2009	Swab test ROZ. Recovered part of FG liner. Test results 4.5% oil cut.
6/16/2009	POOH w/lined tbg and replace w/new CLS FG lined tbg string.

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
133	2-7/8" 6.5# J-55 CLS FG lined tbg	4,243.00	4,243.00
1	T-2 on/off tool w/1.81" profile (nickel coated)	2.00	4,245.00
1	5-1/2" x 2-7/8" Arrowset 1X nickel coated pkr	7.00	4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00
			4,252.00

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00

Hole Size:	
Prod. Csg:	5-1/2" 15.5# J-55
Set @:	4494'
Cmt: Lead:	400 sx Class C 50/50 poz 10% gel
Tail:	100 sx Class C 50/50 poz, 2% gel

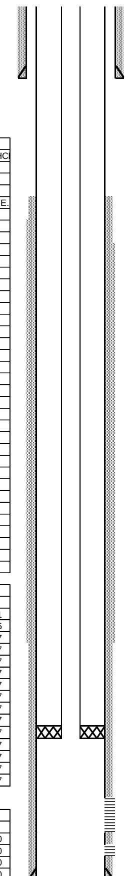
Pumping Unit: Injector
Updated: 6/19//2009 SDY

Field: **Goldsmith Landreth San Andres Unit** — **GLSAU 204R W**

Reservoir: San Andres

	Location:
Footage:	949' FNL & 940' FWL
Section:	32
Block:	44, T-1-N
Survey:	T&P RR Co.
County:	Ector
Lat:	31 deg 58'54.063"
Long:	102 deg 39'45.956"
	Elevations:
GL:	3195
KB:	3206
KB Calc:	11
ck w/log?	Yes

Wellbore Diagram



Well ID Info:	
API No:	42-135-39830
Spud Date:	4/9/2009

Hole Size:	
Surf. Csg:	8-5/8" 24#
Set @	1515'
Cement w/	700 sx
Circ:	Yes
TOC:	Surface
Est TOC:	2600' Bond log

Date	History
5/11/2009	Perf 4404 - 4428' and 4302-4384' w/4 JSPF. Acidized w/5000 gals 15% HCl
	200 bs & 2100# rock salt. Ran inj tbg and pkr. Set pkr @ 4254'.
5/19/2009	Swab test ROZ. Recovered part of FG liner. Test results 4.5% oil cut.
6/16/2009	POOH w/lined tbg and replace w/new CLS FG lined tbg string.
10/4/2010	Perf 4,181' - 4,302' w/ 4 SPF. MIRU CT & acidize w/ 2000 gals 15% NEFE.
	Run CLS tbg w/ AB modified couplings & set pkr at 4,120'.

	Tubing Detail (top to bottom)		
Joints	**Description**	**Footage**	**Depth**
133	2-7/8" 6.5# J-55 CLS FG lined tbg w/ AB mod	4,110.91	4,110.91
1	T-2 on/off tool w/1.81" profile (nickel coated)	1.74	4,112.65
1	5-1/2" x 2-7/8" Arrowset 1X nickel coated pkr	7.42	4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07
			4,120.07

	Rod Detail (top to bottom)		
Rods	**Description**	**Footage**	**Depth**
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00
			0.00

Hole Size:	
Prod. Csg:	5-1/2" 15.5# J-55
Set @:	4494'
Cmt: Lead:	400 sx Class C 50/50 poz 10% gel
Tail:	100 sx Class C 50/50 poz, 2% gel

Pumping Unit: Injector
Updated: 10/4/2010 MCB

Table 4.22. CO_2 Injection and Flow Profile for Pattern #190

CO2 Injection Profile for Production Pattern #190																	June 26, 2015
Injector Well 177				**Injector Well 178**				**Injector Well 203**		**Injector Well 204**							
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011	Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
Gas Cap	0%	0%	0%	Gas Cap	0%	0%	0%	Gas Cap	0%	Gas Cap	0%	0%	0%	19%	4%	11%	
MPZ	0%	16%	8%	MPZ	2%	0%	1%	MPZ	0%	MPZ	0%	0%	0%	47%	61%	54%	
ROZ	100%	84%	92%	ROZ	98%	100%	99%	ROZ	100%	ROZ	100%	100%	100%	34%	35%	35%	
NonPay	0%	0%	0%	NonPay	0%	0%	0%	NonPay	0%	NonPay	0%	0%	0%	0%	0%	0%	
Gas Cap Interv 4144-4174				Gas Cap Interval	4146-4176			Gas Cap Interval	4140-4180	Gas Cap Interval	4152-4181						**Gas Cap**
(ft from top)				(ft from top)				(ft from top)		(ft from top)							**Avg**
10	0%	0%	0%	10	0%	0%	0%	10	0%	10	0%	0%	0%	0%	0%	10%	**2%**
20	0%	0%	0%	20	0%	0%	0%	20	0%	20	0%	0%	0%	0%	0%	6%	**2%**
30	0%	0%	0%	30	0%	0%	0%	30	0%	30	0%	0%	0%	7%	0%	7%	**2%**
40	0%	0%	0%	40	0%	0%	0%	40	0%	40	0%	0%	0%	12%	4%	4%	**1%**
MPZ Interval	4174-4285			MPZ Interval	4176-4285			MPZ Interval	4180-4295	MPZ Interval	4181-4291		Period			Period	**MPZ**
MPZ				MPZ				MPZ		MPZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)				(ft from top)				(ft from top)		(ft from top)							
10	0%	0%	0%	10	0%	0%	0%	10	0%	10	0%	0%	0%	9%	7%	10%	**2%**
20	0%	0%	0%	20	0%	0%	0%	20	0%	20	0%	0%	0%	7%	7%	6%	**2%**
30	0%	0%	0%	30	0%	0%	0%	30	0%	30	0%	0%	0%	2%	16%	7%	**2%**
40	0%	0%	0%	40	0%	0%	0%	40	0%	40	0%	0%	0%	2%	15%	4%	**1%**
50	0%	16%	8%	50	0%	0%	0%	50	0%	50	0%	0%	0%	2%	6%	9%	**4%**
60	0%	0%	0%	60	0%	0%	0%	60	0%	60	0%	0%	0%	13%	2%	8%	**2%**
70	0%	0%	0%	70	0%	0%	0%	70	0%	70	0%	0%	0%	9%	2%	10%	**2%**
80	0%	0%	0%	80	0%	0%	0%	80	0%	80	0%	0%	0%	3%	2%	6%	**1%**
90	0%	0%	0%	90	0%	0%	0%	90	0%	90	0%	0%	0%	1%	2%	3%	**1%**
100	0%	0%	0%	100	0%	0%	0%	100	0%	100	0%	0%	0%	0%	1%	1%	**0%**
110	0%	0%	0%	110	2%	0%	0%	110	0%	110	0%	0%	0%	0%	0%	1%	**0%**
120	0%	0%	0%	120	0%	0%	1%	120	0%	120	0%	0%	0%	0%	0%	0%	**0%**
130	0%	0%	0%	130	0%	0%	3%	130	0%	130	0%	0%	0%	0%	0%	0%	**1%**
Injector Well 177				**Injector Well 178**				**Injector Well 203**		**Injector Well 204**							
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011	Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
ROZ Interval	4285-4400			ROZ Interval	4285-4400			ROZ Interval	4295-4407	ROZ Interval	4291-4410		Period			Period	**ROZ**
ROZ				ROZ				ROZ		ROZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)				(ft from top)				(ft from top)		(ft from top)							
10	11%	0%	6%	10	6%	0%	3%	10	16%	10	0%	0%	0%	0%	0%	0%	**6%**
20	23%	69%	46%	20	6%	15%	11%	20	6%	20	5%	0%	3%	0%	2%	1%	**16%**
30	66%	15%	40%	30	22%	15%	19%	30	23%	30	14%	2%	8%	0%	6%	3%	**21%**
40	0%	0%	0%	40	14%	10%	12%	40	36%	40	10%	11%	11%	16%	6%	11%	**15%**
50	0%	0%	0%	50	16%	18%	17%	50	5%	50	8%	13%	10%	18%	21%	19%	**10%**
60	0%	0%	0%	60	15%	12%	13%	60	3%	60	22%	19%	20%	0%	0%	0%	**4%**
70	0%	0%	0%	70	0%	5%	2%	70	1%	70	13%	16%	15%	0%	0%	0%	**1%**
80	0%	0%	0%	80	7%	11%	9%	80	10%	80	10%	15%	13%	0%	0%	0%	**5%**
90	0%	0%	0%	90	12%	13%	13%	90	0%	90	17%	16%	16%	0%	0%	0%	**3%**
100	0%	0%	0%	100	0%	0%	0%	100	0%	100	0%	8%	4%	0%	0%	0%	**0%**
110	0%	0%	0%	110	0%	0%	0%	110	0%	110	0%	0%	0%	0%	0%	0%	**0%**

4.b.3.5 Distribution of CO_2 Injection Into ROZ (Pattern #190)

While the 4,420 Mmcf of CO_2 entering the ROZ in Pattern #190 equates to 98% of HCPV, (close to the "target" CO_2 injection volumes under "current" technology practices) the vertical distribution of this injected CO_2 varies greatly among the ROZ flow unit and intervals, Table 4.23.

The top two ROZ intervals, together encompassing 28 feet of net pay and holding 318,000 barrels of oil in-place, have each received nearly 2 HCPV of CO_2, considerably more than the "target" 1 HCPV.

The next ROZ interval, encompassing 23 feet of net pay and holding 201,000 barrels of oil in-place has received 1.16 HCPV of CO_2.

The basal ROZ interval, encompassing 28 feet of net pay and holding 330,000 barrels of oil in-place, has received very little (0.12 HCPV) CO_2.

Table 4.23. Distribution of CO_2 Injection Into ROZ (Pattern #190)

ROZ Interval	Net Pay	ROIP	Volume of CO2 Injection	HCPV of ROZ		Volume of CO2 Injection
(ft)	(ft)	(M Bbls)	(Mmcf)	(M Bbls)	(Mmcf of CO2)	(HCPV)
Top 20	12	120	1,110	240	570	1.95
Next 20	16	200	1,900	400	960	1.98
Next 40/50	23	200	1,170	420	1,010	1.16
Base 30	28	330	240	820	1,970	0.12
TOTAL	**79**	**850**	**4,420**	**1,880**	**4,510**	**0.98**

4.b.3.6 Distribution of CO_2 Injection into MPZ: GLSAU "Pilot Test" (Pattern #190)

The 830 Mmcf of CO_2 injected into the MPZ in the GLSAU ROZ "Pilot Test" equates to only 13% of HCPV, Table 4.24.

The Gas Cap, containing 220 thousand barrels of oil in-place, has received 0.11 HCPV of CO_2.

The top two MPZ (oil) units, containing a combined 550 thousand barrels of oil in-place, have received about 0.2 HCPV of CO_2.

The next MPZ (oil) unit containing 300 thousand barrels of oil in-place, has received less than 0.1 HCPV of CO_2.

The base MPZ unit, containing a 130 thousand barrels of oil in-place, has only little CO_2.

Table 4.24. Distribution of CO_2 Injection into MPZ: GLSAU ROZ "Pilot Area"

MPZ Interval	Net Pay	ROIP	Volume of CO2 Injection	HCPV of MPZ		Volume of CO2 Injection
(ft)	(ft)	(M Bbls)	(Mmcf)	(M Bbls)	(Mmcf of CO2)	(HCPV)
Gas Cap (30 ft)	20	220	120	470	1,120	0.11
Top 30	23	230	270	550	1,330	0.20
Next 30	26	320	320	630	1,510	0.21
Next 30	22	300	110	650	1,560	0.07
Base 20	13	130	10	290	700	0.01
TOTAL	**104**	**1,200**	**830**	**2,590**	**6,220**	**0.13**

4.b.4. CO_2 Injection Profiles: GLSAU "Study Area"

4.b.4.1 The GLSAU MPZ/ROZ "Study Area"

The GLSAU MPZ/ROZ project established a confined MPZ/ROZ "Study Area" to better understand how CO_2 injection into the dual San Andres MPZ/ROZ interval would perform in the Goldsmith oil field.

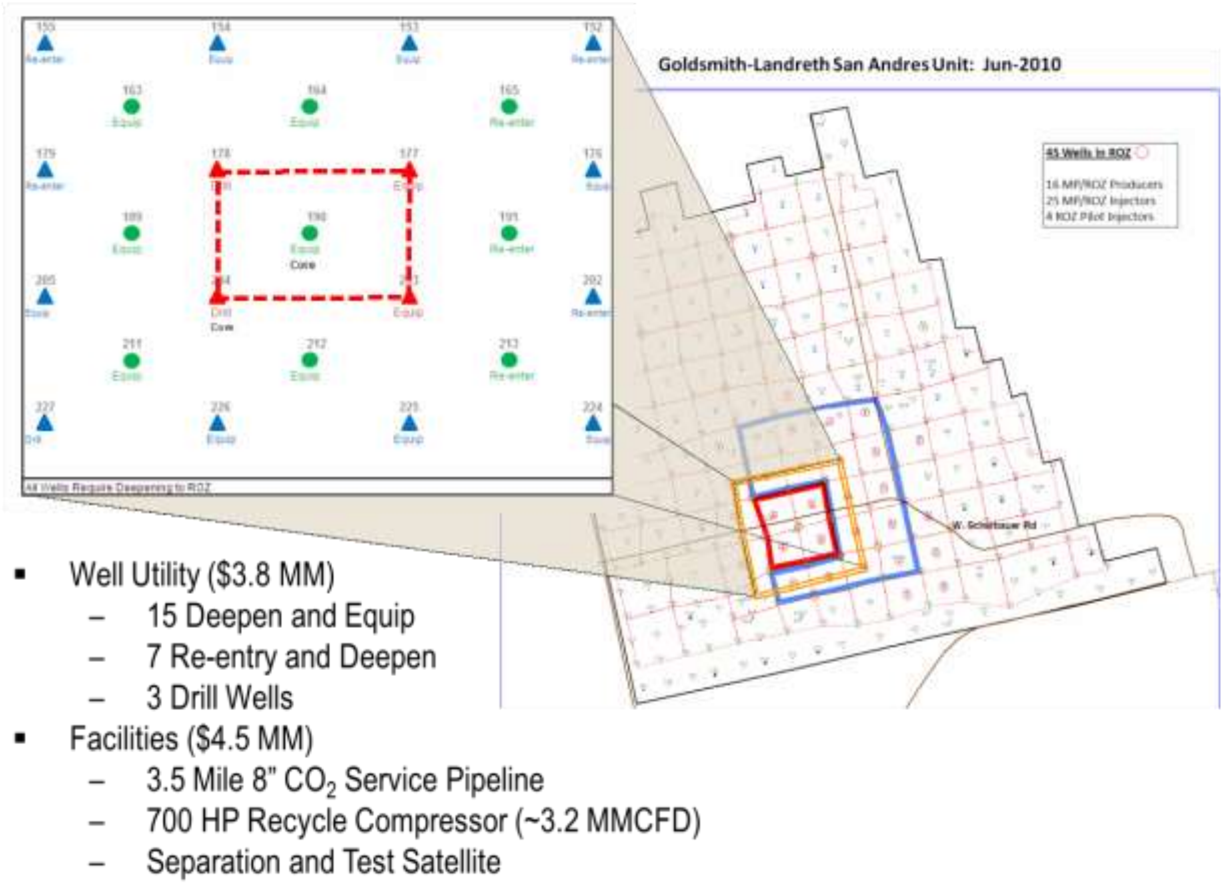
The MPZ/ROZ "Study Area" consisted of nine production wells (patterns) surrounded by 16 CO_2 injection wells, Figure 4.17.

A significant amount of effort was undertaken within the MPZ/ROZ "Study Area", including deepening 22 existing wells and drilling 3 new wells as well as installing a host of field facilities.

The 16 CO_2 injection wells have a variety of well completion practices, with open-hole (OH) being the most common practice.

CO_2 injection started in mid- to late-2009, followed by expansion of CO_2 injection into the "Study Area" in 2010 and 2011.

Figure 4.17. GLSAU ROZ "Study Area" and Pilot Test Facility



Source: Legado Resources, 2010.

4.b.4.2 CO_2 Injection into the GLSAU "Study Area"

Overall, 55.2 Bcf of CO_2 has been injected into the 16 CO_2 injection wells located in the GLSAU CO_2-EOR Pilot. Of this volume:

35.8 Bcf entered the 9 pattern GLSAU "Study Area", with the remaining 19.4 Bcf entering the 16 patterns surrounding the "Study Area".

The bulk of the 33.8 Bcf of injected CO_2, 21.2 Bcf (59%) entered the ROZ, particularly in patterns #190 and #191 where many of the CO_2 injection wells were completed in the ROZ only.

Approximately 12.8 Bcf of the injected CO_2 (36%) has entered the MPZ, with 1.8 Bcf (5%) entering other non-pay reservoir intervals.

Table 4.25 tabulates the volume of injected CO_2 and the distribution of the injected CO_2 for: (1) each of the nine production patterns in the GLSAU "Study Area" and (2) the distribution of the injected CO_2 into the MPZ and ROZ.

4.b.4.3 Effectiveness of CO_2 Injection into the MPZ: GLSAU "Study Area"

The 12,740 Mmcf of CO_2 injected into the MPZ in the GLSAU "Study Area" equates to only 23% of HCPV; however, the CO_2 that has been injected into the MPZ has been distributed fairly uniformly across the five vertical flow units, Table 4.26:

The Gas Cap, a fairly attractive target containing 1.95 million barrels of oil in-place, has received 0.19 HCPV of CO_2.

The top two MPZ (oil) units, containing a combined 4.96 million barrels of oil in-place, have received about 0.3 HCPV of CO_2.

The bottom two MPZ units, containing a combined 3.83 million barrels of oil in-place, have each received a little over 0.15 HCPV of CO_2.

4.b.4.4 Effectiveness of CO_2 Injection into the ROZ: GLSAU "Study Area"

While the 21,250 MMcf of CO_2 entering the ROZ in the "Study Area" equates to 52% of HCPV, the vertical distribution of this injected CO_2 varies greatly among the ROZ flow units and intervals, Table 4.27.

The top ROZ interval (flow unit), encompassing 12 feet of net pay and holding 1.07 million barrels of oil in-place, has received 1.25 HCPV of CO_2.

The second ROZ interval, encompassing 16 feet of net pay and holding 1.79 million barrels of oil in-place, has received 0.93 HCPV of CO_2.

The third ROZ interval, encompassing 23 feet of net pay and holding 1.81 million barrels of oil in-place, has received 0.68 HCPV of CO_2.

The basal ROZ interval, encompassing 28 feet of net pay and holding 2.97 million barrels of oil in-place, has received essentially no CO_2.

Table 4.25. CO_2 Injection into the GLSAU "Study Area"

CO2 Injection	GLSAU "Study Area": CO2 Volume by Production Pattern (Bcf)									TOTAL (Bcf)
	#163	**#164**	**#165**	**#189**	**#190**	**#191**	**#211**	**#212**	**#213**	
2009	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.2	0.0	**0.7**
2010	0.3	0.6	0.3	0.6	1.3	0.7	0.4	0.9	0.5	**5.6**
2011	0.5	1.0	1.1	0.5	1.1	1.2	0.5	1.1	1.1	**8.2**
2012	0.6	1.0	1.1	0.7	1.2	1.3	0.6	1.3	1.0	**8.8**
2013	0.3	0.6	0.9	0.6	0.6	0.7	1.1	1.1	0.9	**6.8**
2014	0.4	0.4	0.5	0.6	0.7	0.6	0.9	0.7	0.7	**5.5**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**
Gas Cap	13%	10%	8%	4%	2%	5%	4%	3%	5%	**5%**
MPZ	34%	28%	31%	34%	13%	14%	67%	37%	26%	**30%**
ROZ	42%	58%	45%	58%	84%	68%	29%	60%	68%	**59%**
NonPay	11%	3%	17%	3%	0%	13%	0%	1%	2%	**5%**
Gas Cap Volume	0.3	0.4	0.3	0.1	0.1	0.2	0.1	0.1	0.2	**1.9**
MPZ Volume	0.7	1.0	1.2	1.1	0.7	0.6	2.5	1.9	1.1	**10.8**
ROZ Volume	0.9	2.1	1.7	1.9	4.4	3.2	1.1	3.1	2.8	**21.2**
NonPay Volume	0.2	0.1	0.6	0.1	0.0	0.6	0.0	0.0	0.1	**1.8**
Total	**2.1**	**3.6**	**3.8**	**3.2**	**5.2**	**4.6**	**3.7**	**5.3**	**4.1**	**35.8**

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Table 4.26. Distribution of CO_2 Injection to MPZ: GLSAU "Study Area"

MPZ Interval	Net Pay	ROIP	Volume of CO_2 Injection	HCPV of MPZ		Volume of CO_2 Injection
(ft)	(ft)	(M Bbls)	(Mmcf)	(M Bbls)	(Mmcf of CO2)	(HCPV)
Gas Cap (30 ft)	20	1,950	1,910	4,190	10,060	0.19
30	23	2,060	4,170	4,980	11,950	0.35
30	26	2,900	3,530	5,650	13,560	0.26
30	22	2,670	2,060	5,830	13,990	0.15
20	13	1,160	1,070	2,620	6,290	0.17
TOTAL	**104**	**10,740**	**12,740**	**23,270**	**55,850**	**0.23**

Table 4.27. Distribution of CO_2 Injection into the ROZ: GLSAU Study Area

ROZ Interval	Net Pay	ROIP	Volume of CO2 Injection	HCPV of ROZ		Volume of CO2 Injection
(ft)	(Ft)	(M Bbls)	(Mmcf)	(M Bbls)	(Mmcf of CO2)	(HCPV)
Top 20	12	1,070	6,470	2,150	5,170	1.25
Next 20	16	1,790	8,090	3,630	8,700	0.93
Next 40/50	23	1,810	6,230	3,820	9,170	0.68
Base 30	28	2,970	460	7,360	17,660	0.03
TOTAL	**79**	**7,640**	**21,250**	**16,960**	**40,700**	**0.52**

4.c Modeling the Performance of the ROZ CO_2-EOR Pilot Using Next Generation Feedback and Control Technology

4.c.1 Background.

The Goldsmith oil field is located in Ector County, West Texas. It is on the eastern edge of the middle portion of the Central Basin Platform, a prominent geological feature of the Permian Basin.

The Goldsmith oil field contains a series of “units”. The Goldsmith-Landreth San Andres Unit (GLSAU) is currently operated by Kinder Morgan CO_2 Company. The large Goldsmith San Andres Unit (GSAU), to the south of GLSAU, is currently operated by XTO (part of ExxonMobil), Figure 4.18.

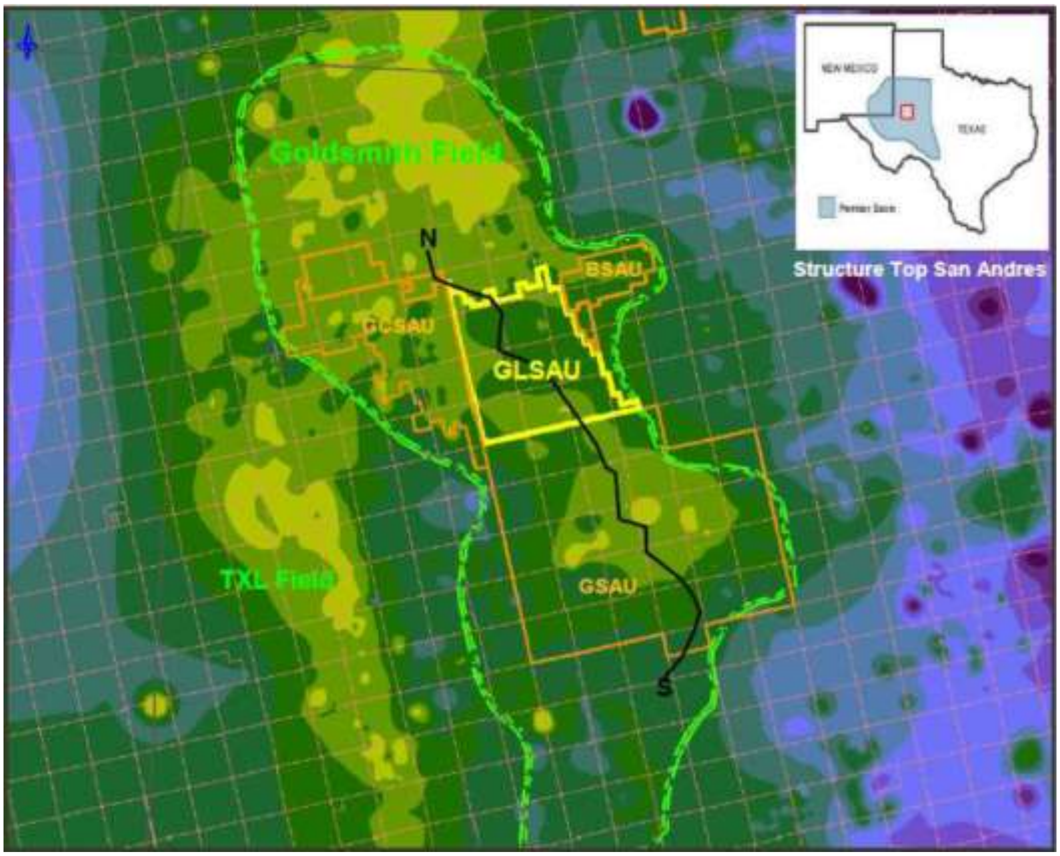
The GLSAU is the location of the joint industry/NETL field research project entitled: “Next-Generation CO_2-EOR Technologies to Optimize the Residual Oil Zone CO_2 Flood at the Goldsmith-Landreth Unit, Ector County, Texas.” The project is conducted by the University of Texas of the Permian Basin (UTPB), KinderMorgan, Melzer Consulting, and Advanced Resources International.

4.c.2 Goals and Objectives of the Field Research Project at GLSAU

The goal of the joint industry/NETL field research project at the Goldsmith-Landreth San Andres Unit (GLSAU) is to optimize the technical and economic performance of a residual oil zone (ROZ) carbon dioxide (CO_2) flood and transfer the knowledge to other operators.

The four objectives of the GLSAU research project are to: (1) characterize the MPZ and the ROZ within the GLSAU “Study Area”; (2) conduct analyses and reservoir simulations to evaluate the performance of the ROZ pilot flood; (3) provide recommendations for actions that might improve the performance of the CO_2 flood in the ROZ; and (4) transfer the insights from this field-based research project.

Figure 4.18 Goldsmith Field Complex



Source: Legado Resources, 2015

The GLSAU project has considerable interest in determining whether simultaneous injection of CO_2 into the MPZ and ROZ would prove to be feasible:

> The Goldsmith-Landreth project is a little different from other quaternary efforts because Legado is, from the onset of CO_2 flooding, simultaneously injecting into both the MPZ and the deeper ROZ in an attempt to produce both at the same time, points out Tom Thurmond, Engineering Manager.
>
> "I believe we are the first to develop the ROZ contemporaneously with the MPZ. It is an opportunity to do something that, on one hand, has not been done before, but on the other hand, is an extension of technology that has been around for 30 years. We have made that our niche, doing something that is a little bit new by taking existing technology and expanding its application."

Source: **American Oil & Gas Reporter**
December 29, 2011

4.c.3 GLSAU Reservoir Characterization

A major geologic and reservoir characterization effort was conducted as part of the CO_2–EOR field research project at the GLSA Unit, including:

Deepening of existing wells through the ROZ,

A major CO_2 tracer program to establish CO_2 injection and flow profiles for both the MPZ and the ROZ.

A whole core in production Well #190, from the top of the ROZ into the low oil saturation San Andres limestone below the base of the commercial ROZ interval.

A whole core in CO_2 injection Well #204R, from the Gas Cap at the top of the MPZ and ROZ into the low oil saturation San Andres limestone below the base of the commercial ROZ interval.

The information from this extensive geologic and reservoir characterization proved to be most valuable for establishing the reservoir properties of the ROZ and MPZ, the distribution of the remaining oil in-place, and the CO_2 "flow units" within the 40-acre GLSAU ROZ "Pilot Test" (Pattern #190), Figure 4.19.

The core and log based data on net pay, the porosity of net pay, and the oil saturation of net pay for wells #190 and #204R (in Pattern #190) are shown on Table 4.c.1. The data are provided by 10 foot intervals from the top of the ROZ to the base of.

Figure 4.19. The GLSAU ROZ "Pilot Test": Pattern #190

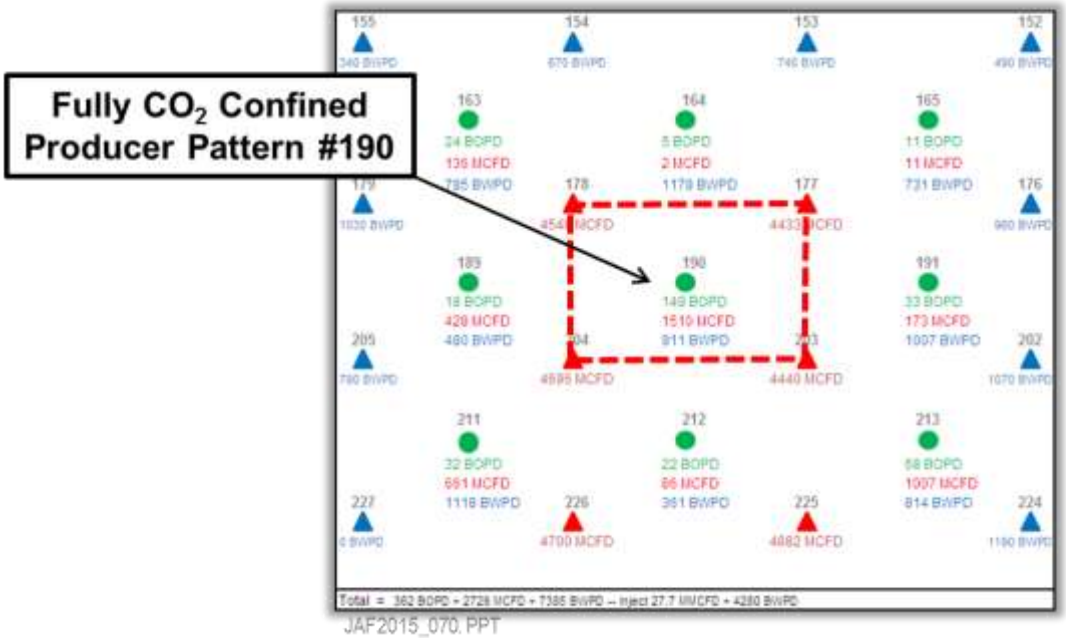


Table 4.28 ROZ Reservoir Properties: Pattern #190

Ft from Top of ROZ	Well #190			Well #204R		
	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay
	(feet)	(%)	(%)	(feet)	(%)	(%)
10	7	8	45	4	11.1	48
20	5	7.8	50	7	9.7	40
30	9	10.0	53	10	14.3	41
40	6	10.9	43	6	8.9	41
50	2	6.7	46	6	10.0	35
60	6	7.2	47	6	8.1	45
70	5	8.6	45	5	8.7	46
80	8	9.3	40	2	7.7	45
90	8	11.2	56	5	7.4	44
100	10	15.7	44	8	7.7	30
110	10	17.3	32	10	10.4	34
				10	12.7	27
Total	**76**	**11.0**	**46**	**79**	**10.2**	**38**

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the ROZ, covering depths of 4,280' to 4,390' for well #190 and depths of 4,290' to 4,410' for well #204R

Below the commercial base of the ROZ (at 4,390' to 4,450') is an extensive free water zone with low (non-commercial) oil saturation. This interval, below the base of the commercial ROZ interval, has relatively attractive porosity (9% to 11%) but low (non-commercial) levels of oil saturation (9% to 23%), as shown by the core- and log-based data for Wells #190 and #204R, Tables 4.29 and 4.30.

Table 4.29. Below ROZ Reservoir Properties for Well #190

Well #190			
Depth (ft)	**Net Pay (ft)**	**Porosity of Net Pay (ft)**	**Oil Saturation of Net Pay (%)**
4390-4400	9	9.1	15%
4400-4410	10	10.6	13%
4410-4420	10	10.3	8%
4420-4430	6	8.6	15%

Table 4.30. Below ROZ Reservoir Properties for Well # 204R

Well #204R			
Depth (ft)	**Net Pay (ft)**	**Porosity of Net Pay (ft)**	**Oil Saturation of Net Pay (%)**
4410-4420	7	10	14%
4420-4430	7	10.3	23%
4430-4440	10	9.8	12%
4440-4450	10	11.0	11%

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4.c.4 ROZ Oil In-Place and Flow Units for Pattern #190

The full set of reservoir properties for Pattern #190 are provided in Table 4.31. These reservoir properties were used to estimate the remaining oil in-place of 855,000 barrels for the ROZ in the 40-acre Pattern #190 and to establish the higher and lower oil concentration intervals for the ROZ in Pattern #190, Table 4.32.

Table 4.31. Reservoir Properties: ROZ Interval in Pattern #190

	ROZ
Area (Ac)	40
Depth (ft)	
▪ Top	4,290'
▪ Base	4,300' to 4,310'
Net Pay (ft)	
▪ Gross	110' to 120'
▪ Net	78'
Porosity (%)	10.6%
Oil Saturation (%)	
▪ Initial	74% (e)
▪ Current	41%
Initial Pressure (psi)	1,760
Temperature (^{o}F)	96
Oil Gravity (^{o} API)	34
Formation Volume Factor	1.23

Table 4.32 Reservoir Properties and Oil In-Place: ROZ Interval in Pattern #190

ROZ Interval (ft from top)	Net Pay (ft)	Oil Concentration* (Bbls/AF)	Resource Volume (Acre-feet)	Oil In-Place (M Bbls)
#1. Top 20	11.5	257	460	120
#2. Next 20	15.5	321	620	200
#3. Next 40/50	23.0	223	920	205
#4. Base 30	28.0	295	1,120	330
Total	**78.0**	**274****	**3,120**	**855**

*In stock tank barrels using a FVF of 1:23. **Average

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At the top of the ROZ (in the Upper ROZ) is a 20' (gross), 11.5' (net pay) moderate oil concentration interval, with 120,000 barrels of OIP.

A higher oil concentration ROZ interval, with 200,000 barrels of OIP, exists in the second 20' (gross), 15.5' (net pay) interval in the middle of the Upper ROZ.

A lower oil concentration ROZ interval, with 205,000 barrels of OIP, exists in the extensive 40' to 50' (gross), 23' (net pay) interval at the bottom of the Upper ROZ

Much of the oil in-place, 330,000 barrels, is in the 30' (gross), 28' (net pay) in the Lower ROZ interval at the base of the commercial an attractive ROZ in Pattern #190.

Below the base of the commercially attractive ROZ (at $\pm$4,400') is an extensive low oil saturation (non-commercial) interval. Core analysis of the first 40 feet of this interval showed moderate porosity (10%) and low oil saturation (14%).

The core and log-based reservoir properties for wells #190 and #204R were combined to establish four distinct ROZ flow units for Pattern #190, Table 4.33.

Table 4.33 ROZ Flow Units for Pattern #190

ROZ Flow Unit	Well #190			Well #204R			Avg. of Wells #190 and #204R		
	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay	Net Pay	Porosity of Net Pay	Oil Saturation of Net Pay
(ft)	(ft)	(%)	(%)	(ft)	(%)	(%)	(ft)	(%)	(%)
#1. Top 20	12	7.9	47	11	10	43	**11.5**	**9.1**	**45**
#2. Next 20	15	10.4	49	16	12	41	**15.5**	**4.3**	**45**
#3. Next 40/50	21	7.9	44	24	9	43	**23.0**	**8.2**	**43**
#4. Base 30	28	15.0	43	28	11	30	**28.0**	**12.7**	**37**
Total/ Average	**76**	**11.0**	**45**	**79**	**10.2**	**38**	**78.0**	**10.6**	**41**

*Based on 30 feet in Well #190 and 40 feet in Well #204R. **Net pay weighted average for porosity and oil saturation. JAF2015_028.XLS

4.c.5 Establishing the CO_2 Injection Profile for Pattern #190

Overall, 21 Bcf of CO_2 has been injected into the four CO_2 injection wells surrounding the GLSAU CO_2-EOR "Pilot Test" (Pattern #190) through the end of 2014.

Of the estimated the 21 Bcf of CO_2 injected, 5.25 Bcf entered Pattern #190, with the remaining 15.75 Bcf of CO_2 entering the eight patterns surrounding Pattern #190.

Of the 5.25 Bcf of CO_2 injected into Pattern #190, 4.42 Bcf entered the ROZ and 0.83 Bcf entered the MPZ. The use of three "ROZ only" completions in CO_2 injection wells #177, #178 and #203 and one "dual MPZ/ROZ" completion in Well #204 (the four CO_2 injection wells surrounding Pattern #190) directed the bulk of the injected CO_2 into the ROZ.

While the 4.42 Bcf of CO_2 entering the ROZ in Pattern #190 equates to 98% of HCPV (close to a "target" CO_2 HCPV injection value of 100% of HCPV), the vertical distribution of this injected CO_2 varies greatly among the four ROZ flow units of Pattern #190, Table 4.34.

The top two ROZ flow units, together holding 27 feet of net pay and 320,000 barrels of oil in-place, have each received nearly 2 HCPV of CO_2.

The third ROZ flow unit, with 23 feet of net pay and 205,000 barrels of oil in-place, has received 1.16 HCPV of CO_2.

The basal ROZ flow unit, with 28 feet of net pay and 330,000 barrels of oil in-place, has received very little (0.12 HCPV) CO_2.

Table 4.34. Distribution of CO_2 Injection, Pattern #190

ROZ Interval	ROZ Net Pay	ROZ OIP	Volume of CO2 Injection into Pattern #190	One HCPV of ROZ in Pattern #190		Volume of CO2 Injection into Pattern #190
(ft)	(ft)	(M Bbls)	(MMcf)	(M Bbls)	(MMcf of CO2)	(HCPV)
#1. Top 20	11.5	120	1,110	240	570	1.95
#2. Next 20	15.5	200	1,900	400	960	1.98
#3. Next 40/50	23.0	205	1,170	420	1,010	1.16
#4. Base 30	28.0	330	240	820	1,970	0.12
TOTAL	**78**	**855**	**4,420**	**1,880**	**4,510**	**0.98**

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4.c.6 Modeling the ROZ CO_2 Flood: History Matching the Performance of Pattern #190 "Pilot Test"

To analyze the performance of the ROZ flood in Pattern #190 and assess its future performance, we modeled the ROZ CO_2 flood using CO_2-PROPHET, a stream tube reservoir simulator. Because three of the four injection wells in Pattern #190 are not completed in the bottom flow unit of the ROZ, the CO_2 flood was only placed in the top three flow units of the ROZ, consisting of 50 feet of net pay, and excluded the bottom 28 feet of pay in the ROZ.

We then injected similar annual volumes of CO_2 and water in CO_2-PROPHET as actually injected into the ROZ in Pattern #190, as shown in Figure 4.20 and 4.21.

Figure 4.20. Cumulative Water Injection (MBbls)

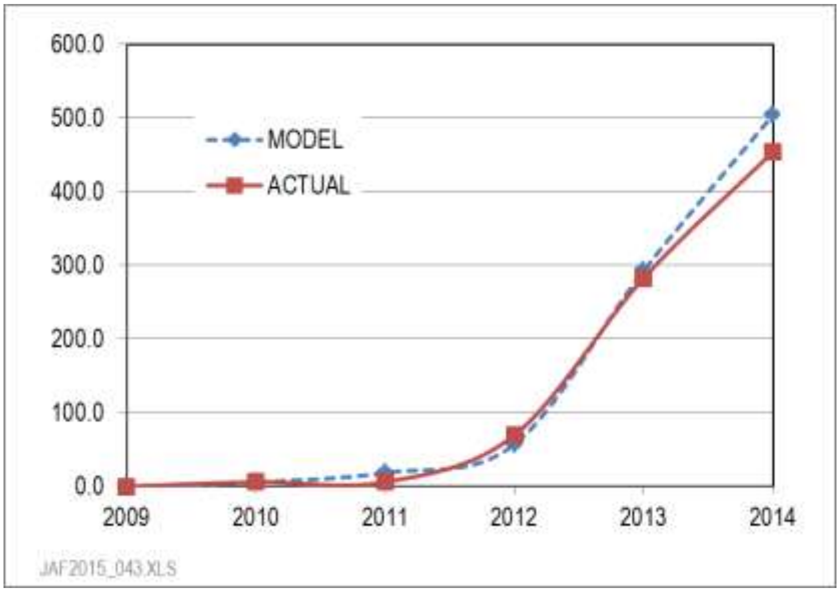
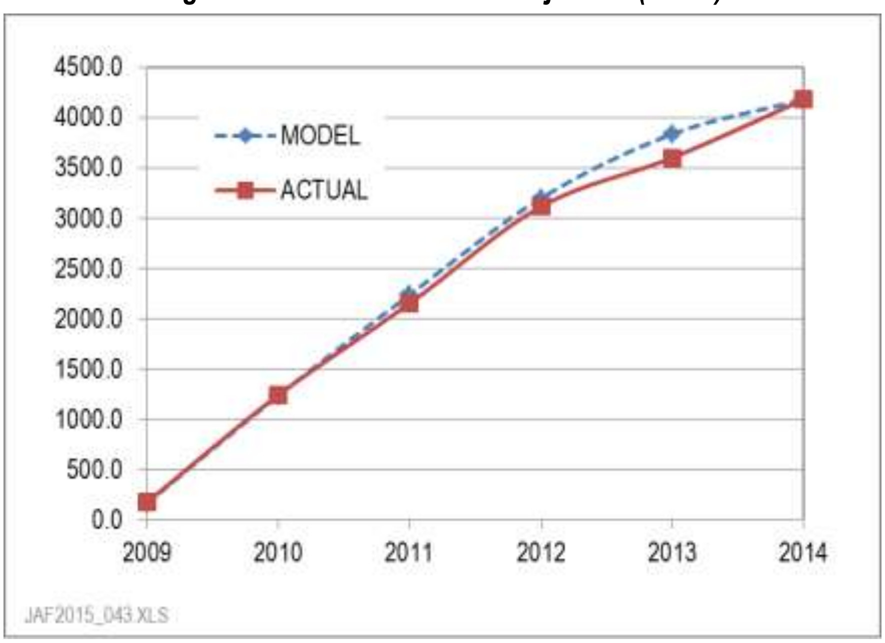


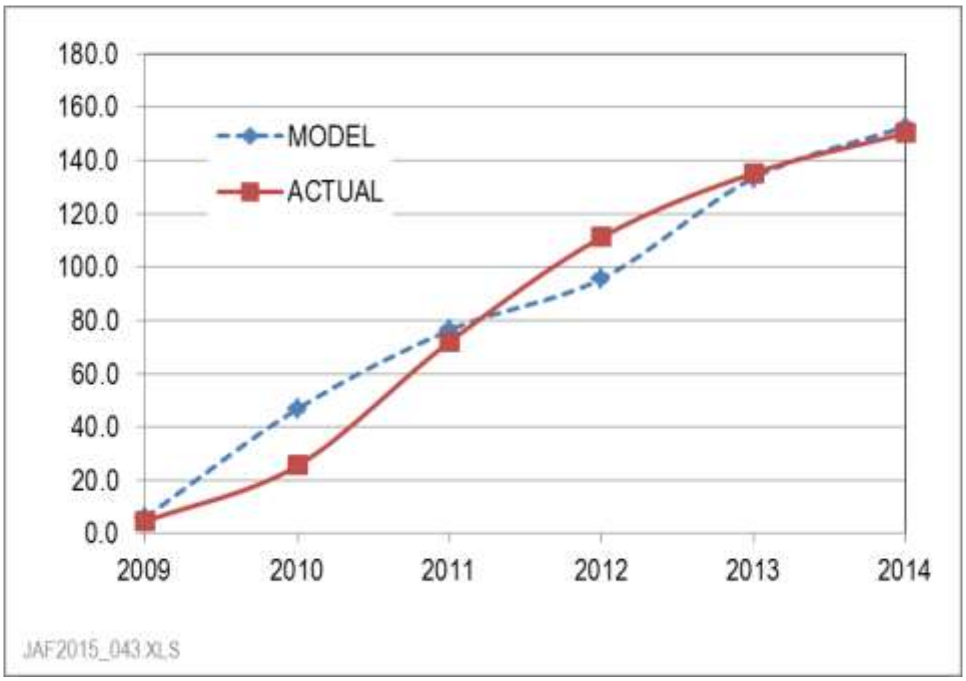
Figure 4.21. Cumulative CO2 Injection (Mmcf)



The CO_2-PROPHET calculated oil production from the ROZ in Pattern #190 closely matched actual oil production, Figure 4.22. This provides confidence that CO_2-

PROPHET can be used to give a reasonable estimate of future flood performance and can also be used to examine ways to improve the flood using information gained from next generation feedback and control technology. In addition, as discussed further below and in Section 3 of this report, we also applied the fully compositional finite-difference reservoir simulator, GEM, to the analysis of ROZ performance in Pattern #190. Modeling using GEM provided results comparable to the results from CO_2-PROPHET.

Figure 4.22 Cumulative Oil Production (History Match) (MBbls)



At the end of 2014, after six years of operations, Pattern #190 had produced a cumulative of 166,800 barrels of oil. Of this, 150,200 barrels are estimated from the ROZ with the remaining 16,600 barrels from the MPZ, Table 4.35.

Table 4.35. Oil Production from GLSAU ROZ "Pilot Test" (Pattern #190)

Years	Total Pattern (Bbls)	ROZ (Actual) (Bbls)	ROZ (CO2-PROPHET) (Bbls)
2009	5,100	4,600	6,100
2010	23,200	20,900	40,700
2011	51,700	46,500	29,600
2012	43,500	39,200	19,300
2013	26,800	24,100	37,800
2014	16,500	14,900	19,300
Sub-Total	**166,800**	**150,200**	**152,800**
After 2014	**-**	**-**	**29,600**
Total			**182,400**

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CO_2-PROPHET calculated 152,800 barrels of oil recovery from the ROZ in Pattern #190, a result within 2% of actual oil recovery of 150,200 barrels.

The GEM compositional simulator calculated 152,000 barrels of oil recovery from the ROZ in Pattern #190, a value essentially the same as calculated by CO_2-PROPHET (see discussion in Section 3 of the report).

Continued operation of the project with water injection (but no additional CO_2 injection) would provide an additional 30,000 to 50,000 barrels of oil, based on the CO_2-PROPHET and GEM models respectively.

As such, without changes to well completions or flood designs, the ROZ in Pattern #190 would provide from 180,000 to 200,000 barrels of oil recovery, equal to 21% to 24% of OIP in the ROZ.

However, as shown by the CO_2 tracer surveys, essentially all (95%) of the injected CO_2 (4,180 Mmcf of the 4,420 Mmcf injected) entered the top three ROZ flow units (Flow Units #1, #2 and #3) that contain 520,000 barrels of OIP and only 5% (240 Mmcf) entered the lower ROZ Flow Unit (Flow Unit #4). Using only the OIP in the top three ROZ Flow Units, the recovery of 180,000 to 200,000 barrels of oil would represent 35% to 38% recovery of OIP.

4.c.7 Optimizing the ROZ CO_2 Flood

One option for improving the ROZ CO_2 flood would be to undertake a CO_2 conformance program for the ROZ in Pattern #190. This would involve:

Plugging the top three ROZ Flow Units (#1, #2 and #3), because the top two Flow Units have each already received nearly 2 HCPV and the third Flow Unit has already received nearly 1.2 HCPV of CO_2.

Targeting the CO_2 injection into the fourth ROZ Flow Unit (#4) that has only received 0.1 HCPV of CO_2. This Flow Unit, with 28 feet of net pay and an oil concentration of 295 B/AF, has 330,000 barrels of OIP, with very little of this OIP produced to date.

Our evaluation of this strategy, using GEM and CO_2-PROPHET, indicates that an additional 75,000 to 102,700 barrels of oil would be recovered from the ROZ, as shown for the results from CO_2-PROPHET modeling, Table 4.36

Table 4.36. CO_2-PROPHET Based Cumulative Oil, Production and CO2 Injections, ROZ Flow Unit #4 in Pattern #190

Years	Cumulative Oil Production (Barrels)	Cumulative CO2 Injection (MMcf)
1	35,900	110
2	61,300	250
3	78,800	394
4	91,700	503
5	102,700	850

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Adding together actual oil recovery from the ROZ of 150,200 barrels (years 2009-2014), the additional oil recovery from follow-on water injection (years 2015-2020) and expected oil production from targeting the unswept ROZ Flow Unit #4, would enable oil production from the ROZ in Pattern #190 to reach 275,200 to 285,800 barrels, equal to 32% to 33% of OIP, Table 4.37.

Table 4.37. Potential Oil Recovery from ROZ in Pattern #190

	GEM Model	CO2-PROPHET Model
	(Barrels)	(Barrels)
Actual (Years 2009-2014)	150,200	150,200
Water Injection (Years 2015-2020)	50,000	29,600
ROZ Interval #4	75,000	102,700
Total	**275,200**	**282,500**
JAF2015_043.XLS		

4.c.8 Simultaneous vs. Sequential MPZ/ROZ Flooding

As set forth in the introductory materials, a major research goal of the GLSAU project was to determine whether simultaneous injection of CO_2 into the MPZ and the deeper ROZ would efficiently displace oil from both intervals.

To address this question, we used the CO_2-PROPHET model to assess how Pattern #190 would perform: (1) if all four CO_2 injection wells (#176, #177, #203 and #204) were dually completed and simultaneously flooded in the ROZ and MPZ, and (2) if the operators were to separately and sequentially CO_2 flood the MPZ and ROZ. For the sequential MPZ/ROZ CO_2 flood case, we assumed the operator would first complete and inject CO_2 only into the MPZ and then plug off the MPZ and inject CO2 into only into the ROZ.

For this analysis, we needed to establish the reservoir properties of the MPZ in Pattern #190 and place these properties, along with the CO_2 injection design, into CO_2-PROPHET. As part of reservoir characterization of the GLSAU “Study Area” , core data were obtained for the Gas Cap and MPZ intervals in Well #204R. The Well #204R core data were used to establish the net pay, the porosity of net pay, and the oil saturation of net pay for the Gas Cap and the MPZ, for depths from 4150’ to 4290’ in Pattern #190, Table 4.38.

Table 4.38. MPZ Reservoir Properties for Pattern #190

Well # 204R				
San Andres Interval	Core Depth	Net Pay	Average Porosity of Net Pay	Average So of Net Pay
		(Feet)]	(%)	(%)
Gas Cap	4150-4160*	2	9.8	40
	4160-4170	10	11.7	41
	4170-4180	8	8.3	43
Main Pay	4180-4190	8	10.9	31
	4190-4200	9	10.3	45
	4200-4210	6	10.2	32
	4210-4220	8	12	45
	4220-4230	9	10.6	50
	4230-4240	9	9.1	42
	4240-4250	8	12.6	40
	4250-4260	7	13.5	40
	4260-4270	7	12.4	42
	4270-4280	5	9	40
	4280-4290	8	10.2	39
	Total	**104**	**10.8***	**42***

*Net pay weighted average for porosity and net pay.

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As shown in Table 4.38, the Main Pay Zone in Pattern #190 contains a 30' (gross), 20' (net pay) Gas Cap interval and a 110' (gross), 84' (net pay) MPZ interval. A low permeability reservoir interval separates the MPZ and the ROZ in Pattern #190. The full set of MPZ and ROZ reservoir properties for Pattern #190 are set forth in Table 4.39.

Based on these reservoir properties, Pattern #190 holds the following estimated volumes of original and remaining oil in-place:

- MPZ (OOIP) 2.10 million barrels
  (OIP) 1.20 million barrels

- ROZ (OOIP) 1.54 million barrels (estimated)
  (OIP) 0.85 million barrels

Table 4.39. MPZ and ROZ Reservoir Properties for Pattern #190

	MPZ	ROZ
Area (Ac)	40	40
Depth (ft)		
▪ Top	4,150’	4,290’
▪ Base	4,290’	4,300’ to 4,310’
Net Pay (ft)		
▪ Gross	140’	110’ to 120’
▪ Net	104’	78’
Porosity (%)	10.8%	10.6%
Oil Saturation (%)		
▪ Initial	74%	74% (e)
▪ Current	42%	41%
Initial Pressure (psi)	1,710	1,760
Temperature (^{o}F)	95	96
Oil Gravity (^{o} API)	34	34
Formation Volume Factor	1.23	1.23

Our modeling showed that flooding the MPZ, then plugging off the MPZ and flooding the ROZ (a sequential MPZ/ROZ flood) is more effective than injecting CO_2 into dually completed MPZ and ROZ wells (a simultaneous MPZ/ROZ flood).

The simultaneous MPZ/ROZ flood recovers 496,000 barrels of oil in 12 years, equal to a recovery efficiency of 24% of OIP and 14% of estimated OOIP. The sequential MPZ/ROZ flood enables more of the CO_2 to contact the ROZ, improving oil recovery by 166,000 barrels, thus increasing overall oil recovery from the MPZ and ROZ in Pattern #190 to 662,000 barrels, equal to 32% OIP and 18% of estimated OOIP, Table 4.40 and Figure 4.23.

In addition, the sequential MPZ/ROZ flood reduces the gross (purchased plus recycled) CO_2/oil ratio to 16 Mcf/B from 21 Mcf/B for the simultaneous MPZ/ROZ flood, Figure 4.24. (The net or purchased CO_2/oil ratio is estimated at 10 Mcf/B for the sequential MPZ/ROZ flood and at 13 Mcf/B for the simultaneous MPZ/ROZ flood.)

The actual CO_2 injection experience in Pattern #190 is consistent with the results of CO_2-PROPHET modeling. The CO_2 tracer surveys in Pattern #190 showed that in dually completed CO_2 injection wells, 83% of the CO_2 entered the GasCap MPZ with only 17% of the CO_2 entering the ROZ. (See discussion in Section 4.c.2 of this report.)

Table 4.40. Performance of Sequential vs. Simultaneous MPZ/ROZ CO_2 Flooding.

	Sequential MPZ/ROZ Flood				Simultaneous MPZ/ROZ Flood			
	Fluid Injection			Oil Production	Fluid Injection			Oil Production
		Water	CO2			Water	CO2	
	Yrs	MB	MMcf	MB	Yrs	MB	MMcf	MB
	0	-	-	-	0	-	-	-
	1	192	895	95	1	274	1,278	156
	2	192	895	62	2	274	1,278	32
	3	254	771	54	3	319	1,187	67
	4	256	767	43	4	365	1,096	51
	5	256	767	38	5	365	1,096	36
	6	204	871	30	6	365	1,096	28
	7	192	895	27	7	310	1,207	26
	8	544	191	28	8	274	1,278	27
	9	639	-	21	9	341	1,144	28
Start	10	192	895	78	10	913	-	28
ROZ	11	222	834	56	11	913	-	18
	12	256	767	37	12	-	-	-
	13	249	781	30	13	-	-	-
	14	192	895	24	14	-	-	-
	15	456	367	24	15	-	-	-
	16	517	-	14	16	-	-	-
	TOTAL	**4,810**	**10,590**	**662**	**TOTAL**	**4,715**	**10,661**	**496**

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Figure 4.23 Cumulative Oil Production (MBbls)

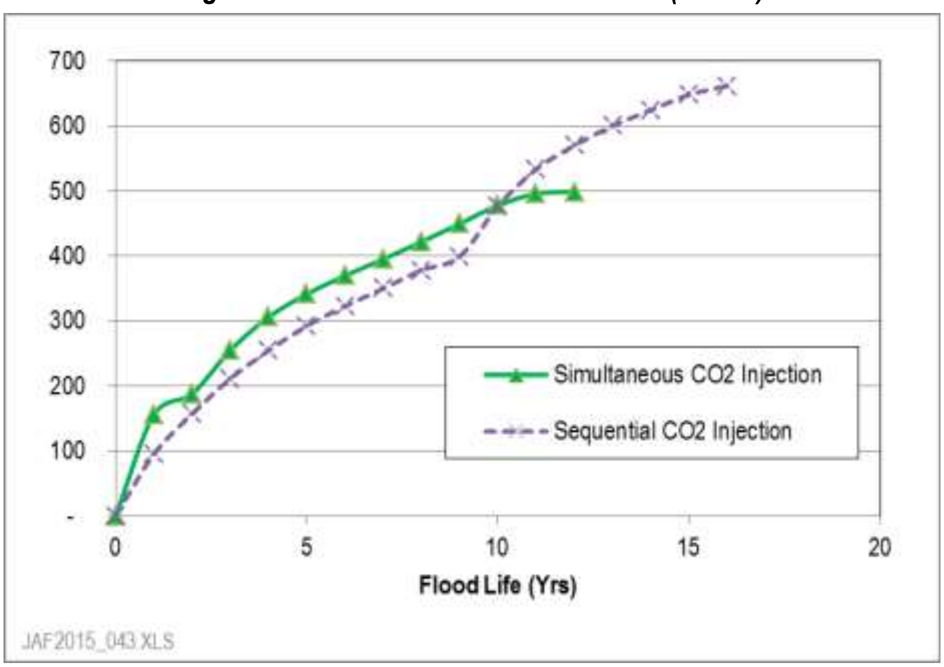
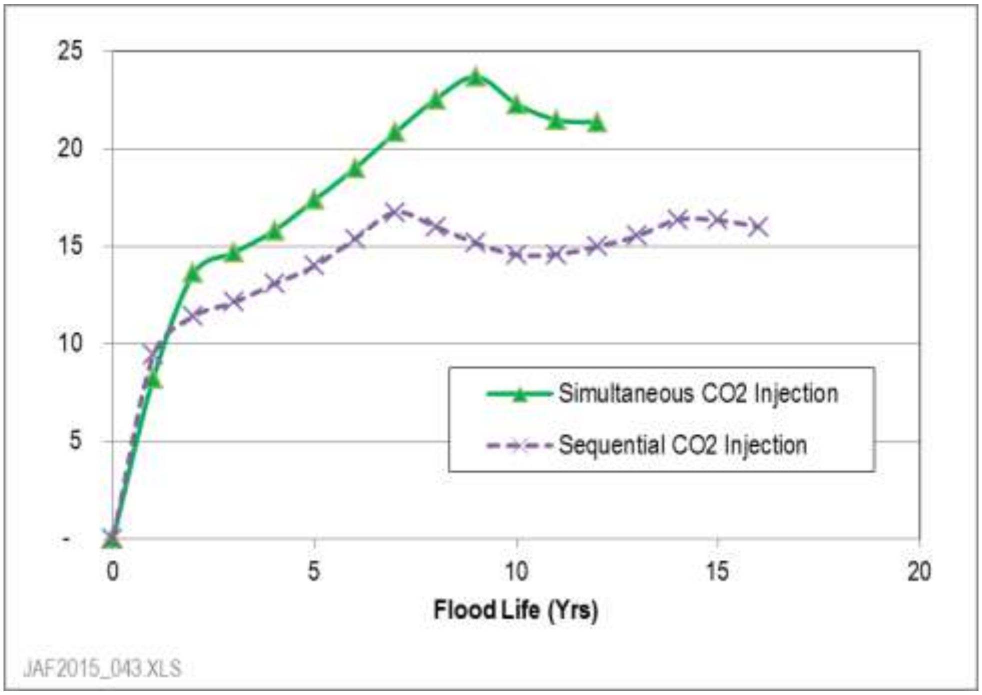


Figure 4.24 CO_2 Ratio (Mcf/B)



Section 5 – Background and History of the CO_2 EOR ROZ Projects, a Detailed Analysis of First ROZ Project, and the ROZ and MPZ Project at the GLSAU

5.a – Evolution and Status of CO_2 Flooding the ROZ

The presence of zones of high residual (immobile) oil saturation have been long recognized as present beneath oil reservoirs but have been generally classified as transition zones wherein capillary and surface tension forces have "smeared" the oil saturations to zero for some finite distance below the oil/water contact. In recent years, new understandings of these zones of immobile oil have include a concept of a 'natural waterfloods' wherein tectonic adjustments within a basin can move oil and water around creating huge volumes of residual oil where oil was previously trapped. Sometimes the residual oil zones (ROZs) are not overlain by a main pay zone (MPZ).

Three types of ROZs are known to occur, each leaving as much as 40% oil saturation levels (Refs 5.1-5.3) in place when the water invades the paleo oil entrapment. The invasion of water can come from below or laterally depending on the tectonic adjustments within the affected basin.

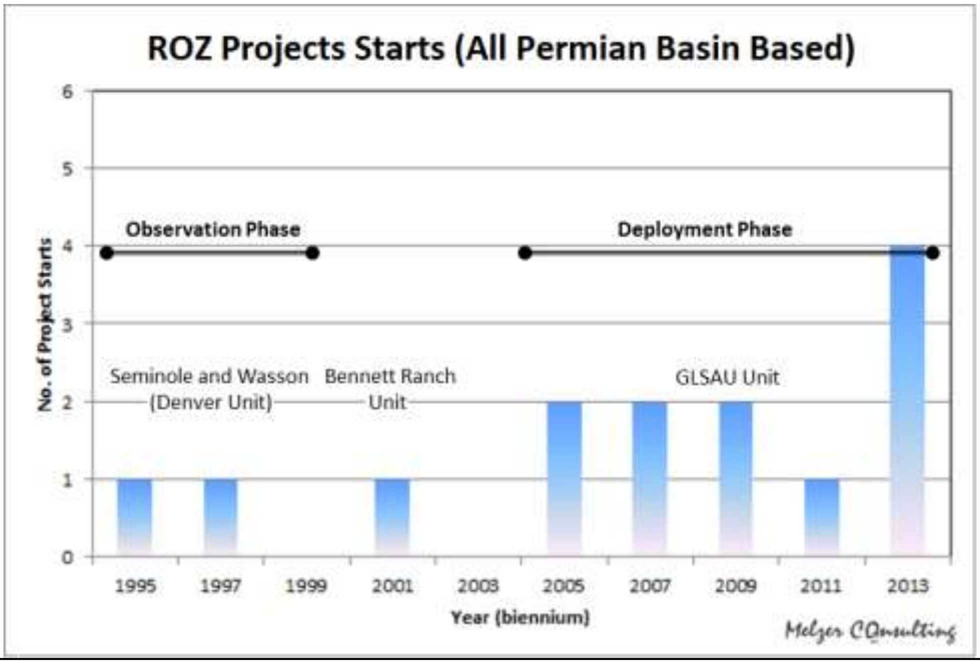
What started out as an experiment to produce the residual oil via CO_2 EOR in the 1990's has now become commonplace in the Permian Basin. Fifteen different field trials are underway demonstrating commercial potential of these ROZs and offering tremendous potential for both incremental oil and, perhaps also, CO_2 storage.

The full understanding of the oil and rock properties within the ROZs is somewhat immature at present with major advances in understandings still required. The San Andres formation in the Permian Basin is furthest along due to the numbers of site studies and commercial projects there. Two of the most mature ROZ project are approaching twenty years old.

Table 5.1 lists the ROZ projects underway with their attributes while Figure 5.1 maps out their locations. Two of these, the Seminole San Andres Unit (SSAU), operated by Hess, and the Goldsmith-Landreth San Andres Unit (GLSAU) operated by Kinder Morgan CO_2 Company, LC are identified and the subject of the analysis in this section of the report. The SSAU project is singled out here since it has a long history of success as a flooding project and has reported its ROZ projects twice at the CO_2 Flooding Conference in Midland, Texas. Most feel it has become the benchmark ROZ project for the Permian Basin and world.

The GLSAU project, the Research Partnership to Secure Energy for America, the Department of Energy and especially those industry pioneers before this project can all claim a great deal of the credit for the emergence of the ROZ as a viable target for EOR. Figure 5.a.2 tracks the evolution of ROZ work and emergence of commercial projects and divides the advancement into A) an observational phase and B) a deployment phase.

Figure 5.1a – ROZ Flooding: Project History and Phases of Development



The authors are especially indebted to the original operator of the GLSAU project, Legado Resources, and the current operator and research co-participant, Kinder Morgan CO_2 Company, LC. Together they have generously allowed access to their field for the research reported herein and assisted the project throughout the separate phases of study.

Figure 5.1b – Map of the Permian Basin Locating the Active ROZ Projects

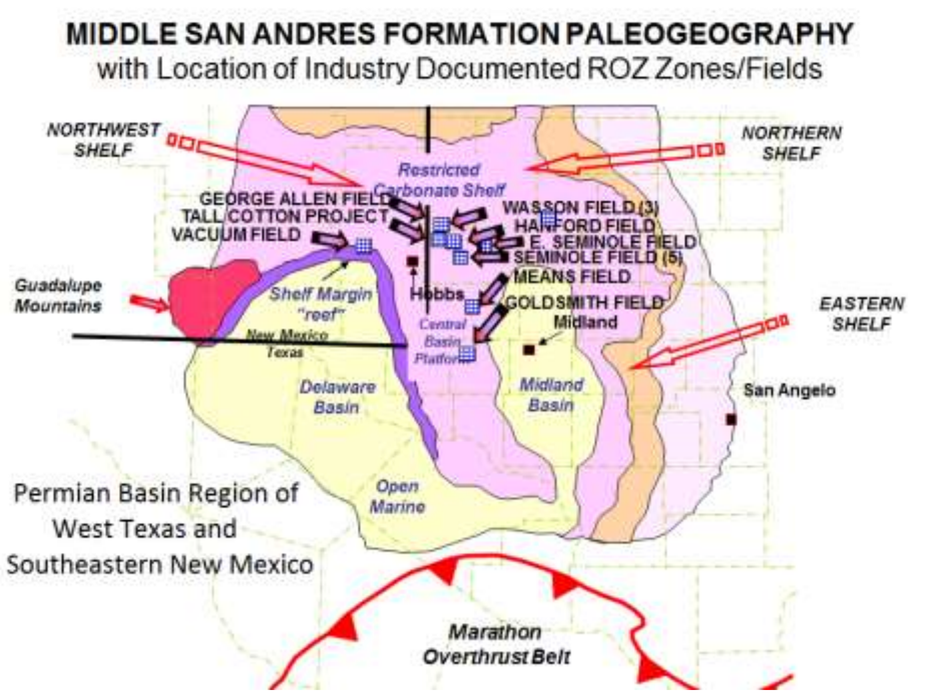


Table 5.1 – Active ROZ Projects

ON-GOING ROZ CO_2 EOR PROJECTS
IN THE PERMIAN BASIN REGION OF THE U.S.

Melzer COnsulting
as of Jan 2015

	Type and operator	Field	State	County	Top MPZ Depth, (ft)	Pay zone	Lith-ology	MPZ Start Date	ROZ Start Date	Strategy
	Active CO_2 miscible									
1	Chevron	Vacuum San Andres Grayburg Unit	NM	Lea Co.	4,550	San Andres	Dolo.	2007	2007	Commingle
2	Fasken	Hanford	Tex.	Gaines	5,500	San Andres	Dolo.	7/86	8/09	Commingle
3	Hess	Seminole Unit-ROZ Phase 1	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	7/96	Commingle
4	Hess	Seminole Unit-ROZ Phase 2	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	4/04	Deepen (Dedicated*)
5	Hess	Seminole Unit-ROZ Stage 1 Full Field Dev	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	10/07	Commingle
6	Hess	Seminole Unit-ROZ Stage 2 Full Field Dev	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	5/11	Commingle
7	Hess	Seminole Unit-ROZ Stage 3 Full Field Dev	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	7/13	Commingle
8	Hess	Seminole Unit-ROZ Stage 4 Full Field Dev	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	7/13	Commingle
9	Kinder Morgan CO_2	Goldsmith-Landreth Unit	Tex.	Ector	4,200	San Andres	Dolo.	8/09	8/09	Commingle
10	Kinder Morgan CO_2	Tall Cotton Pilot Project	Tex.	Gaines	n/a	San Andres	Dolo.	n/a	11/14	Green Field ROZ
11	Occidental	Wasson Bennett Ranch Unit	Tex.	Yoakum	5,250	San Andres	Dolo.	6/95	2000	Commingle
12	Occidental	Wasson Denver Unit	Tex.	Yoakum	5,200	San Andres	Dolo.	4/83	1995**	Commingle
13	Occidental	Wasson ODC	Tex.	& Gaines	5,200	San Andres	Dolo.	Nov-84	2005?	Commingle
14	Trinity CO2	George Allen (BF&GF)	Tex.	Yoakum	4,900	San Andres	Dolo.	12/12	2012	Deepen&Drill
15	Tabula Rasa	East Seminole	Tex.	Gaines	5,400	San Andres	Dolo.	1/13	1/13	Commingle
16	XTO/ExxonMobil	Salt Creek	Tex.	Kent	6,300	Canyon Reef	LS	Jun-05	1996	Commingle
17	XTO/ExxonMobil	Means	Tex.	Andrews	4,500	GrBrg/San Andres	Dolo.	Nov-83	1/12	Commingle

* Dedicated ROZ Pilot
** Initial Dev called Transition Zone Sweetspot, now followed by Phases 1-4

5.b - Background and History of the Seminole San Andres Unit

The Hess Corporation is well advanced in what many persons have called the "Gold Standard" oil recovery project using carbon dioxide (CO_2) flooding. Their application of new technology, excellent recovery success and maturity at the Seminole San Andres Unit (SSAU) has resulted in it often being called one of the most innovative and benchmark cases of advanced oil recovery. The SSAU project is located in the Permian Basin region of the Southwestern U.S. and began the tertiary (or enhanced oil recovery) phase of production in 1983 (Fig 5.1).

The field had a long history prior to this tertiary phase. The tertiary, or enhanced oil recovery (EOR), phase started 15 years after initiation of the secondary or water flooding phase which began 33 years after it was originally drilled on 40-acre spacing starting in 1936. Its production history

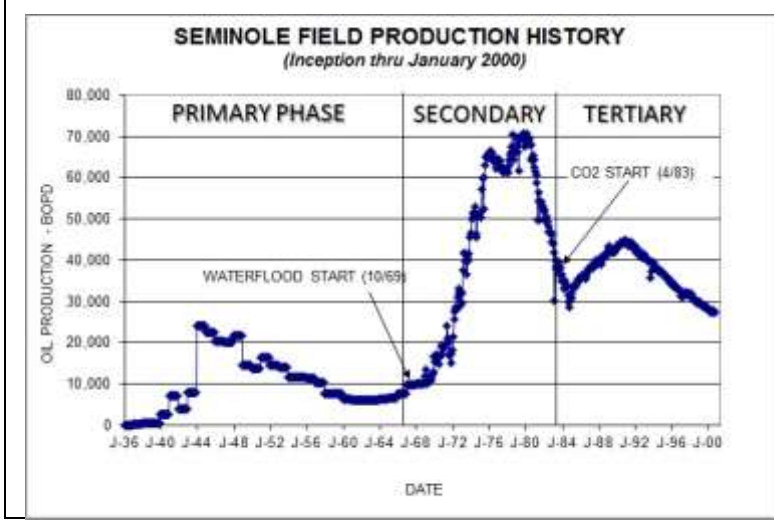
Table 5.2 – Seminole Field Reservoir and Fluid Properties

RESERVOIR/FLUID ATTRIBUTE	VALUE
DEPTH OF PRODUCING ZONE -FT	5355
AVE NET PAY THICKNESS - FT	195
AVE EFF POROSITY - %	13.2
AVE HOR PERM - MD	31
ORIG RES PRESSURE - PSI	2020
OIL GRAVITY - DEGREES API	35
OIL VISCOSITY - Centipoise	1
OIL TEMPERATURE - Degrees F	104

includes 120 million barrels of stock tank oil during primary recovery and 340 million barrels under water flooding. The tertiary phase and is mature and is likely to produce another 200 million barrels from tertiary (CO_2 enhanced oil recovery). All of this production comes from a total estimated original oil in place of 1000 million barrels. Table 5.2 (Refs 5.5, 5.6) summarizes the San Andres (Permian age) reservoir and fluid properties at the field while Figure 5.2 recaps the production history through the three phases up to the turn of the century.

The classic three peak character of the production history of the Seminole field in Figure 5.2 is shared by many conventional fields/reservoirs that have witnessed secondary and tertiary exploitation phases. The low permeability reservoirs, solution gas drive and maturity of the Permian Basin production make it very common there. The Seminole field, however, is perhaps the model for the three peak case history.

Figure 5.2 – SSAU Production History through Jan 2000

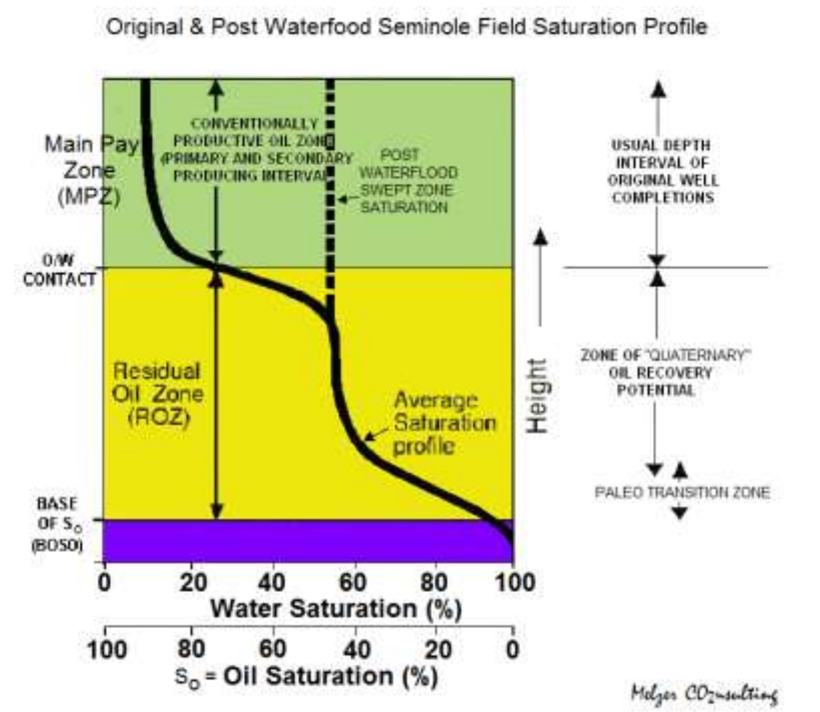


The nature of a decline in any phase of production often leads to an opinion by the casual observers that the best days of a reservoir's life are over and that the end of a reservoir's productive life will be coming soon. It is a tribute to the industry that such resignations were most often replaced by entrepreneurs and research efforts that were determined to find a way to get more of the oil that was left behind. The success of water flooding and enhanced oil recovery techniques are certainly products of those people and efforts.

5.b.1 – The Seminole San Andres Unit ROZ Projects

In the 1980's, Hess' personnel noted, while drilling deeper below the Seminole San Andres Unit (SSAU), that the shows of oil continued for hundreds of feet below the identified oil/water contact (OWC). That surprising observation prompted a detailed study at the interval's rock and fluid properties. As the results of the ROZ oil saturations (S_o) came in, it was noted that the residual oil saturations to water flooding (S_{orw}) in the ROZ were roughly the same as those S_o values that were attributed to the swept interval (S_{orw}) in the on-going CO_2 flood of the main pay zone (MPZ). The swept zones of the water flood are also the target oil of the tertiary CO_2 flooding leading to a belief that a flood of the ROZ could be as successful as the CO_2 EOR project in the MPZ. Figure 5.3 recaptures their characterization work, with the aid of several methods of determining the distribution of S_o values, and shows those attributes extended below the original and post water flood (swept zone) oil saturation profile.

Figure 5.3 – Zonation and Oil Saturations vs. Depth at the SSAU



The operator's land department had to get involved, however, as the unit agreement did not go deep enough to include the ROZ. A unitization initiative in the mid-1980s was successful in revising the depths covered to amend the unit and extend to the needed depths should further work suggest that the ROZ CO_2 flood would prove to be an analogue to the MPZ flood.

It was widely recognized that many fields had transition zones (TZ's) below the OWC which would linearly decrease in oil saturation with increasing depth. SSAU was different it seemed, as they characterized it, from classic intervals below the OWC in that it did not linearly decay the S_o to zero but, in contrast, possessed a thick interval of nearly constant oil saturation in the middle (Figure 5.3). The term residual oil zone (ROZ) was adopted to provide a more general description of the nature of the vertical oil saturation distribution although the reasons for the non-linear shape were yet to be resolved.

Table 5.3 – SSAU Fluid Properties of the ROZ Interval

ROZ Oil, H_2O and CO_2 Properties at 2000 psia and 105 °F *

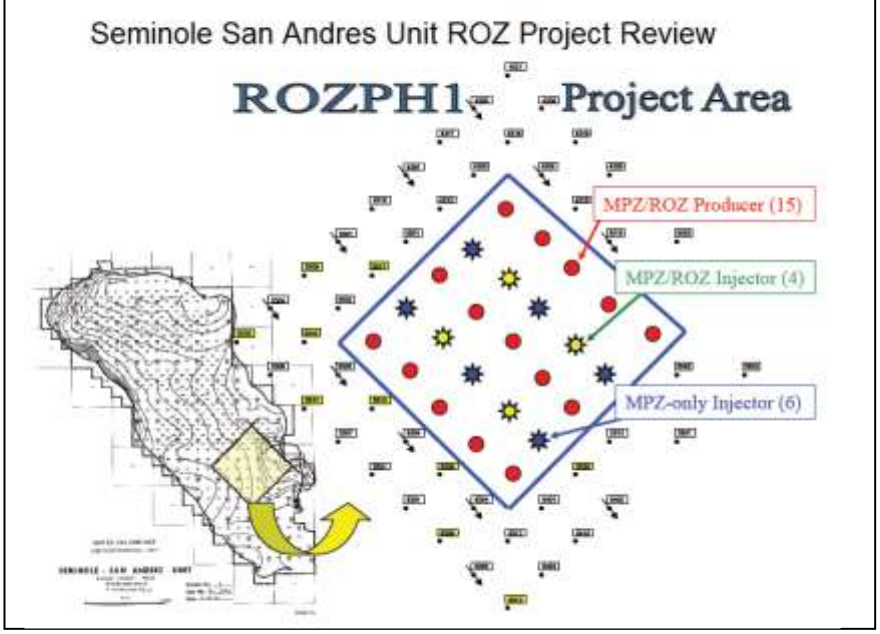
Fluid	Viscosity cP	Density lb/cft	CO2 Injection		CO_2 Solubility scf/stb			IFT dynes/cm
			Swelling	Viscosity	H_2O	Brine	ROZ Oil	
Oil	1.2119	46.4042	77%	0.477			1600	< 0.2
CO_2	0.0564	43.7874						
Water	0.7179	62.1753	6%	0.706	176	50		

* Reference 3

Hess' engineers estimated that this large volume ROZ interval possessed an oil-in-place (OIP) comparable with the original oil in place in the MPZ in spite of its lower oil saturation. With such a large OIP resource in mind, it would seem that this zone below the OWC would be a viable target for CO_2 flooding just like the water flooded zone above it. An investigation ensued to answer the remaining questions and all the coring, laboratory testing (Table 5.3, Ref 5.7) and modeling work accomplished to assess the CO_2 floodability of the ROZ pointed toward a likely positive outcome. So, in 1996, Hess recommended, and received the approvals from their partners, that a pilot CO_2 demonstration project be deployed through the entire ROZ interval. That pilot has become known as the 1996 pilot or Phase I ROZ pilot. Both the design and performance were reported by Jim Bush of Hess in 2001 at the CO_2 Flooding Conference in Midland, Texas (Ref 5.8).

The area for the ROZ CO_2 pilot was selected in the central-eastern region of the field where the MPZ was thin (Fig 5.4). A four pattern, 80-acre spacing pilot was chosen and both production and injection wells were commingled with the MPZ.

Figure 5.4 – SSAU ROZ Phase I Pilot Layout (Ref 5.8)



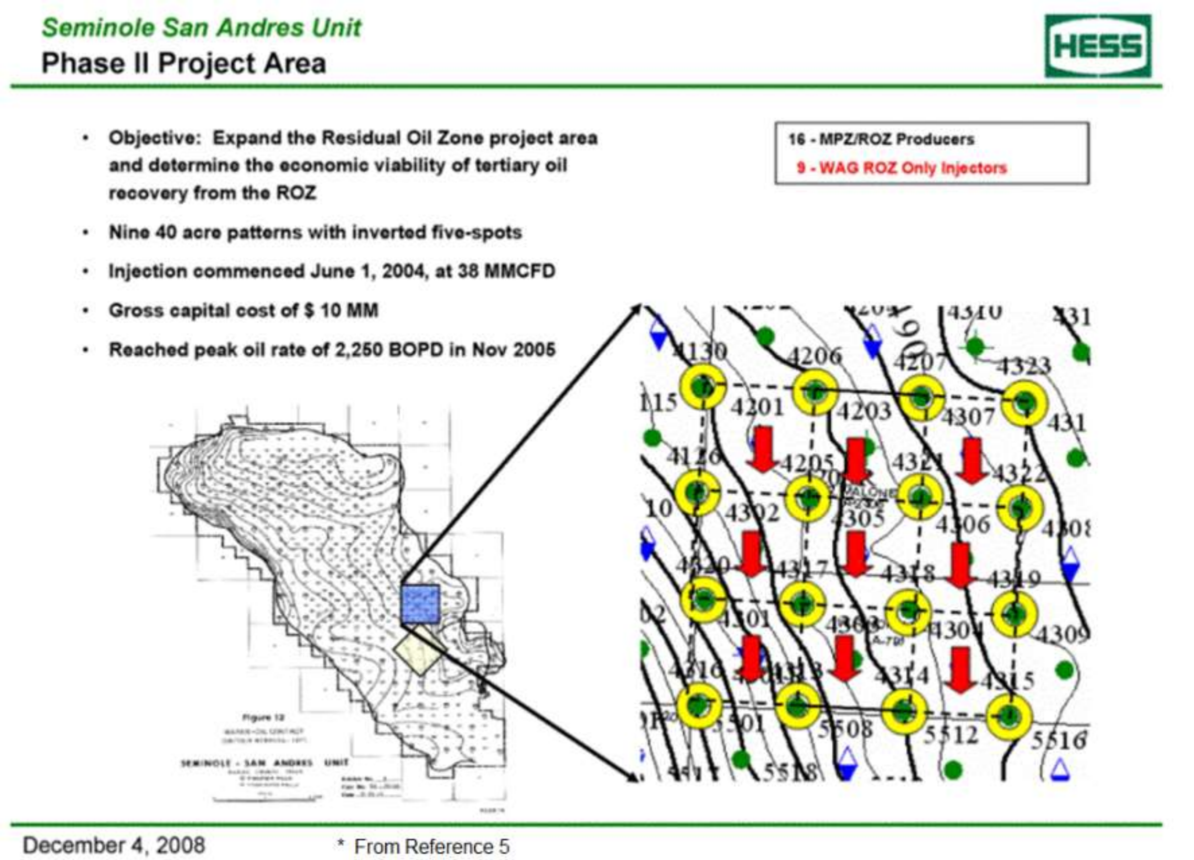
Phase I results were very encouraging but some issues plagued the effective injection into the ROZ and necessity of deriving the incremental production from the ROZ interval haunted the decision to proceed field wide with ROZ exploitation. So, in 2004, the judgment was made to maintain progress on the concept of flooding the ROZ with an alternatively designed Phase II pilot.

The Phase II pilot design chosen used a 40-acre well spacing with dedicated (new drill) ROZ injectors and commingled (MPZ+ROZ) producing wells. Figure 5.5, from Ref 5.9.
displays the layout as implemented. Results of the Phase II pilot were reported at the 2008 CO_2 Conference by Scott Biagiotti of the Hess Corporation.

With the oil recovery success noted in both the Phase I and II pilots, the decision to proceed with a field-wide CO_2 ROZ flood was made. In 2007 approvals were sought and received. The field implementation began with 29 patterns of inverted 80-acre five spots, dedicated ROZ injection wells and commingled producer wells, taking the lessons from both the Phase I and II projects to go field wide with the ROZ flood.

Figure 5.5 – SSAU Phase II ROZ Pilot (Ref 5.9)

Phase II Pilot Design
Seminole San Andres Unit Performance Review*



Fgure 5.6 illustrates the layout of the Stage 1 project. At the time of this report, Stages 2 and 3 have been deployed and field work for Stage 4 is underway. There are 14 additional patterns in Stage 2, nine in Stage 3 and six more in Stage 4 for a total of 29 injectors among the Stages 2-4, doubling the number of injector wells implemented in Stage 1. With the continuing four active injectors in the Phase I and nine in Phase II pilots, a total of 65, 80-acre ROZ patterns are being flooded.

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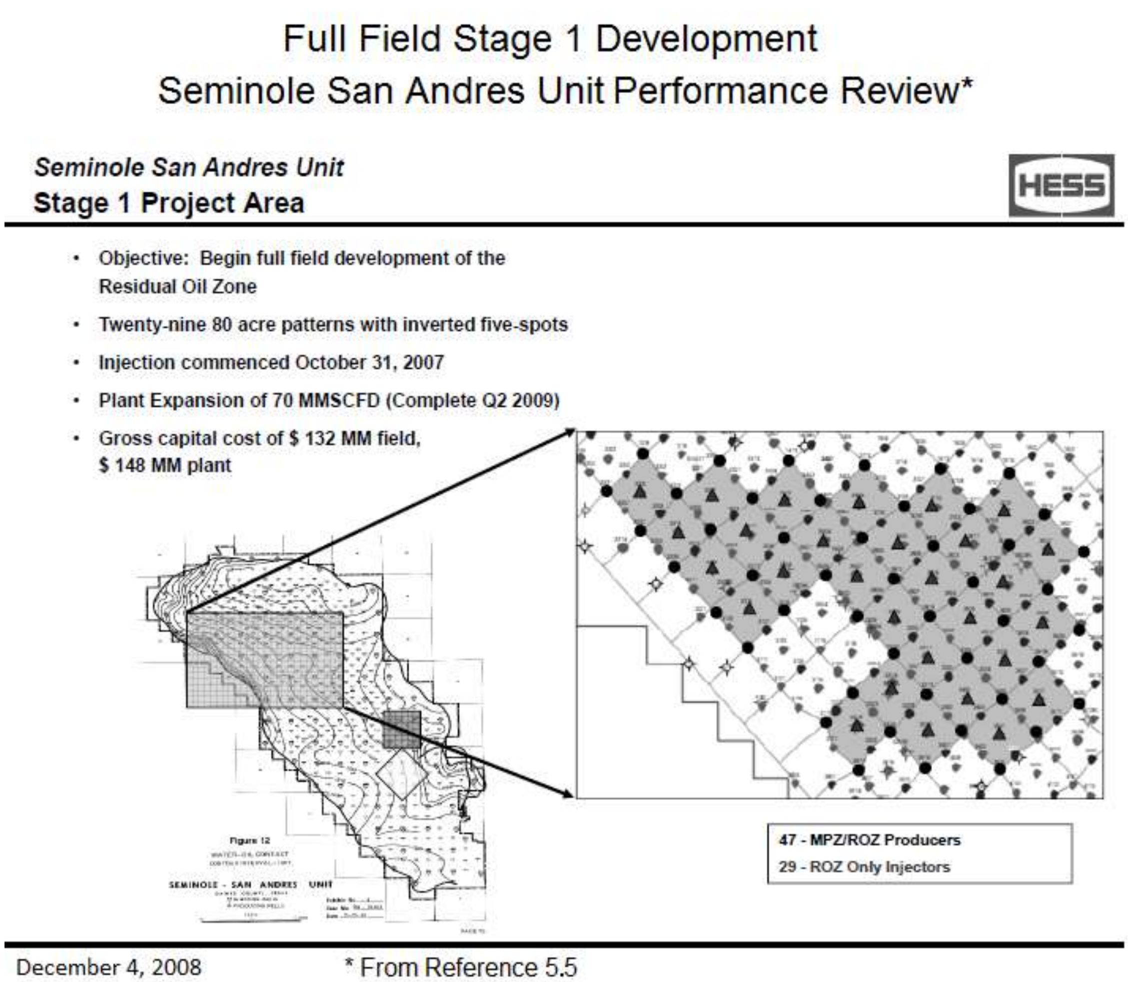
5.b.3 – SSAU CO_2 and ROZ Project Results

As discussed previously, the tertiary phase of production at the SSAU began in 1983 with the CO_2 flooding of the MPZ. That long-lived phase of activity remains on-going. The ROZ phase, sometimes referred to as the “quaternary” phase of production,

Figure 5.6 – SSAU ROZ Stage 1 Project Layout (Ref 5.10)



began with the Phase I pilot in 1996. That was followed by the ROZ Phase II Pilot implemented in 2003. Both of those pilots and the initial response on Stage 1 of the on-going full-field ROZ deployment were reported publicly at the CO_2 flooding Conference in 2008 (Ref 5.9). These were the last public disclosures of individual ROZ project response.

A detailed look at the individual ROZ projects at SSAU are shown in Table 5.4. Much information on this table including the future project parameters and forecasts are the author's and not the operator's. Some projections about the size of the individual and future projects are assumed based upon the analog to the MPZ numbers adjusted for net pay thicknesses. Included herein are estimated ultimate recovery (EUR) numbers as well as individual pattern response. The MPZ was developed on 80-acre patterns while the Phase 1 pilot also demonstrated that the ROZ could be very successfully developed on 80-acres. If it is assumed that the entire group of full-field stages of production develop out to a total of 160 patterns on a pace of roughly ten per month.

Table 5.4 – Seminole San Andres Unit – Project Parameters in the CO_2 EOR Era

SSAU CO_2 ERA PROJECT PARAMETERS

<<<<< LOOK-BACK | ON-GOING | FORECAST >>>>>

	Units	MPZ	ROZ Ph 1	ROZ Ph 2	ROZ St 1-3	Remaining ROZ Pattern Areas	ROZ St 4-6	ROZ St 7-9	ROZ St 10-12
Net Reservoir Thickness	feet	126	197	197	197	197	197	197	197
No of Patterns	inverted	160	4	9	52	95	24	24	23
Area Flooded	acres	12,800	320	360	4,160	7,960	1,920	1,920	1,840
EUR (million bbls)	million bbls	201.1	5.03	11.31	65.36	119	39.81	39.81	39.81
EUR/PATTERN	million bbls	1	1.26	1.26	1.26	1.26	1.26	1.26	1.26
YEARS TO DEPLOY	years	< 3	1	1	4	12	4	4	4
PEAK OIL PROD	bbls/day	30,000	750	1,688	9,750	17,813	4,500	4,500	4,500
PEAK OIL PROD/PATTERN	bbls/day	187.5	187.5	187.5	187.5	188.0	187.5	187.5	187.5

Figure 5.7 captures the oil production history as was presented in Figure 5.2 but also the recent production history at the Seminole field. Note the departures from the regular declines beginning with the first ROZ project in 1996. For the sake of simplicity in analysis, the entire CO_2 phase of the field production history is captured in a separate curve.

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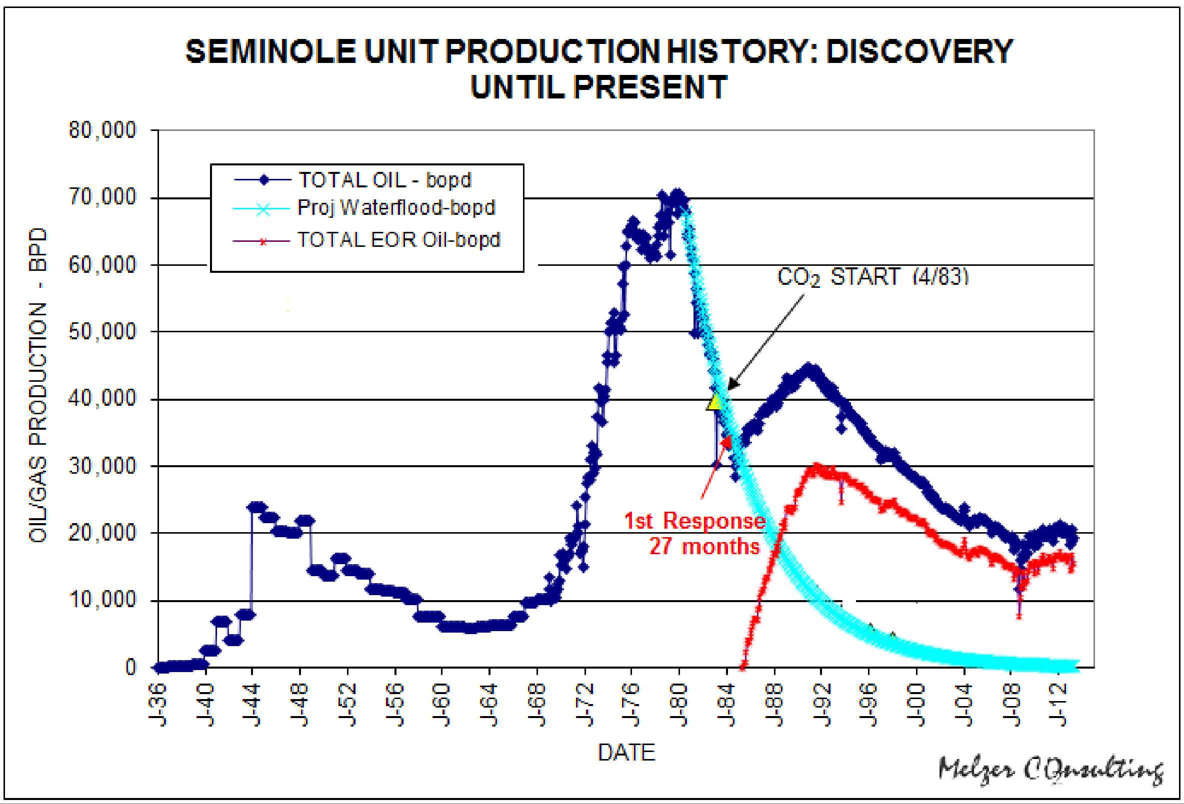
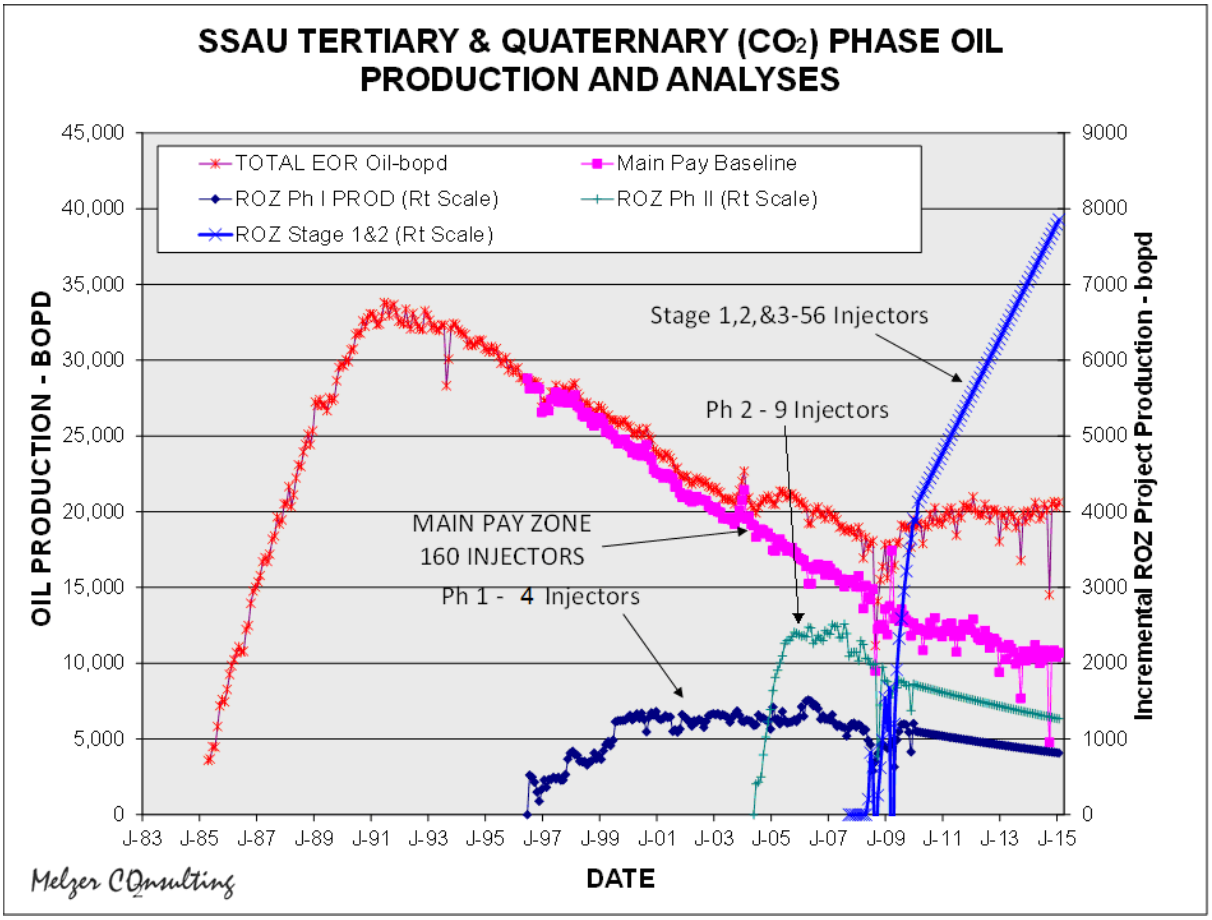
Figure 5.8 provides our allocation[4] of the total oil production to each of the ROZ projects including the two ROZ pilots and the full-scale Stages 1-3. The individual project breakouts are carefully matched to Ref 5.9 reporting however, the decline rate assumptions used in the analysis beyond early 2010 force the linear nature of the curves. Note that the assumptions used result in a lessened decline for the MPZ CO_2 project and one or more of the individual ROZ project responses could be higher than as shown. Nonetheless, note that the total ROZ oil production is close to 10,000 bopd.

Figure 5.7 – Tertiary (CO_2) Phase of Production at SSAU



[4] The analysis for Figure 5.b.7 was performed by Melzer Consulting from publicly available data but with the aid of Reference 5.9 (through 2010) production figures for each of the phases of ROZ exploitation.

Figure 5.8 – CO_2 Era Production at SSAU by Individual Project

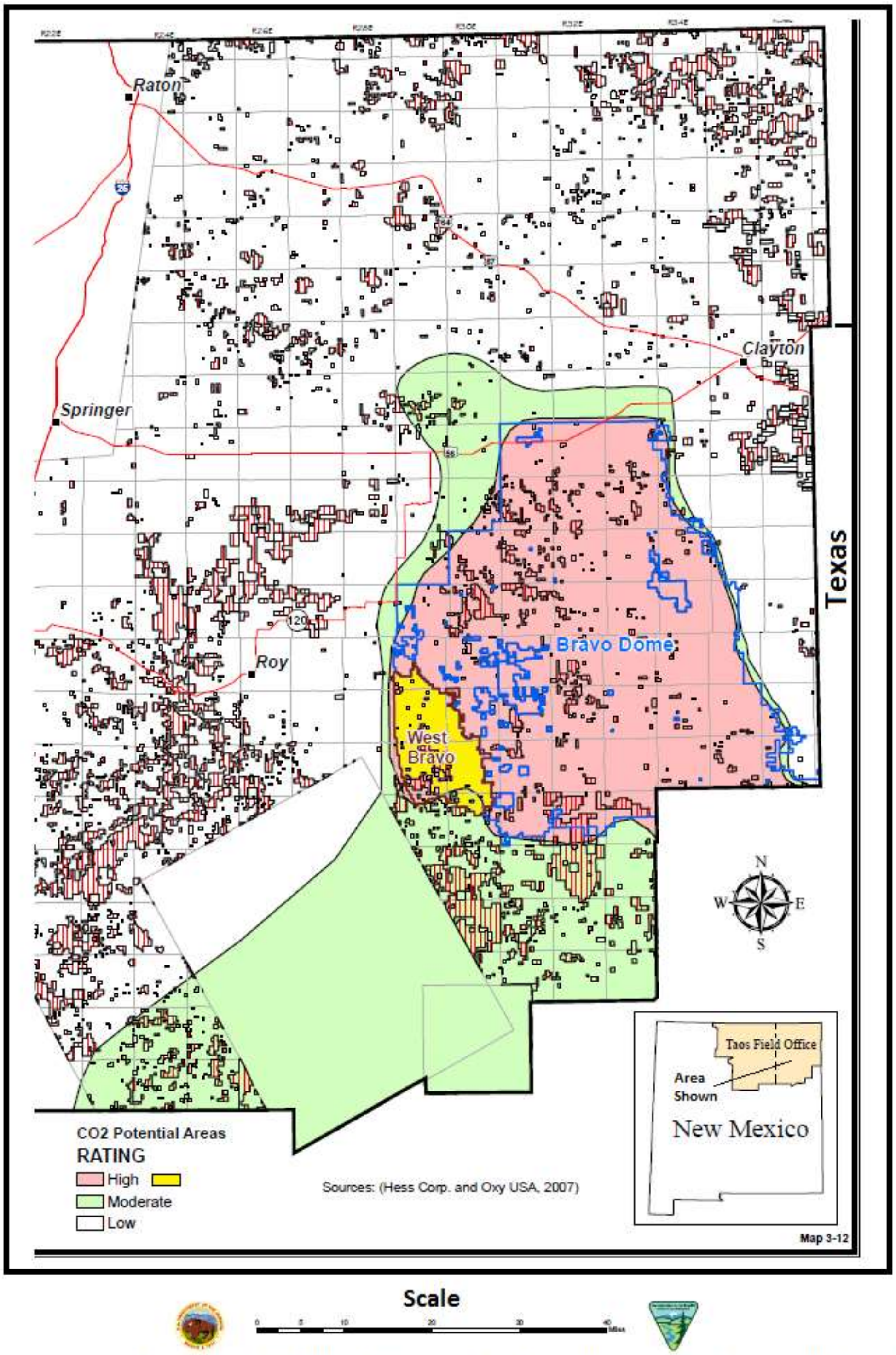


The total EOR oil production decline attributable to the MPZ prior to 1996 has been clearly flattened by the addition of the ROZ interval projects. We could argue that a further increase in production might be present in recent years but that the limited CO_2 supplies in the Permian Basin and available to the SSAU, along with the staged ROZ deployment schedule, is holding back total EOR production. Hess anticipated this problem and moved to develop the West Bravo Dome source of supply in northeastern New Mexico (Fig 5.9, Ref 5.11). This project was hoped to provide the needed additional supplies but the combination of constrained, existing supplies and continuing good economics of the MPZ patterns forced an allocation the new and recycle CO_2 supplies to only their most profitable patterns. If patterns were denied CO_2, they must necessarily advance to that is commonly termed “chase” water status and their oil production decline is accelerated. According to Reference 5.6, only 110 of the 160 main pay zone injection wells were still receiving CO_2 in late 2011 giving doubt as to our “optimistically” extrapolated (recent years) decline rate for the MPZ in Figure 5.8. By contrast to the on-going full-field ROZ schedule, the MPZ was effectively deployed in less than three years. What this means of course is the accentuated third peak in production for the MPZ will not be as accentuated in the quaternary (ROZ) phase but drawn out over time. Figure 5.10 displays the forecast by Melzer Consulting using the above assumptions and the ROZ Phase I pilot response as the guide. The reader is cautioned that the availability of CO_2 and other factors could change the deployment schedule and forecast.

5.b.5 – Summary of SSAU ROZ Project Experience

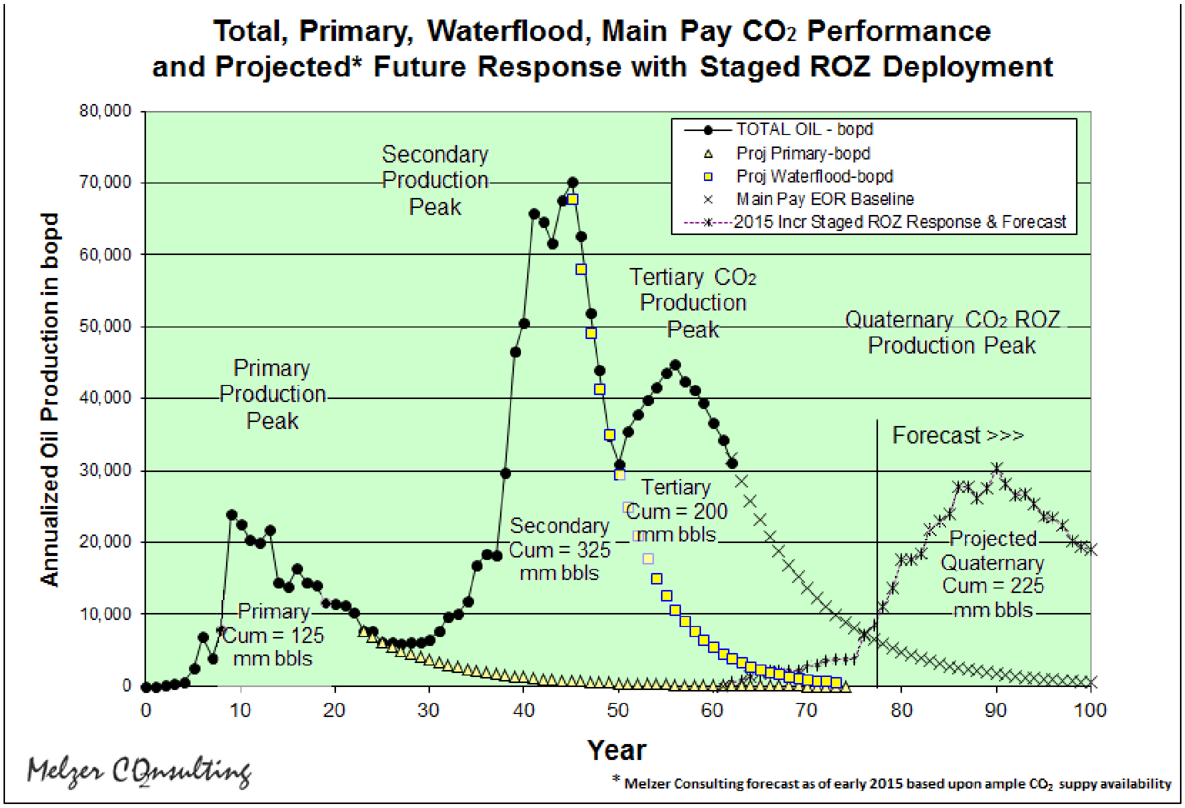
Because of its long history, innovative designs, farsighted engineers/ management teams, and the willingness of the operator to share design and performance data, the Seminole Field in Gaines County of west Texas has emerged as the benchmark project for CO_2 EOR and Residual Oil Zone exploitation in all of the world. The CO_2 era began in 1983 and that tertiary phase of production has been responsible for essentially all production from the field since the year 2000. Current production at the time of this report is just over 20,000 barrels of oil per day of which approximately 10,000 bopd is attributable to the ROZ. The ROZ interval was not capable of being produced during the primary or secondary phases of production since the oil there is residual and immobile to water flooding.

Figure 5.9 – Bravo Dome and West Bravo Dome Unit Areas, Northeastern New Mexico



Adapted From Ref: http://www.blm.gov/pgdata/etc/medialib/blm/nm/field_offices/taos/taos_planning/taos_proposed_rmp/taos_proposed_rmp0.Par.32593.File.pdf/Map_3-012_Mineral_Potential-Carbon_Dioxide.pdf

Figure 5.10 – SSAU Production History and Future Forecasted Response



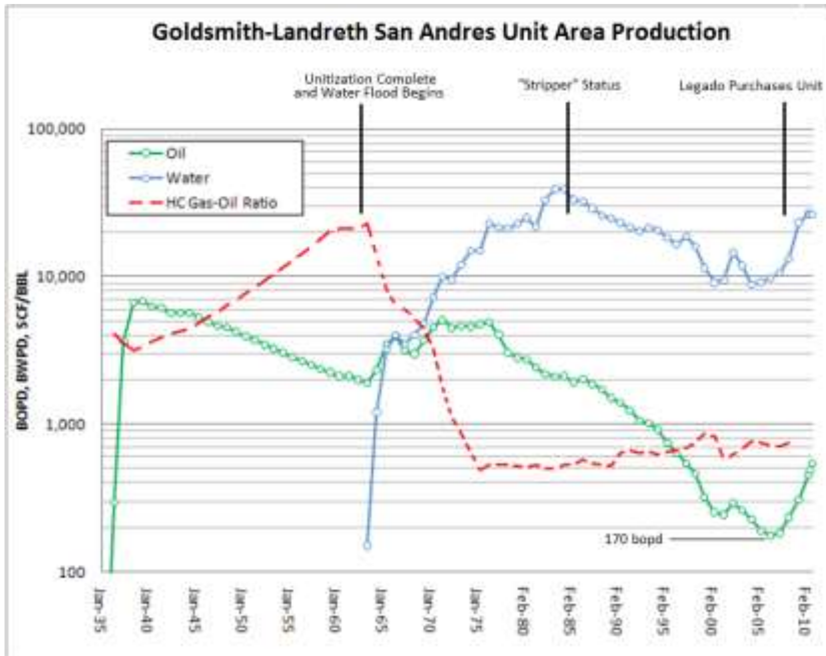
Field production coming from the main pay zone is likely to end by 2025 whereupon all production will be coming from the ROZ. As currently modeled, the ROZ production will continue for another 30 years at which time the recovery factor from the MPZ will have been 65% of the billion barrels of original oil in place and easily 22.5% of the 960 million barrels from the ROZ oil place resource.

It is always critical to keep in mind that commodity prices drive any resource recovery industry. Rates of project deployment are clearly a function of oil prices and also, in this case, CO_2 availability. The reader is cautioned that the aforementioned projections are the author's and based upon a careful study, best judgments and future oil pricing.

5.c – Background and History of the Goldsmith-Landreth San Andres Unit (GLSAU)

The Goldsmith-Landreth San Andres Unit (GLSAU) is another of the San Andres dolomite fields of the Central Basin Platform and Northern Shelf regions of the Permian Basin. Like the SSAU, it was discovered int the 1930s and, after a long history of primary production, was unitized for water flooding in the 1960s. But, unlike the SSAU, its original oil in place in the MPZ put it lower in the list in priority for CO_2 flooding and the tertiary phase was not started until 2009. The following table recaps the history of oil exploration and CO_2 EOR development at the Goldsmith-Landreth Unit Area.

Figure 5.11 – GLSAU Unit Area Production History



1934 – Field Discovery

1945 – Completed Initial Development Phase (250 Wells)

1948 – Began Gas Cap Re-injection for Conservation and Fluid Pressure Maintenance

1963 – Unitization and Deployment of Peripheral Water flood (Amoco {Stanolind} as Operator)

1965 – Begin Phasing into the Pattern Waterflood

1985 – Stripper Operations and Beginning of Well Abandonments

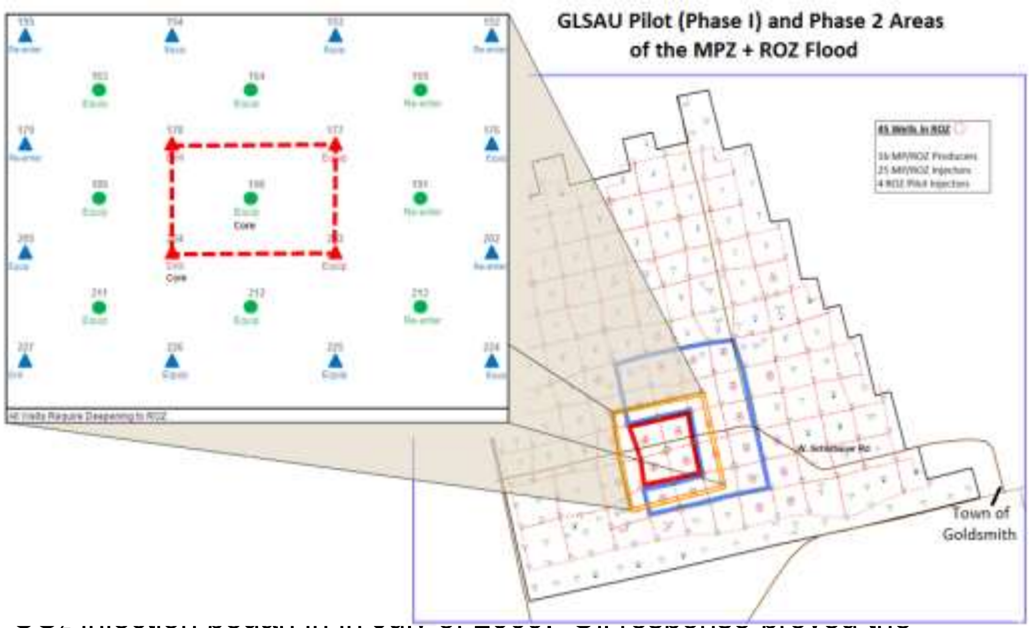
2008 – Legado Resources Acquires Field Operations

2009 – (July) CO_2 Pilot (with ROZ interval included) Operations Commenced Late 2010 and 2011 – Phase 1 CO_2 Development with Commingled ROZ and MPZ

2013 – Kinder Morgan CO_2 Company Acquires GLSAU Operations.

Figure 5.11 illustrates the production history of the GLSAU. Note that the classic three peak nature of production (to include the CO2 tertiary phase) is present at GLSAU as it was with the SSAU. The water flood responded well but performed not as well as the SSAU water flood. By the mid-1990s, the field was witnessing well problems and many wells were abandoned during that time as can be noted by the increasing production decline rate through the turn of the century. Some in-fill drilling occurred to temporarily suspend the decline but the increased production was short lived.

Figure 5.12 – Goldsmith-Landreth San Andres Unit Pilot and Phase I CO_2 Map



Legado Resources acquired the unit in 2008 when the production was at its low point of 170 bopd. The revival of the field required extensive well reworking and an pilot (Figure 5.12). [illegible] viability of oil recovery from the ROZ and the MPZ interval was added to the producing interval in mid-2010 and, by 2011 Phase I of the CO_2 flood was underway.

Figure 5.13 illustrates the recent 20 years of production at GLSAU and into the CO_2 EOR phase. Shown on the chart are two extrapolated declines of the existing (water flood) production noting that essentially all of the production is coming from the CO_2 response of the combined ROZ and MPZ flood. Note that the production has climbed to over 2000 barrels of oil per day.

5.d - References

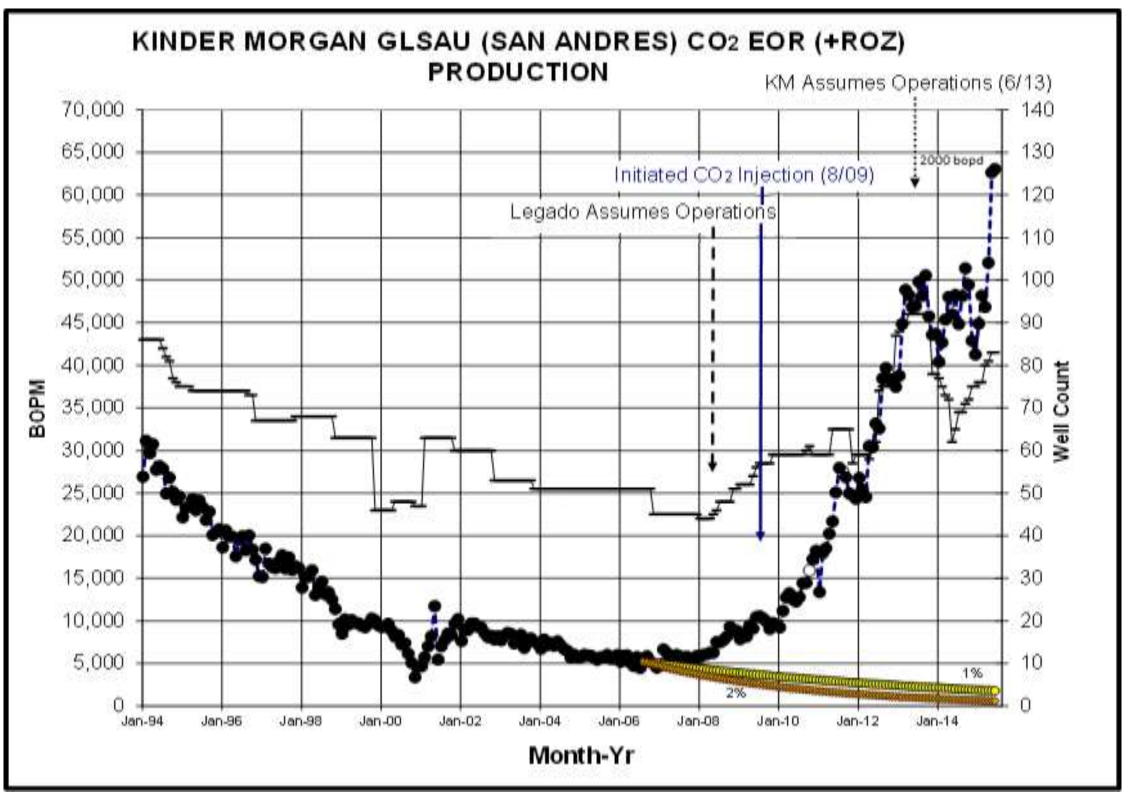
5.1 Stranded Oil in the Residual Zone, U.S. Department of Energy Report, Feb 2006, *http://www.melzerconsulting.com/pdf/ROZ_Melzer_Document_51.pdf*

5.2 The Origin and Resource Potential of Residual Oil Zones, SPE paper 102964, w/ G.J. Koperna and V.A. Kuuskraa, presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Tx Sept 24-27, 2006.

5.3 Recovery of Oil Resources from the Residual and Transitional Oil Zones of the Permian Basin, SPE 102972, w/ G.J. Koperna and V.A. Kuuskraa presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, Sept 24-27, 2006.

5.4 Identifying and Developing Technology for Enabling Small Producers to

Figure 5.13 – GLSAU Production History: Jan 94 – Jun 15



Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres, Jun 2012, RPSEA Grant Final Report, *http://www.rpsea.org/0812319/*

5.5 Texas Railroad Commission Bulletin 82 (1982)

5.6 Oil & Gas Journal Annual Production Report, Apr 2, 2012

5.7 Honarpour, M.M. et al, (2010), Rock-Fluid Characterization for Miscible CO_2 Injection: Residual Oil Zone, Seminole Field, Permian Basin, SPE 133089.

5.8 Bush, Jim (2001), The Seminole San Andres Unit ROZ (Residual Oil Zone) CO_2 Flood, Dec 2001 CO_2 Conference, Hess Corporation, Midland, Tx

5.9 Biagiotti, Scott (2008), Seminole San Andres Unit: An Updated Reservoir Status, Dec 2008 CO_2 Flooding Conference, Hess Corporation, Midland, Tx

5.10 The Future of CO_2, Permian Basin Oil and Gas Magazine, July 2012; http://pbog.zacpubs.com/the-future-of-co2/

5.11 Bureau of Land Management Document, Taos Office, 2012; *http://www.blm.gov/pgdata/etc/medialib/blm/nm/field_offices/taos/taos_planning/taos_proposed_rmp/taos_proposed_rmp0.Par.32593.File.pdf/Map_3-012_Mineral_Potential-Carbon_Dioxide.pdf*

Technology Transfer Activities

Since the Permian Basin is the only place exploiting commercial oil production from the ROZs to date and the DOE GLSAU project is the only public project, the project team is being asked to present on ROZ flood progress on a regular basis. Mr. Melzer and Dr. Trentham participated in a ROZ workshop in Casper, Wyoming in July 2013 relating findings in the Permian Basin as they may help guide ROZ research being conducted by the Enhanced Oil Recovery Institute (EORI) on the Tensleep formation in the Big Horn Basin.

A significant amount of time was been spent in 2013 making presentations to, and in discussions with, Kinder Morgan. As they assume operations of the field, they wanted to be brought up to speed on the project as quickly as possible. Discussions, power point based talks, and core layout presentations were made in Kinder Morgan's Houston and Midland offices, and at UTPB in Odessa (core layouts). Permissions were granted by Kinder Morgan and the project was completed with their concurrence incuding making future presentation for the Southwest Section of the American Association of Petroleum Geologists and the EORI at their CO2 Conference in Wyoming.

Project content has been added periodically to the www.residualoilzones.com website for the GLSAU DOE project. The link is: http://research.aptapb.org/doe-next-gen/.

Specific Articles/Papers/.Presentations:

Stoudt, E. L. 2012, Comparison of Depositional Facies and Diagenetic Overprint on Reservoir Quality in the Residual Oil Zone and Main Pay Reservoirs in the Goldsmith Landreth San Andres Unit, Goldsmith Field, Ector County, Texas – A Progress Report GSA South Central meeting, Alpine TX,

Trentham, R. C., 2014, GLSAU 203R – A CO2 Flood Front Caught in the Act, Southwest Section, AAPG, Midland, TX,

Melzer L. S., Trentham, R. C., Kiker, R., 2012 Goldsmith Field: GLSAU Geology & Volumetrics, Golden COLO.

Trentham, R. C., 2012, Goldsmith ROZ Core, WTGS Core Workshop, Midland, TX, 2012

Melzer, L. S. Trentham, R. C., Kuuskrra, V., 2014 ROZ Workshop, Steamboat Springs, COLO.

Melzer, L. S., Trentham< R. C., 2014, Case History-Driven Research: Residual Oil Zones, 2014 CO2 Conference Workshop, Midland TX, 2014

"The Emergence of Residual Oil Zones, Price, and CO2 Factors Usher in a New Day for CO_2 EOR," Prepared for Cryogas International, May '11 - CO_2 Edition (http://www.cryogas-digital.com/cryogas-comp/201105c?sub_id=ghoALiFRqsE5&folio=30#pg32)

"Residual Oil Zones, CO_2 EOR and the Environment: A Model For New Oil Reserve Potential While Offering Opportunity For Significant Carbon Emission Reductions," American Oil & Gas Reporter Feb '11, pp 104-113.

"The Excitement In Oil And Gas: Two Ongoing Revolutions," Prepared for Cryogas International, March '11 - Oil and Gas Edition *(http://www.cryogas-digital.com/cryogas-comp/201104c?sub_id=ghoALiFRqsE5&folio=22#pg24)*

LIST OF ACRONYMS AND ABBREVIATIONS

Bopd	Barrels of Oil per Day
CBP	Central Basin Platform
EOR	Enhanced Oil Recovery
G-1, G-8	Guadalupian 1, Guadalupin 8
GL	Ground Level
GLSAU	Goldsmith Landreth San Andres Unit
Fraced	Hydraulically Fractured
KB	Elevation from Kelly Bushing
L-7, L-8	Leonardian 7, Leonardian 8
Mbls	Million Barrels of Oil
MCF	Thousand Cubic Feet of Gas
MPZ	Main Pay Zone
MMCF	Million Cubic Feet of Gas
MMSTB	Millions of Stock Tank Barrels
OIO	Oil in Place
OOIP	Original Oil in Place
Perfed	Perforated
PV	Pore Volume
RFT	Repeat Formation Tester
ROZ	Residual Oil Zone
So	Oil Saturation
SS	Subsurface
Sw	Water Saturation
TVD	True Vertical Depth

Appendix 1.

Section 2. Core Descriptions for wells used in this study.

Cored and described wells in the Goldsmith Landreth San Andres Unit:

#26 GLSAU

#58 GLSAU

#126GLSAU

#142A GLSAU

#190 GLSAU

#203RW GLSAU

#204W GLSAU

#222W GLSAU

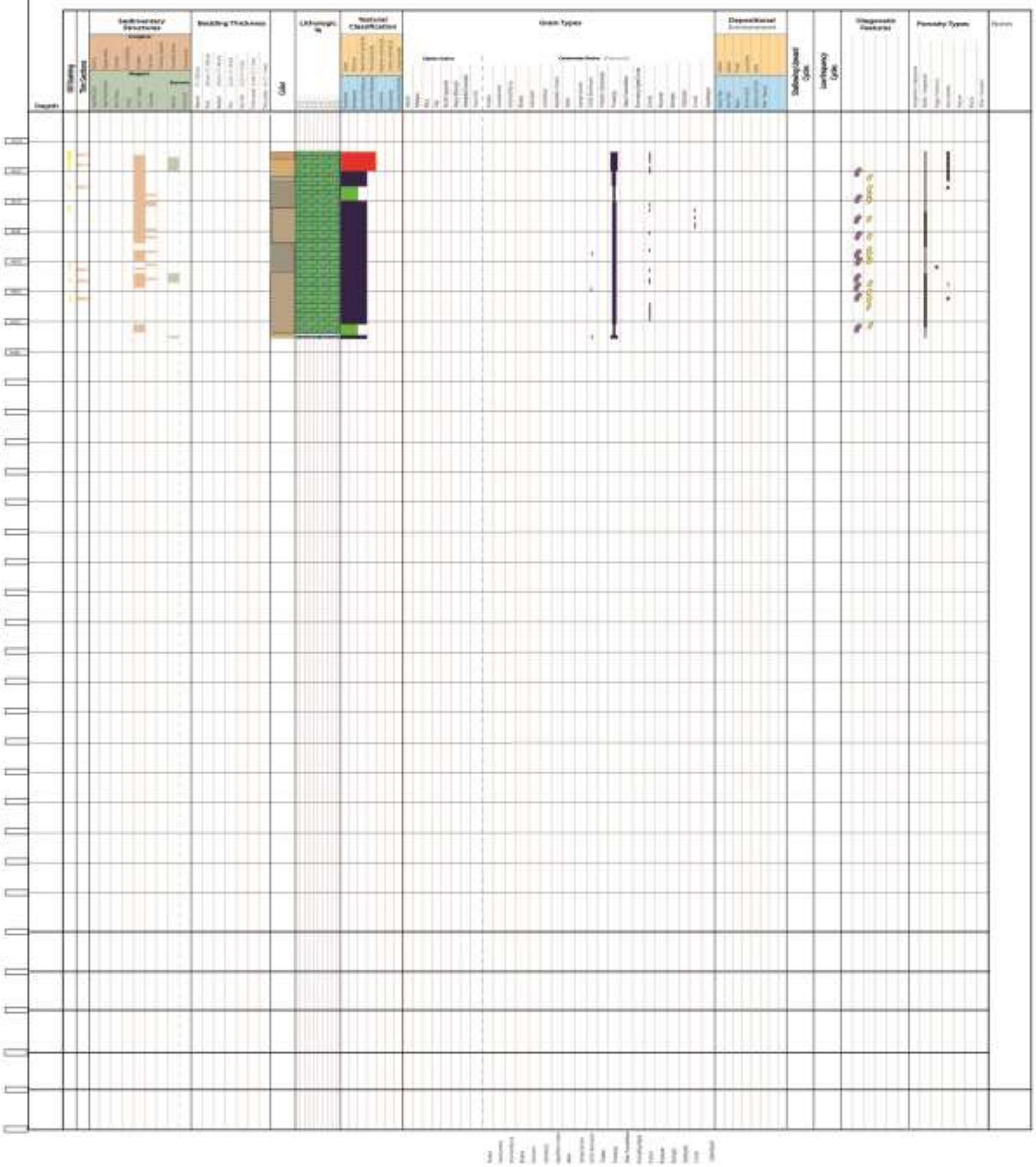
#313 GLSAU

Explanation for Core Description

Well or Measured Section Name GLSAU # 26 , Location , Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged JULY-SEPTEMBER, 2011

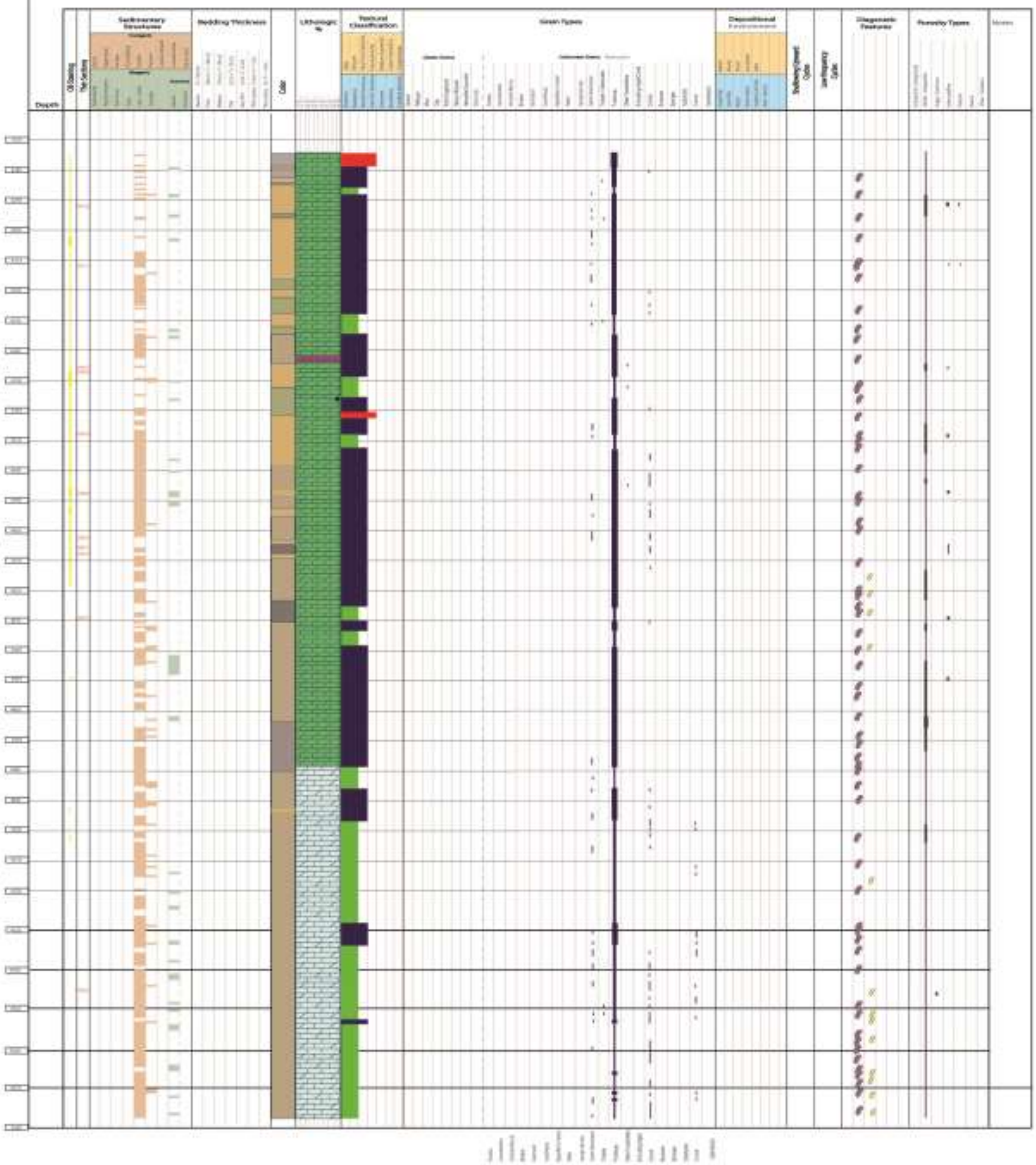
Formation(s) SAN ANDRES Depth or Outcrop Interval 4414-4475.2



Well or Measured Section Name GLSAU # 58 Location, Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged JULY-SEPTEMBER, 2011

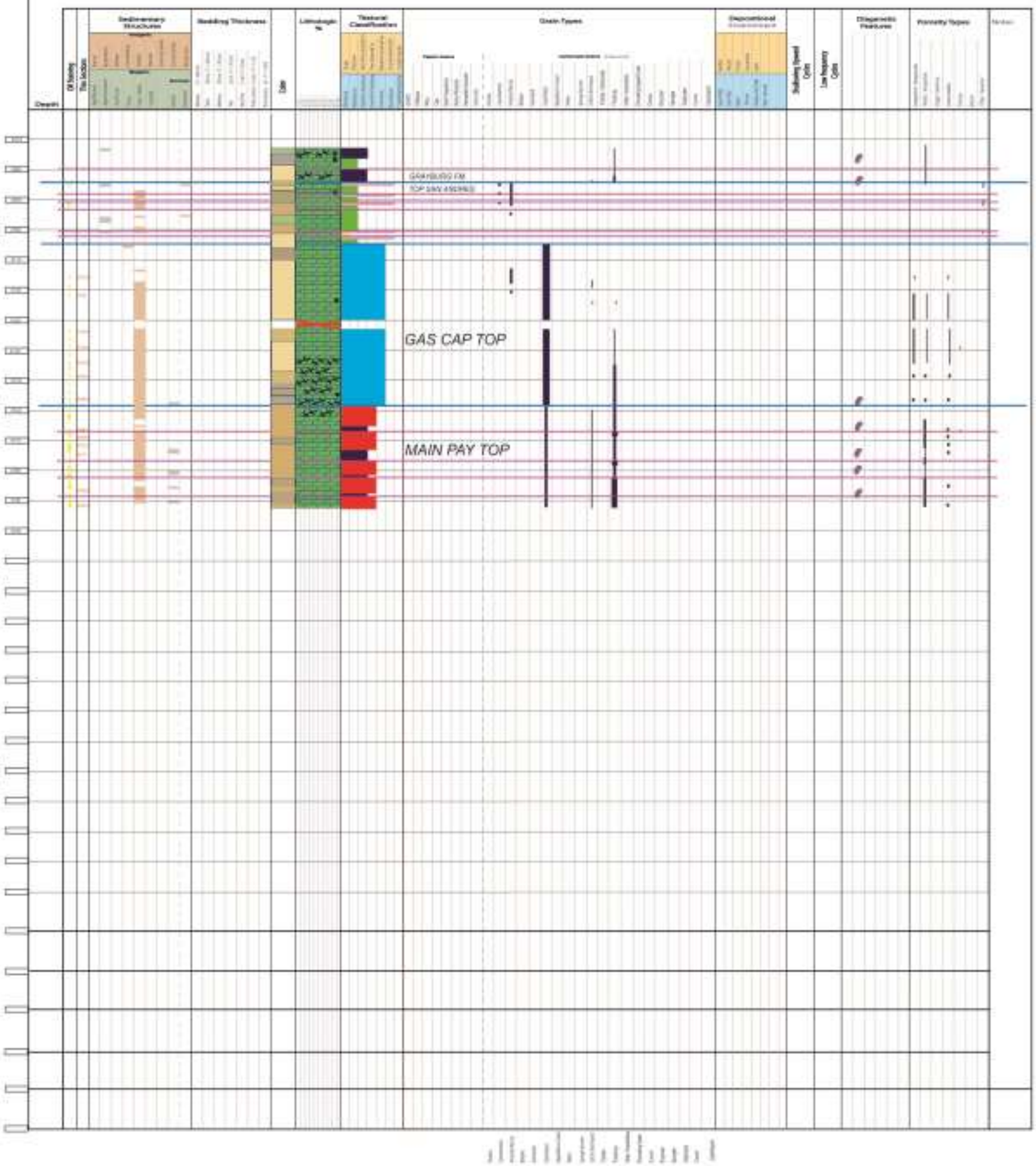
Formation(s) SAN ANDRES Depth or Outcrop Interval 4274-4577



Well or Measured Section Name __GLSAU # 126 R__ , Location __ECTOR COUNTY, TEXAS__

Logged by __EMILY STOUDT AND TOYLY ABDULLAYEV__ Date Logged __JULY-SEPTEMBER, 2012__

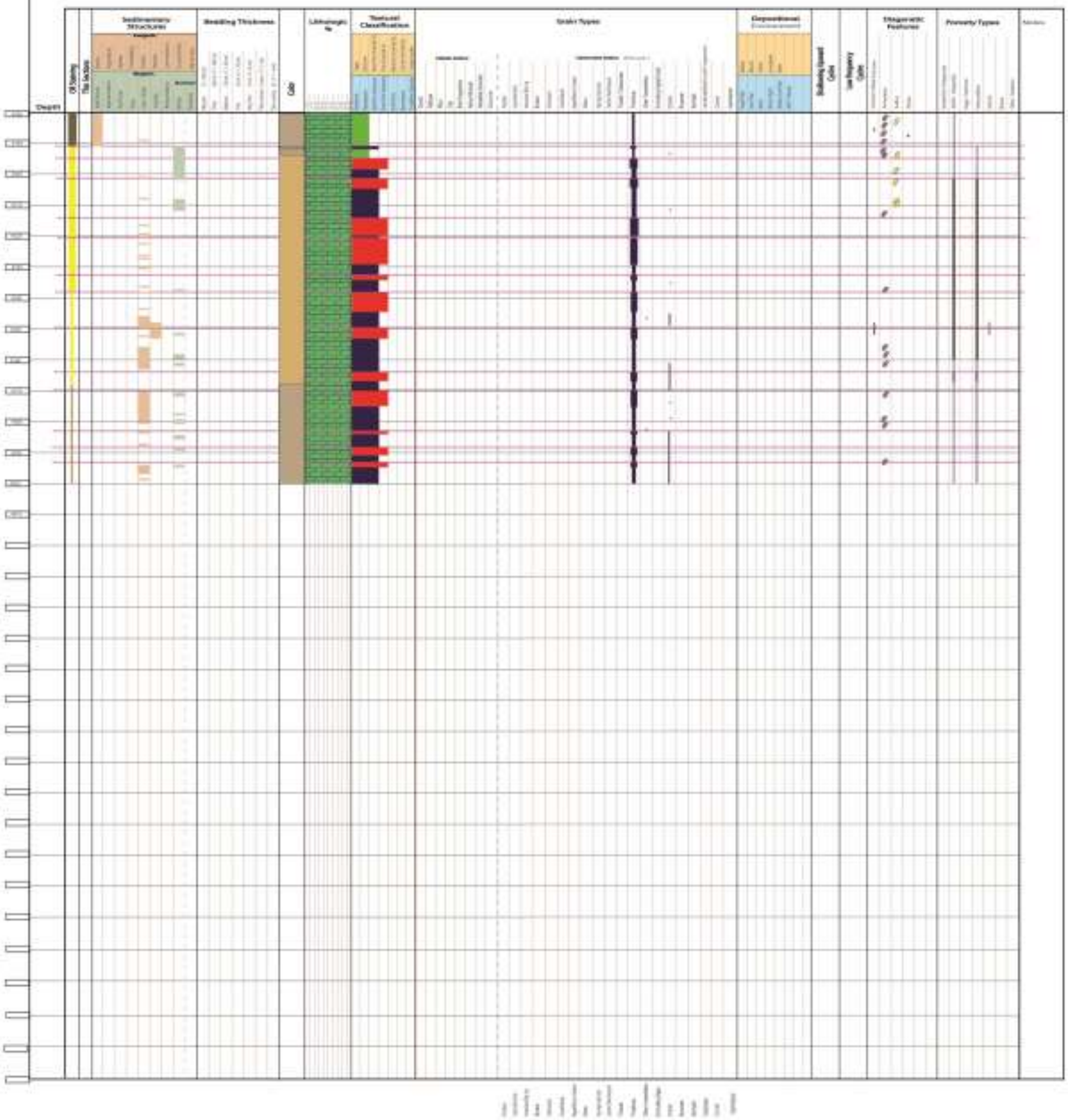
Formation(s) __SAN ANDRES__ Depth or Outcrop Interval __4073-4192__



Well or Measured Section Name GLSAU # 14-2 A Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged December, 2012

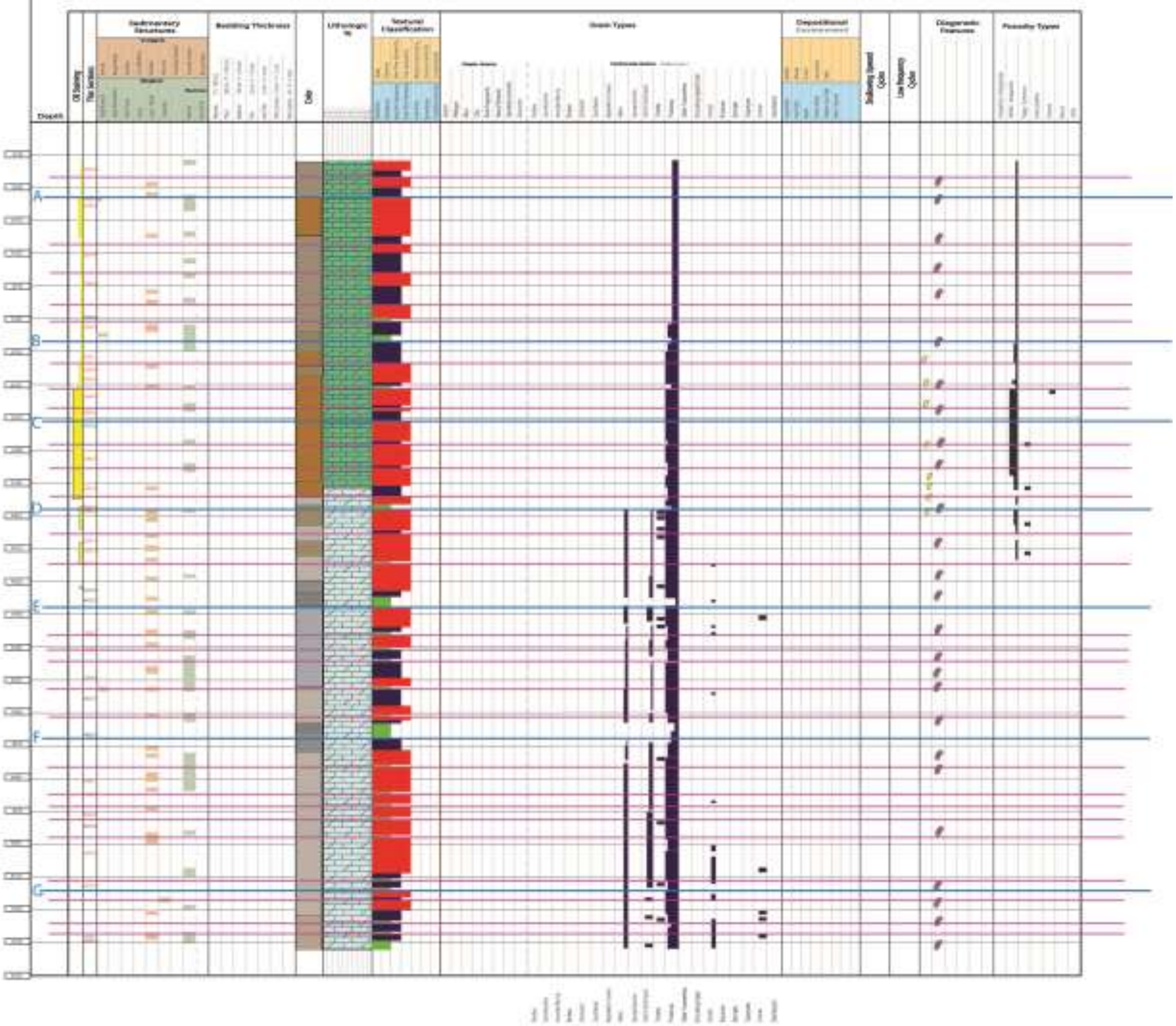
Formation(s) SAN ANDRES Depth or Outcrop Interval 4280-4400.24



Well or Measured Section Name GLSAU # 190 Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged JULY-SEPTEMBER, 2012

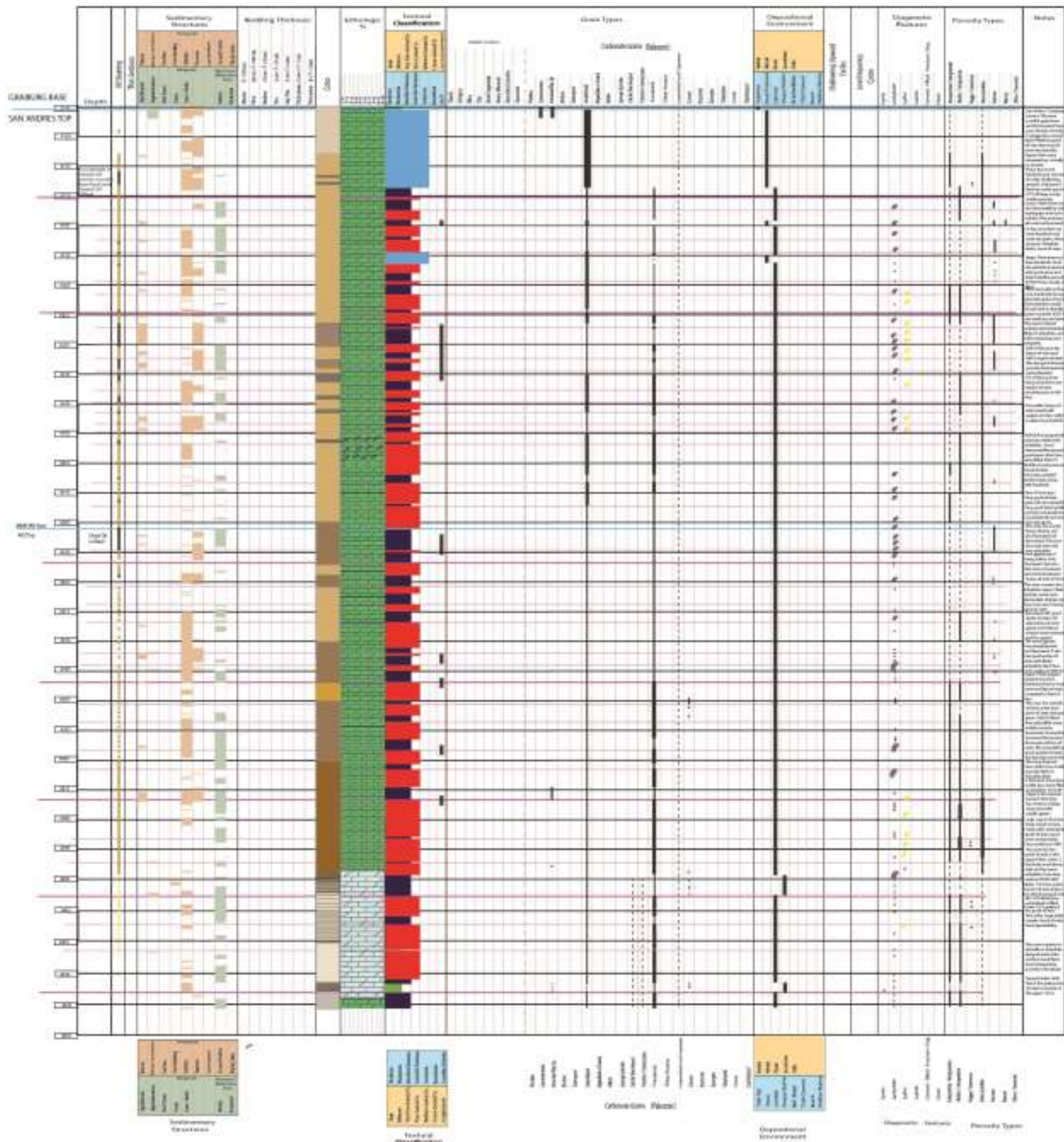
Formation(s) SAN ANDRES Depth or Outcrop Interval 4292-4532



Well Name GLSAU - 203 RW Location ECTOR COUNTY, TEXAS

Logged by TOYLY ABDULLAYEV Date Logged August 17, (Start) 2013

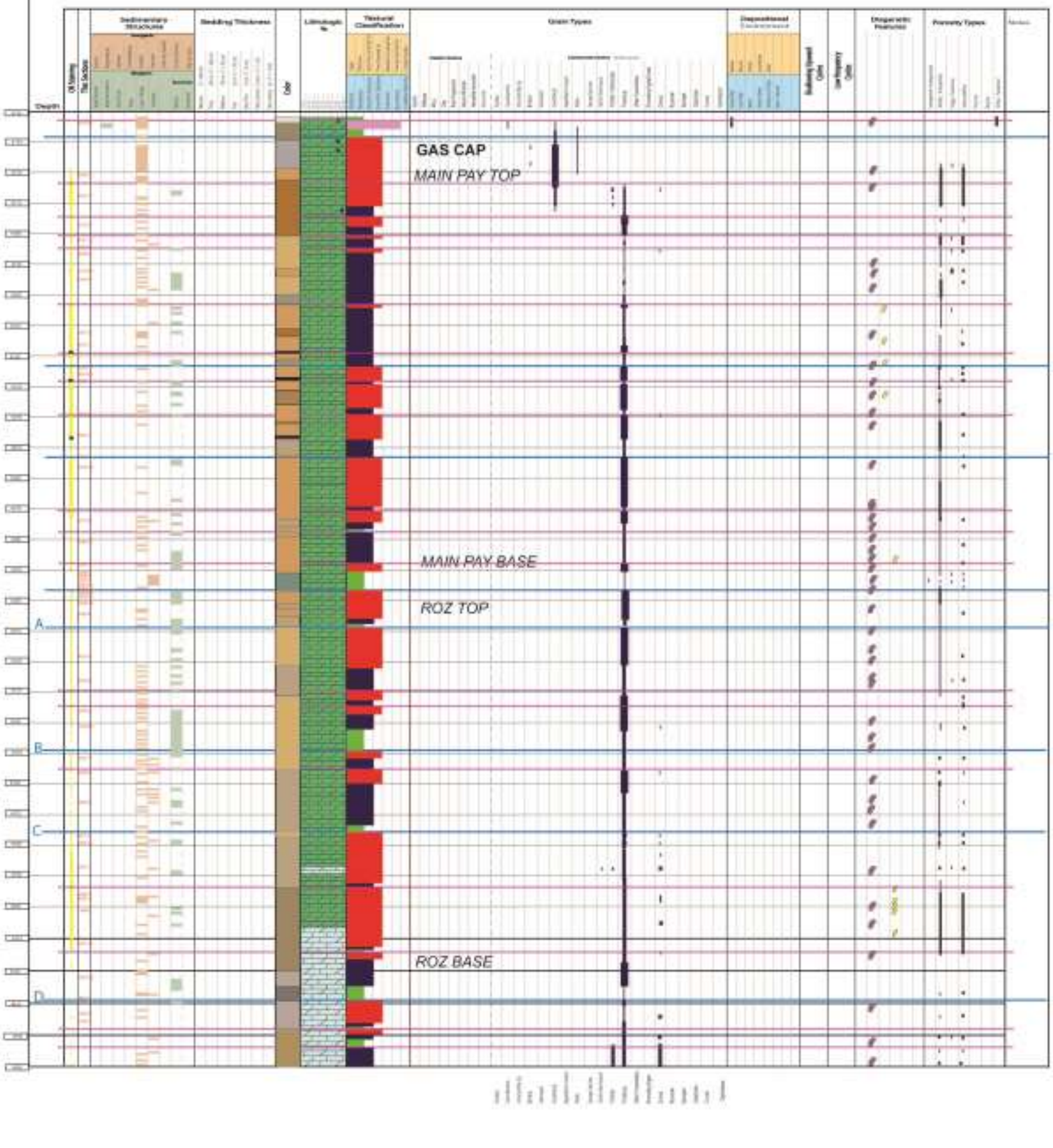
Formation(s) SAN ANDRES Depth or Outcrop Interval 4145 - 4446.35



Well or Measured Section Name GLSAU # 204, Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged JULY-SEPTEMBER, 2012

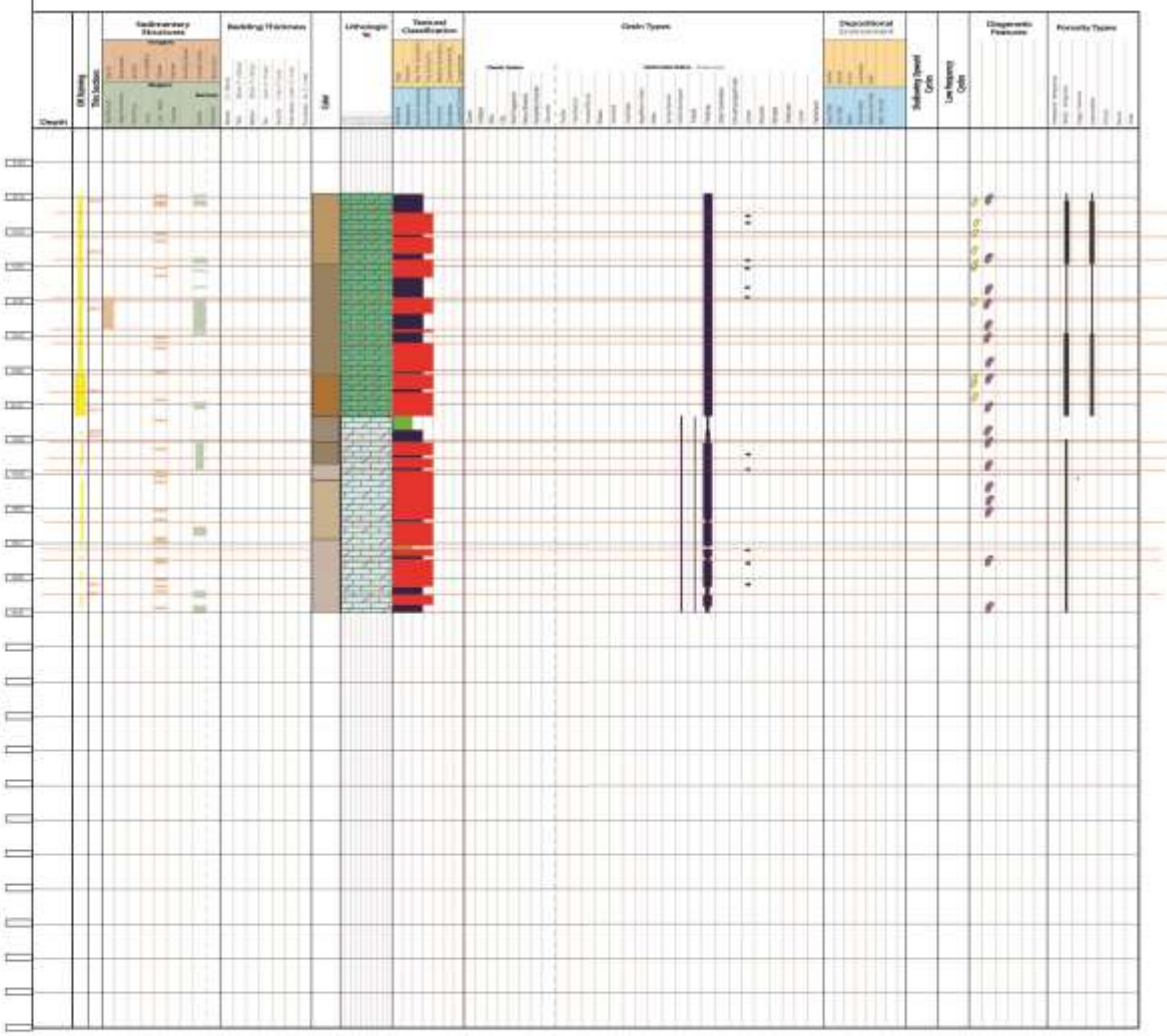
Formation(s) SAN ANDRES Depth or Outcrop Interval 4141-4450



Well or Measured Section Name GLSAU # 222 W Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged OCTOBER, 2012

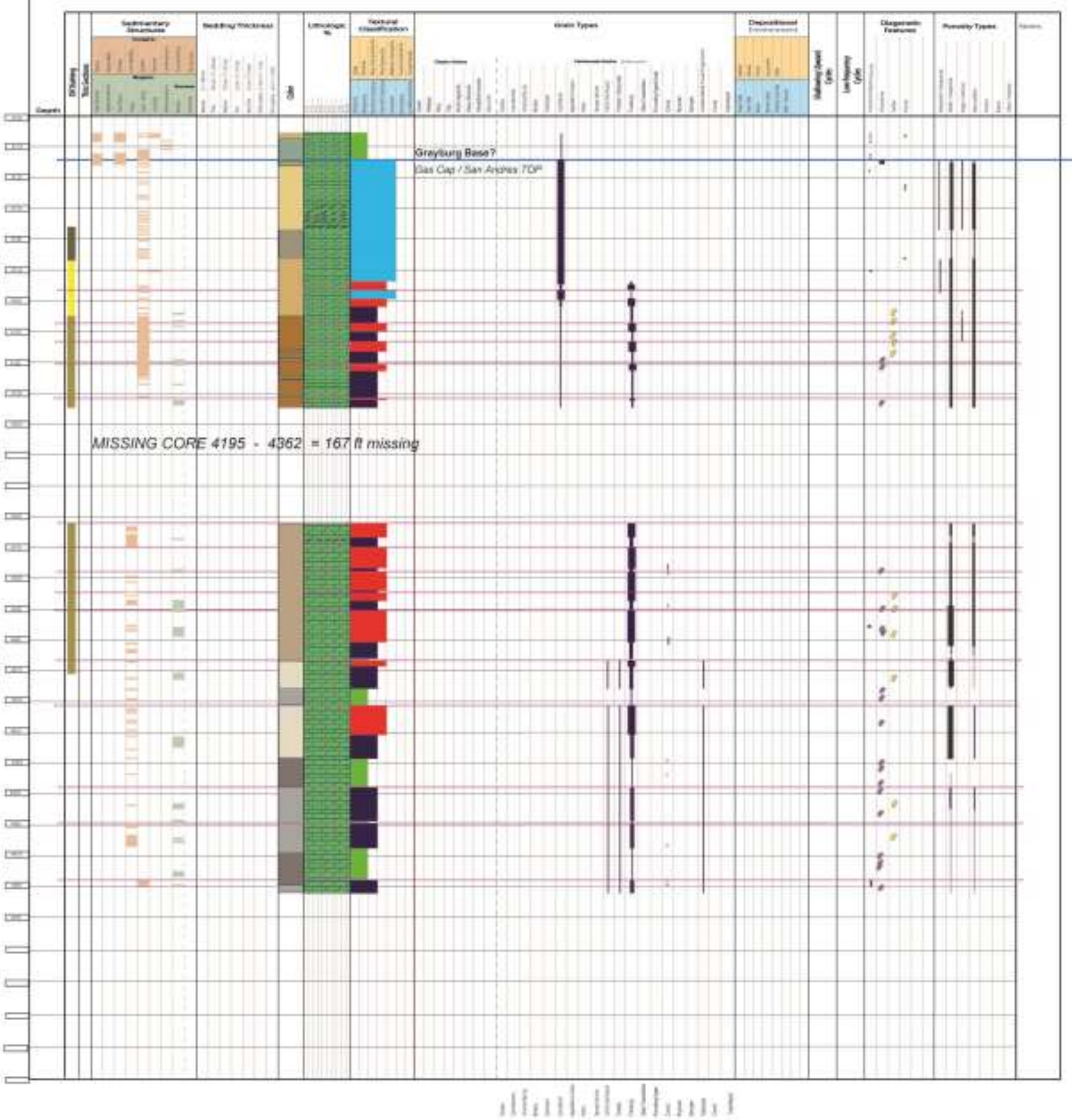
Formation(s) SAN ANDRES Depth or Outcrop Interval 4309-4429.1



Well or Measured Section Name GLSAU # 313 R Location ECTOR COUNTY, TEXAS

Logged by EMILY STOUDT AND TOYLY ABDULLAYEV Date Logged December, 2012

Formation(s) SAN ANDRES Depth or Outcrop Interval 4105-4195 4362-4481.9



Appendix 2.

Appendix for 4-A: Quantitative Analysis of CO_2 Tracer Surveys

Appendix 4-A provides the quantitative interpretation of CO_2 entry, by 10 foot intervals in the MPZ, the ROZ and other reservoir intervals for each of the 41 CO_2 tracer surveys in the 16 CO_2 injection wells of the GLSAU "Study Area."

CO2 Injection Well		CO2 Injection Well	
Well #	No. of Surveys	Well #	No. of Surveys
152W	1	202W	3
153	3	203	1
154	3	204R	4
155W	2	205W	3
176W	4	224W	2
177	2	225W	5
178R	2	226W	3
179	2	224R	1

CO2 Injection Well 152W		July 1, 2015
MPZ Interval (ft)	4167-4292	
ROZ Interval (ft)	4292-4412	
Well Type	**Openhole**	
Date	**3/3/2011**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**
Gas Cap		
4130-4140	0%	0.0%
4140-4150	0%	0.0%
4150-4160	0%	0.0%
4160-4170	2%	0.2%
Top of MPZ		
4170-4180	7%	0.7%
4180-4190	6%	0.6%
4190-4200	5%	0.5%
4200-4210	0%	0.0%
4210-4220	0%	0.0%
4220-4230	13%	1.3%
4230-4240	13%	1.3%
4240-4250	12%	1.2%
4250-4260	12%	1.2%
4260-4270	4%	0.4%
4270-4280	0%	0.0%
4280-4290	3%	0.3%
Top of ROZ		
4290-4300	3%	0.3%
4300-4310	5%	0.5%
4310-4320	6%	0.6%
4320-4330	7%	0.7%
4330-4340	3%	0.3%
4340-4350	0%	0.0%
4350-4360	0%	0.0%
4360-4370		
4370-4380		
4380-4390		
4390-4400		
4400-4410		
4410-4420		
Base of ROZ		

CO2 Injection Well 153W				July 1, 2015
MPZ Interval (ft)	4160-4275			
ROZ Interval (ft)	4275-4396			
Well Type	Openhole		perfed 4142-4152, openhole 4164-TD	
Date	2/25/2011		12/3/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Losses Above		0.0%		0.0%
4110-4120	2%	0.2%		0.0%
4120-4130	5%	0.5%		0.0%
4130-4140	4%	0.4%		0.0%
Gas Cap				
4140-4150	0%	0.0%	24%	2.4%
4150-4160	0%	0.0%	25%	2.5%
Top of MPZ				
4160-4170	3%	0.3%	18%	1.8%
4170-4180	5%	0.5%	12%	1.2%
4180-4190	8%	0.8%	9%	0.9%
4190-4200	4%	0.4%	6%	0.6%
4200-4210	1%	0.1%	4%	0.4%
4210-4220	5%	0.5%	2%	0.2%
4220-4230	6%	0.6%	0%	0.0%
4230-4240	0%	0.0%	0%	0.0%
4240-4250	0%	0.0%	0%	0.0%
4250-4260	0%	0.0%		0.0%
4260-4270	5%	0.5%		0.0%
4270-4280	10%	1.0%		0.0%
Top of ROZ				
4280-4290	6%	0.6%		0.0%
4290-4300	0%	0.0%		0.0%
4300-4310	6%	0.6%		0.0%
4310-4320	6%	0.6%		0.0%
4320-4330	6%	0.6%		0.0%
4330-4340	6%	0.6%		0.0%
4340-4350	7%	0.7%		0.0%
4350-4360	3%	0.3%		0.0%
4360-4370	0%	0.0%		0.0%
4370-4380	0%	0.0%		0.0%
4380-4390	0%			
4390-4400				
4400-4410				
4410-4420				
4420-4430				
Base of ROZ				

CO2 Injection Well 154W						July 1, 2015
MPZ Interval (ft)	4158-4268					
ROZ Interval (ft)	4268-4401					
Well Type	perfs 4132,4135,4145, openhole 4162-4401					
Date	2/28/2011		11/8/2011		7/6/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Losses Above						
4060-4070		0.0%	6%	0.6%		0.0%
4070-4080		0.0%	11%	1.1%		0.0%
4080-4090		0.0%	3%	0.3%		0.0%
4090-4100		0.0%	2%	0.2%		0.0%
4100-4110	9%	0.9%	3%	0.3%		0.0%
4110-4120	6%	0.6%	2%	0.2%		0.0%
4120-4130	3%	0.3%	1%	0.1%	2%	0.2%
Gas Cap						
4130-4140	6%	0.6%	2%	0.2%	3%	0.3%
4140-4150	6%	0.6%	2%	0.2%	5%	0.5%
4150-4160	6%	0.6%	0%	0.0%	15%	1.5%
Top of MPZ						
4160-4170	13%	1.3%	1%	0.1%	17%	1.7%
4170-4180	13%	1.3%	2%	0.2%	11%	1.1%
4180-4190	3%	0.3%	4%	0.4%	8%	0.8%
4190-4200		0.0%	5%	0.5%	6%	0.6%
4200-4210	3%	0.3%	7%	0.7%	12%	1.2%
4210-4220	3%	0.3%	12%	1.2%	21%	2.1%
4220-4230	6%	0.6%	13%	1.3%		0.0%
4230-4240	8%	0.8%	5%	0.5%		0.0%
4240-4250	15%	1.5%	6%	0.6%		0.0%
4250-4260		0.0%	15%	1.5%		0.0%
4260-4270		0.0%		0.0%		0.0%
Top of ROZ						
4270-4280		0.0%		0.0%		0.0%
4280-4290		0.0%		0.0%		0.0%
4290-4300		0.0%		0.0%		0.0%
4300-4310		0.0%		0.0%		0.0%
4310-4320		0.0%		0.0%		0.0%
4320-4330		0.0%		0.0%		0.0%
4330-4340		0.0%		0.0%		0.0%
4340-4350		0.0%		0.0%		0.0%
4350-4360		0.0%		0.0%		0.0%
4360-4370		0.0%		0.0%		0.0%
4370-4380		0.0%		0.0%		0.0%
4380-4390						
4390-4400						
Base of ROZ						

CO2 Injection Well 155W				July 1, 2015
MPZ Interval (ft)	4168-4283			
ROZ Interval (ft)	4283-4413			
Well Type	perfs in MPZ and open hole btm MPZ and ROZ			
Date	9/26/2011		10/18/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Losses Above				
4090-4100		0.0%	1%	0.1%
4100-4110	1%	0.1%	2%	0.2%
4110-4120	9%	0.9%	4%	0.4%
4120-4130	3%	0.3%	6%	0.6%
4130-4140	2%	0.2%	7%	0.7%
Gas Cap				
4140-4150	6%	0.6%	13%	1.3%
4150-4160	10%	1.0%	13%	1.3%
4160-4170	15%	1.5%	38%	3.8%
Top of MPZ				
4170-4180	17%	1.7%	15%	1.5%
4180-4190	19%	1.9%		0.0%
4190-4200	6%	0.6%		0.0%
4200-4210	13%	1.3%		0.0%
4210-4220		0.0%		0.0%
4220-4230		0.0%		0.0%
4230-4240		0.0%		0.0%
4240-4250		0.0%		0.0%
4250-4260		0.0%		0.0%
4260-4270		0.0%		0.0%
4270-4280		0.0%		0.0%
4280-4290		0.0%		0.0%
Top of ROZ				
4290-4300		0.0%		0.0%
4300-4310		0.0%		0.0%
4310-4320		0.0%		0.0%
4320-4330		0.0%		0.0%
4330-4340		0.0%		0.0%
4340-4350		0.0%		0.0%
4350-4360		0.0%		0.0%
4360-4370		0.0%		0.0%
4370-4380		0.0%		0.0%
4380-4390				
4390-4400				
4400-4410				
Base of ROZ				

CO2 Injection Well 176W						July 1, 2015
MPZ Interval (ft)	4174-4279					
ROZ Interval (ft)	4279-4410					
Depth Interval (ft)	perf 4150-4160, opnhl 4160-4365 4/22/2010 % Tracer Loss	Loss/ft	perf 4150-4160, opnhl 4160-4432 3/8/2011 % Tracer Loss	Loss/ft	10/4/2012 % Tracer Loss	new perfs 4330-4370, 4390-4430 Loss/ft
4060-4070		0.0%		0.0%		0.0%
4070-4080		0.0%		0.0%		0.0%
4080-4090		0.0%		0.0%		0.0%
4090-4100		0.0%		0.0%		0.0%
4100-4110		0.0%		0.0%		0.0%
4110-4120		0.0%		0.0%		0.0%
4120-4130	14%	1.4%		0.0%		0.0%
4130-4140	8%	0.8%		0.0%		0.0%
Gas Cap						
4140-4150	4%	0.4%	4%	0.4%		0.0%
4150-4160		0.0%	6%	0.6%		0.0%
4160-4170	6%	0.6%	2%	0.2%		0.0%
Top of MPZ						
4170-4180	1%	0.1%		0.0%		0.0%
4180-4190		0.0%		0.0%		0.0%
4190-4200		0.0%		0.0%		0.0%
4200-4210	3%	0.3%	2%	0.2%		0.0%
4210-4220	7%	0.7%	2%	0.2%		0.0%
4220-4230	4%	0.4%	2%	0.2%		0.0%
4230-4240	2%	0.2%	1%	0.1%		0.0%
4240-4250	9%	0.9%	2%	0.2%		0.0%
4250-4260	16%	1.6%	2%	0.2%		0.0%
4260-4270	4%	0.4%	2%	0.2%		0.0%
4270-4280	3%	0.3%	2%	0.2%		0.0%
Top of ROZ						
4280-4290		0.0%	0%	0.0%	0%	0.0%
4290-4300		0.0%	1%	0.1%	0%	0.0%
4300-4310	1%	0.1%		0.0%	0%	0.0%
4310-4320	4%	0.4%	6%	0.6%	0%	0.0%
4320-4330	7%	0.7%	9%	0.9%	0%	0.0%
4330-4340	6%	0.6%	11%	1.1%	0%	0.0%
4340-4350		0.0%	9%	0.9%	2%	0.2%
4350-4360		0.0%	4%	0.4%	5%	0.5%
4360-4370		0.0%	4%	0.4%	5%	0.5%
4370-4380		0.0%	3%	0.3%	0	0.0%
4380-4390		0.0%	4%	0.4%	0%	0.0%
4390-4400		0.0%	2%	0.2%	3%	0.3%
4400-4410		0.0%	6%	0.6%	3%	0.3%
Base of ROZ						
Losses Below ROZ						
4410-4420		0.0%	14%	1.4%	3%	0.3%
4420-4430		0.0%			66%	6.6%
4430-4440					14%	1.4%

CO2 Injection Well 177W				July 1, 2015
MPZ Interval (ft)	4174-4285			
ROZ Interval (ft)	4285-4400			
Well Type	**perfed 4290-4350**			
Date	**9/21/2011**		**12/1/2012**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**
Gas Cap				
4140-4150		0.0%		0.0%
4150-4160		0.0%		0.0%
4160-4170		0.0%		0.0%
Top of MPZ				
4170-4180		0.0%	0%	0.0%
4180-4190		0.0%	0%	0.0%
4190-4200		0.0%	0%	0.0%
4200-4210		0.0%	0%	0.0%
4210-4220		0.0%	16%	1.6%
4220-4230		0.0%	0%	0.0%
4230-4240		0.0%	0%	0.0%
4240-4250		0.0%		0.0%
4250-4260		0.0%		0.0%
4260-4270		0.0%		0.0%
4270-4280		0.0%		0.0%
4280-4290		0.0%		0.0%
Top of ROZ				
4290-4300	11%	1.1%	0%	0.0%
4300-4310	23%	2.3%	69%	6.9%
4310-4320	66%	6.6%	15%	1.5%
4320-4330	0%	0.0%	0%	0.0%
4330-4340	0%	0.0%	0%	0.0%
4340-4350	0%	0.0%		0.0%
4350-4360	0%	0.0%		0.0%
4360-4370	0%	0.0%		0.0%
4370-4380		0.0%		0.0%
4380-4390				
4390-4400				
Base of ROZ				

CO2 Injection Well 178R				July 1, 2015
MPZ Interval (ft)	4176-4285			
ROZ Interval (ft)	4285-4400			
Well Type	perfed 4300-4380			
Date	8/25/2011		9/10/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Gas Cap				
4150-4160		0.0%		0.0%
4160-4170		0.0%		0.0%
4170-4180		0.0%		0.0%
Top of MPZ				
4180-4190		0.0%		0.0%
4190-4200		0.0%		0.0%
4200-4210		0.0%		0.0%
4210-4220		0.0%		0.0%
4220-4230		0.0%		0.0%
4230-4240		0.0%		0.0%
4240-4250		0.0%		0.0%
4250-4260		0.0%		0.0%
4260-4270		0.0%		0.0%
4270-4280		0.0%		0.0%
4280-4290	2%	0.2%		0.0%
Top of ROZ				
4290-4300	6%	0.6%		0.0%
4300-4310	6%	0.6%	15%	1.5%
4310-4320	22%	2.2%	15%	1.5%
4320-4330	14%	1.4%	10%	1.0%
4330-4340	16%	1.6%	18%	1.8%
4340-4350	15%	1.5%	12%	1.2%
4350-4360		0.0%	5%	0.1%
4360-4370	7%	0.7%	11%	1.1%
4370-4380	12%	1.2%	13%	1.3%
4380-4390				
4390-4400				
Base of ROZ				

CO2 Injection Well 179W				July 1, 2015
MPZ Interval (ft)	4169-4290			
ROZ Interval (ft)	4290-4410			
Well Type	**Perfs 4132-4145, openhole 4150-4405**			
Date	**9/23/2011**		**10/20/2012**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**
Losses Above				
4060-4070		0.0%	28%	2.8%
4070-4080		0.0%	4%	0.4%
4080-4090	3%	0.3%	14%	1.4%
4090-4100	4%	0.4%	9%	0.9%
4100-4110	3%	0.3%	20%	2.0%
4110-4120	2%	0.2%	6%	0.6%
4120-4130	2%	0.2%	6%	0.6%
4130-4140	2%	0.2%	1%	0.1%
Gas Cap				
4140-4150	2%	0.2%		0.0%
4150-4160	0%	0.0%	4%	0.4%
4160-4170		0.0%	8%	0.8%
Top of MPZ				
4170-4180	2%	0.2%		0.0%
4180-4190	4%	0.4%		0.0%
4190-4200	4%	0.4%		0.0%
4200-4210	4%	0.4%		0.0%
4210-4220	3%	0.3%		0.0%
4220-4230	3%	0.3%		0.0%
4230-4240	3%	0.3%		0.0%
4240-4250	7%	0.7%		0.0%
4250-4260	6%	0.6%		0.0%
4260-4270	1%	0.1%		0.0%
4270-4280		0.0%		0.0%
4280-4290	47%	4.7%		0.0%
Top of ROZ				
4290-4300		0.0%		0.0%
4300-4310		0.0%		0.0%
4310-4320		0.0%		0.0%
4320-4330		0.0%		0.0%
4330-4340		0.0%		0.0%
4340-4350		0.0%		0.0%
4350-4360		0.0%		0.0%
4360-4370		0.0%		0.0%
4370-4380		0.0%		0.0%
4380-4390				
4390-4400				
4400-4410				
Base of ROZ				

CO2 Injection Well 202W						July 1, 2015
MPZ Interval (ft)	4175-4290					
ROZ Interval (ft)	4290-4410					
Well Type	Openhole					
Date	3/31/2010		2/18/2011		5/22/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Gas Cap						
4140-4150		0.0%		0.0%		0.0%
4150-4160	6%	0.6%	17%	1.7%	1%	0.1%
4160-4170	12%	1.2%	22%	2.2%	1%	0.1%
4170-4180	1%	0.1%	1%	0.1%	2%	0.2%
Top of MPZ						
4180-4190	1%	0.1%	1%	0.1%	2%	0.2%
4190-4200	8%	0.8%	1%	0.1%	2%	0.2%
4200-4210	8%	0.8%	2%	0.2%	1%	0.1%
4210-4220	9%	0.9%	2%	0.2%	1%	0.1%
4220-4230	9%	0.9%	3%	0.3%	5%	0.5%
4230-4240	3%	0.3%	2%	0.2%	6%	0.6%
4240-4250	13%	1.3%	1%	0.1%	7%	0.7%
4250-4260	8%	0.8%	1%	0.1%	9%	0.9%
4260-4270	3%	0.3%	2%	0.2%	8%	0.8%
4270-4280	4%	0.4%	2%	0.2%	7%	0.7%
4280-4290	7%	0.7%	12%	1.2%	14%	1.4%
Top of ROZ						
4290-4300	6%	0.6%	13%	1.3%	23%	2.3%
4300-4310	1%	0.1%	5%	0.5%	13%	1.3%
4310-4320	3%	0.3%	5%	0.5%		0.0%
4320-4330		0.0%	10%	1.0%		0.0%
4330-4340		0.0%		0.0%		0.0%
4340-4350		0.0%		0.0%		0.0%
4350-4360		0.0%		0.0%		0.0%
4360-4370		0.0%		0.0%		0.0%
4370-4380		0.0%		0.0%		
4380-4390		0.0%		0.0%		
4390-4400		0.0%		0.0%		
4400-4410		0.0%		0.0%		
4410-4420		0.0%		0.0%		
Base of ROZ						

CO2 Injection Well 203W		July 1, 2015
MPZ Interval (ft)	4180-4295	
ROZ Interval (ft)	4295-4407	
Well Type	perfed 4297-4365	
Date	9/19/2011	
Interval (ft)	% Tracer Loss	Loss/ft
Gas Cap		
4140-4150		0.0%
4150-4160		0.0%
4160-4170		0.0%
4170-4180		0.0%
Top of MPZ		
4180-4190		0.0%
4190-4200		0.0%
4200-4210		0.0%
4210-4220		0.0%
4220-4230		0.0%
4230-4240		0.0%
4240-4250		0.0%
4250-4260		0.0%
4260-4270		0.0%
4270-4280		0.0%
4280-4290		0.0%
4290-4300		0.0%
Top of ROZ		
4300-4310	16%	1.6%
4310-4320	6%	0.6%
4320-4330	23%	2.3%
4330-4340	36%	3.6%
4340-4350	5%	0.5%
4350-4360	3%	0.3%
4360-4370	1%	0.1%
4370-4380	10%	1.0%
4380-4390		
4390-4400		
4400-4410		
Base of ROZ		

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CO2 Injection Well 204R								July 1, 2015
Openhole (ft)								
MPZ Interval (ft)	4181-4291							
ROZ Interval (ft)	4291-4410							
Well Type	**Perfed 4302-84, 4404-28**				**Perfed 4181-4404**			
Date	**8/24/2009**		**9/24/2009**		**2/16/2011**		**7/16/2012**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**
Gas Cap								
4150-4160						0.0%		0.0%
4160-4170						0.0%		0.0%
4170-4180					7%	0.7%	4%	0.4%
Top of MPZ								
4180-4190					12%	1.2%	7%	0.7%
4190-4200					9%	0.9%	7%	0.7%
4200-4210					7%	0.7%	16%	1.6%
4210-4220					2%	0.2%	15%	1.5%
4220-4230					2%	0.2%	6%	0.6%
4230-4240					2%	0.2%	2%	0.2%
4240-4250					13%	1.3%	2%	0.2%
4250-4260					9%	0.9%	2%	0.2%
4260-4270					3%	0.3%	2%	0.2%
4270-4280					1%	0.1%	1%	0.1%
4280-4290						0.0%	0%	0.0%
Top of ROZ								
4290-4300		0.0%		0.0%		0.0%	0%	0.0%
4300-4310	5%	0.5%		0.0%		0.0%	2%	0.2%
4310-4320	14%	1.4%	2%	0.2%		0.0%	6%	0.6%
4320-4330	10%	1.0%	11%	1.1%	16%	1.6%	6%	0.6%
4330-4340	8%	0.8%	13%	1.3%	18%	1.8%	21%	2.1%
4340-4350	22%	2.2%	19%	1.9%		0.0%		0.0%
4350-4360	13%	1.3%	16%	1.6%		0.0%		0.0%
4360-4370	10%	1.0%	15%	1.5%		0.0%		0.0%
4370-4380	17%	1.7%	16%	1.6%		0.0%		0.0%
4380-4390			8%	0.8%		0.0%		0.0%
4390-4400								
4400-4410								
4410-4420								
Base of ROZ								

CO2 Injection Well 205W						July 1, 2015
MPZ Interval (ft)	4175-4290					
ROZ Interval (ft)	4290-4420					
Well Type	Openhole 4181-4375					
Date	5/7/2010		12/9/2011		12/6/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
Losses Above						
4130-4140		0.0%	9%	0.9%		0.0%
4140-4150		0.0%	10%	1.0%		0.0%
Gas Cap						
4150-4160		0.0%	6%	0.6%		0.0%
4160-4170		0.0%		0.0%		0.0%
4170-4180		0.0%	1%	0.1%		0.0%
Top of MPZ						
4180-4190	1%	0.1%	3%	0.3%		0.0%
4190-4200	2%	0.2%	3%	0.3%		0.0%
4200-4210	4%	0.4%	7%	0.7%		0.0%
4210-4220	7%	0.7%	6%	0.6%	47%	4.7%
4220-4230	6%	0.6%	3%	0.3%		0.0%
4230-4240	5%	0.5%	3%	0.3%	4%	0.4%
4240-4250	5%	0.5%	8%	0.8%	7%	0.7%
4250-4260	13%	1.3%	9%	0.9%	3%	0.3%
4260-4270	24%	2.4%	13%	1.3%	4%	0.4%
4270-4280	10%	1.0%	4%	0.4%	7%	0.7%
4280-4290	1%	0.1%	3%	0.3%	8%	0.8%
Top of ROZ						
4290-4300	2%	0.2%	2%	0.2%	6%	0.6%
4300-4310	4%	0.4%	7%	0.7%	4%	0.4%
4310-4320	2%	0.2%		0.0%	8%	0.8%
4320-4330	13%	1.3%		0.0%		0.0%
4330-4340		0.0%		0.0%		0.0%
4340-4350		0.0%		0.0%		0.0%
4350-4360		0.0%		0.0%		0.0%
4360-4370		0.0%		0.0%		0.0%
4370-4380		0.0%		0.0%		0.0%
4380-4390						
4390-4400						
4400-4410						
4410-4420						
Base of ROZ						

CO2 Injection Well 224W and then 224 R				July 1, 2015
MPZ Interval (ft)	4171-4290			
ROZ Interval (ft)	4290-4390			
Well Type	Openhole		perfed 4300-4340 and 4360-4400	
Depth	6/29/2011		8/31/2012	
Interval (ft)	% Tracer Loss	Loss/ft	% Tracer Loss	Loss/ft
4060-4070		0.0%		0.0%
4070-4080		0.0%		0.0%
4080-4090		0.0%		0.0%
4090-4100		0.0%		0.0%
4100-4110		0.0%		0.0%
4110-4120		0.0%		0.0%
Losses Above				
4120-4130	4%	0.4%		0.0%
4130-4140	6%	0.6%		0.0%
Gas Cap				
4140-4150	6%	0.6%		0.0%
4150-4160	4%	0.4%		0.0%
4160-4170	4%	0.4%		0.0%
Top of MPZ				
4170-4180	8%	0.8%		0.0%
4180-4190	11%	1.1%		0.0%
4190-4200	2%	0.2%		0.0%
4200-4210	6%	0.6%		0.0%
4210-4220	19%	1.9%		0.0%
4220-4230	17%	1.7%		0.0%
4230-4240	14%	1.4%		0.0%
4240-4250		0.0%		0.0%
4250-4260		0.0%		0.0%
4260-4270		0.0%		0.0%
4270-4280		0.0%		0.0%
4280-4290		0.0%		0.0%
Top of ROZ				
4290-4300		0.0%		0.0%
4300-4310		0.0%	14%	1.4%
4310-4320		0.0%	10%	1.0%
4320-4330		0.0%	14%	1.4%
4330-4340		0.0%	17%	1.7%
4340-4350		0.0%		0.0%
4350-4360		0.0%		0.0%
4360-4370		0.0%	9%	0.9%
4370-4380		0.0%	18%	1.8%
4380-4390		0.0%	18%	1.8%
Base of ROZ				

CO2 Injection Well 225W										July 1, 2015
MPZ Interval (ft)	**4165-4275**									
ROZ Interval (ft)	**4275-4395**									
Well Type	**Openhole 4176-4380**								**Perfed 275-4320, 4340-90**	
Date	**2/17/2011**		**6/28/2011**		**7/10/2012**		**9/4/2012**		**11/30/2012**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**
Losses Above										
4070-4080	3%	0.3%								
4080-4090	19%	1.9%								
4090-4100	14%	1.4%								
4100-4110	2%	0.2%								
Gas Cap										
4140-4150		0.0%								
4150-4160		0.0%								
4160-4170	2%	0.2%		0.0%		0.0%		0.0%		0.0%
Top of MPZ										
4170-4180	3%	0.3%	1%	0.1%	36%	3.6%	61%	6.1%		0.0%
4180-4190	3%	0.3%	3%	0.3%	45%	4.5%	16%	1.6%		0.0%
4190-4200	3%	0.3%	3%	0.3%	19%	1.9%	12%	1.2%		0.0%
4200-4210	3%	0.3%	4%	0.4%		0.0%	4%	0.4%		0.0%
4210-4220	3%	0.3%	6%	0.6%		0.0%	8%	0.8%		0.0%
4220-4230	4%	0.4%	8%	0.8%		0.0%		0.0%		0.0%
4230-4240	7%	0.7%	9%	0.9%		0.0%		0.0%		0.0%
4240-4250	8%	0.8%	9%	0.9%		0.0%		0.0%		0.0%
4250-4260	7%	0.7%	10%	1.0%		0.0%		0.0%		0.0%
4260-4270	7%	0.7%	16%	1.6%		0.0%		0.0%		0.0%
Top of ROZ										
4270-4280	13%	1.3%	33%	3.3%		0.0%		0.0%	79%	7.9%
4280-4290		0.0%		0.0%		0.0%		0.0%	21%	2.1%
4290-4300		0.0%		0.0%		0.0%		0.0%		0.0%
4300-4310		0.0%		0.0%		0.0%		0.0%		0.0%
4310-4320		0.0%		0.0%		0.0%		0.0%		0.0%
4320-4330		0.0%		0.0%		0.0%		0.0%		0.0%
4330-4340		0.0%		0.0%		0.0%		0.0%		0.0%
4340-4350		0.0%		0.0%		0.0%		0.0%		0.0%
4350-4360		0.0%		0.0%		0.0%		0.0%		0.0%
4360-4370		0.0%		0.0%		0.0%		0.0%		0.0%
4370-4380		0.0%		0.0%		0.0%		0.0%		0.0%
4380-4390										
4390-4400										
Base of ROZ										

CO2 Injection Well 226W				July 1, 2015
MPZ Interval (ft)	4180-4290			
ROZ Interval (ft)	4290-4410			
Well Type	**perfs 4150, 67', 4200, 06', open hole 4210-4425'**			
Date	**6/20/2011**		**8/27/2012**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**	**% Tracer Loss**	**Loss/ft**
Gas Cap				
4150-4160		0.0%		0.0%
4160-4170		0.0%		0.0%
4170-4180		0.0%	3%	0.3%
Top of MPZ				
4180-4190	8%	0.8%	29%	2.9%
4190-4200	9%	0.9%	15%	1.5%
4200-4210	2%	0.2%	5%	0.5%
4210-4220	3%	0.3%	3%	0.3%
4220-4230	6%	0.6%	7%	0.7%
4230-4240	13%	1.3%	9%	0.9%
4240-4250	17%	1.7%	12%	1.2%
4250-4260	6%	0.6%	3%	0.3%
4260-4270	6%	0.6%		0.0%
4270-4280	11%	1.1%	1%	0.1%
4280-4290	5%	0.5%	4%	0.4%
Top of ROZ				
4290-4300	4%	0.4%	2%	0.2%
4300-4310	1%	0.1%	7%	0.7%
4310-4320		0.0%		0.0%
4320-4330		0.0%		0.0%
4330-4340	8%	0.8%		0.0%
4340-4350		0.0%		0.0%
4350-4360		0.0%		0.0%
4360-4370		0.0%		0.0%
4370-4380		0.0%		0.0%
4380-4390				
4390-4400				
4400-4410				
4410-4420				
4420-4430				
Base of ROZ				

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CO2 Injection Well 227R		July 1, 2015
MPZ Interval (ft)	4184-4290	
ROZ Interval (ft)	4290-4410	
Well Type	**perf 4184-4428**	
Date	**`10/3/2011**	
Interval (ft)	**% Tracer Loss**	**Loss/ft**
Gas Cap		
4160-4170		0.0%
4170-4180		0.0%
Top of MPZ		
4180-4190		0.0%
4190-4200	47%	4.7%
4200-4210	35%	3.5%
4210-4220	16%	1.6%
4220-4230	2%	0.2%
4230-4240		0.0%
4240-4250		0.0%
4250-4260		0.0%
4260-4270		0.0%
4270-4280		0.0%
4280-4290		0.0%
Top of ROZ		
4290-4300		0.0%
4300-4310		0.0%
4310-4320		0.0%
4320-4330		0.0%
4330-4340		0.0%
4340-4350		0.0%
4350-4360		0.0%
4360-4370		0.0%
4370-4380		0.0%
4380-4390		
4390-4400		
4400-4410		
Base of ROZ		

Appendix 3>

Appendix 4-B: Distribution of CO_2 by Production Pattern

Appendix 4-B provides the distribution of CO_2 from the 16 CO_2 injection wells into the 9 production patterns of the GLSAU "Study Area".

The distribution and profiles of CO_2 for each of the nine GLSAU "Study Area" production patterns is based on the "Quantitative Analysis of CO_2 Tracer Survey" provided in Appendix 4-A.

CO2 Injection Profile for Production Pattern #190

Injector Well 177				Injector Well 178				Injector Well 203	
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
Gas Cap	0%	0%	0%	Gas Cap	0%	0%	0%	Gas Cap	0%
MPZ	0%	16%	8%	MPZ	2%	0%	1%	MPZ	0%
ROZ	100%	84%	92%	ROZ	98%	100%	99%	ROZ	100%
NonPay	0%	0%	0%	NonPay	0%	0%	0%	NonPay	0%
Gas Cap Interv	4144-4174			Gas Cap Interval	4146-4176			Gas Cap Interval	4140-4180
(ft from top)				(ft from top)				(ft from top)	
10	0%	0%	0%	10	0%	0%	0%	10	0%
20	0%	0%	0%	20	0%	0%	0%	20	0%
30	0%	0%	0%	30	0%	0%	0%	30	0%
40	0%	0%	0%	40	0%	0%	0%	40	0%
MPZ Interval	4174-4285			MPZ Interval	4176-4285			MPZ Interval	4180-4295
MPZ				MPZ				MPZ	
(ft from top)				(ft from top)				(ft from top)	
10	0%	0%	0%	10	0%	0%	0%	10	0%
20	0%	0%	0%	20	0%	0%	0%	20	0%
30	0%	0%	0%	30	0%	0%	0%	30	0%
40	0%	0%	0%	40	0%	0%	0%	40	0%
50	0%	16%	8%	50	0%	0%	0%	50	0%
60	0%	0%	0%	60	0%	0%	0%	60	0%
70	0%	0%	0%	70	0%	0%	0%	70	0%
80	0%	0%	0%	80	0%	0%	0%	80	0%
90	0%	0%	0%	90	0%	0%	0%	90	0%
100	0%	0%	0%	100	0%	0%	0%	100	0%
110	0%	0%	0%	110	2%	0%	0%	110	0%
120	0%	0%	0%	120	0%	0%	1%	120	0%
130	0%	0%	0%	130	0%	0%	3%	130	0%
Injector Well 177				**Injector Well 178**				**Injector Well 203**	
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
ROZ Interval	4285-4400			ROZ Interval	4285-4400			ROZ Interval	4295-4407
ROZ				ROZ				ROZ	
(ft from top)				(ft from top)				(ft from top)	
10	11%	0%	6%	10	6%	0%	3%	10	16%
20	23%	69%	46%	20	6%	15%	11%	20	6%
30	66%	15%	40%	30	22%	15%	19%	30	23%
40	0%	0%	0%	40	14%	10%	12%	40	36%
50	0%	0%	0%	50	16%	18%	17%	50	5%
60	0%	0%	0%	60	15%	12%	13%	60	3%
70	0%	0%	0%	70	0%	5%	2%	70	1%
80	0%	0%	0%	80	7%	11%	9%	80	10%
90	0%	0%	0%	90	12%	13%	13%	90	0%
100	0%	0%	0%	100	0%	0%	0%	100	0%
110	0%	0%	0%	110	0%	0%	0%	110	0%

CO2 Injection Profile for Production Pattern #190						June 30, 3015	
Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
Gas Cap	0%	0%	0%	19%	4%	11%	
MPZ	0%	0%	0%	47%	61%	54%	
ROZ	100%	100%	100%	34%	35%	35%	
NonPay	0%	0%	0%	0%	0%	0%	
Gas Cap Interval	4152-4181						**Gas Cap**
(ft from top)							**Avg**
10	0%	0%	0%	0%	0%	0%	**0%**
20	0%	0%	0%	0%	0%	0%	**0%**
30	0%	0%	0%	7%	0%	4%	**1%**
40	0%	0%	0%	12%	4%	8%	**2%**
MPZ Interval	4181-4291		Period			Period	**MPZ**
MPZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)							
10	0%	0%	0%	9%	7%	8%	**2%**
20	0%	0%	0%	7%	7%	7%	**2%**
30	0%	0%	0%	2%	16%	9%	**2%**
40	0%	0%	0%	2%	15%	8%	**2%**
50	0%	0%	0%	2%	6%	4%	**3%**
60	0%	0%	0%	13%	2%	8%	**2%**
70	0%	0%	0%	9%	2%	6%	**1%**
80	0%	0%	0%	3%	2%	3%	**1%**
90	0%	0%	0%	1%	2%	1%	**0%**
100	0%	0%	0%	0%	1%	0%	**0%**
110	0%	0%	0%	0%	0%	0%	**0%**
120	0%	0%	0%	0%	0%	0%	**0%**
130	0%	0%	0%	0%	0%	0%	**1%**
Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st	2/16/2011	7/16/2012	Avg 2nd	
ROZ Interval	4291-4410		Period			Period	**ROZ**
ROZ	ROZ only			MPZ/ROZ open			**Avg**
(ft from top)							
10	0%	0%	0%	0%	0%	0%	**6%**
20	5%	0%	3%	0%	2%	1%	**16%**
30	14%	2%	8%	0%	6%	3%	**21%**
40	10%	11%	11%	16%	6%	11%	**15%**
50	8%	13%	10%	18%	21%	19%	**10%**
60	22%	19%	20%	0%	0%	0%	**4%**
70	13%	16%	15%	0%	0%	0%	**1%**
80	10%	15%	13%	0%	0%	0%	**5%**
90	17%	16%	16%	0%	0%	0%	**3%**
100	0%	8%	4%	0%	0%	0%	**0%**
110	0%	0%	0%	0%	0%	0%	**0%**

CO2 Injection Profile for Production Pattern #163							
Injector Well 155				**Injector Well 178**			
Dates of Inj	9/26/2011	10/18/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
ROZ Interval	4283-4423			ROZ Interva	4298-4420	rfed 4300-4380	
Depth (ROZ)				Depth (ROZ)			
(ft from top)				(ft from top)			
10	0%	0%	0%	10	6%	15%	11%
20	0%	0%	0%	20	22%	15%	19%
30	0%	0%	0%	30	14%	10%	12%
40	0%	0%	0%	40	16%	18%	17%
50	0%	0%	0%	50	15%	12%	13%
60	0%	0%	0%	60	0%	5%	2%
70	0%	0%	0%	70	7%	11%	9%
80	0%	0%	0%	80	12%	13%	13%
90	0%	0%	0%	90	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%
120	0%	0%	0%	120	0%	0%	0%
130	0%	0%	0%	130	0%	0%	0%
MPZ	38%	0%	19%	MPZ	8%	0%	4%
NonPay	62%	100%	81%	NonPay	0%	0%	0%

Injector Well 155				**Injector Well 178**			
Dates of Inj	9/26/2011	10/18/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
MPZ Interval	4187-4283			MPZ Interva	4172-4298	rfed 4300-4380	
Depth (MPZ)				Depth (MPZ)			
(ft from top)				(ft from top)			
10	19%	0%	10%	10	0%	0%	0%
20	6%	0%	3%	20	0%	0%	0%
30	13%	0%	7%	30	0%	0%	0%
40	0%	0%	0%	40	0%	0%	0%
50	0%	0%	0%	50	0%	0%	0%
60	0%	0%	0%	60	0%	0%	0%
70	0%	0%	0%	70	0%	0%	0%
80	0%	0%	0%	80	0%	0%	0%
90	0%	0%	0%	90	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%
120	0%	0%	0%	120	2%	0%	1%
130	0%	0%	0%	130	6%	0%	3%
MPZ	0%	0%	0%	MPZ	92%	100%	96%
NonPay	62%	100%	81%	NonPay	0%	0%	0%

CO2 Injection Profile for Production Pattern #163

June 30, 3015

Injector Well 179				Injector Well 154				
Dates of Inj	9/23/2011	10/20/2012	Avg	Dates of Inj	2/28/2011	11/8/2011	7/6/2012	
ROZ Interva	4287-4434			ROZ Interva	4268-4401			ROZ
Depth (ROZ-4145, openhole below				Depth (ROZ	openhole		Remediated	Avg
(ft from top)				(ft from top)				
10	47%	0%	24%	10	0%	0%	0%	9%
20	0%	0%	0%	20	0%	0%	0%	5%
30	0%	0%	0%	30	0%	0%	0%	3%
40	0%	0%	0%	40	0%	0%	0%	4%
50	0%	0%	0%	50	0%	0%	0%	3%
60	0%	0%	0%	60	0%	0%	0%	1%
70	0%	0%	0%	70	0%	0%	0%	2%
80	0%	0%	0%	80	0%	0%	0%	3%
90	0%	0%	0%	90	0%	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%	0%
120	0%	0%	0%	120	0%	0%	0%	0%
130	0%	0%	0%	130	0%	0%	0%	0%
MPZ	36%	12%	24%	MPZ	82%	72%	98%	36%
NonPay	17%	88%	52%	NonPay	18%	28%	2%	34%

Injector Well 179				Injector Well 154				
Dates of Inj	9/23/2011	10/20/2012	Avg	Dates of Inj	2/28/2011	11/8/2011	7/6/2012	
MPZ Interva	4150-4287			MPZ Interva	4132-4268			MPZ
Depth (MPZ)				Depth (MPZ	openhole			Avg
(ft from top)				(ft from top)				
10	0%	4%	2%	10	6%	2%	3%	4%
20	0%	8%	4%	20	6%	2%	5%	3%
30	2%	0%	1%	30	6%	0%	15%	6%
40	4%	0%	2%	40	13%	1%	17%	5%
50	4%	0%	2%	50	13%	2%	11%	3%
60	4%	0%	2%	60	3%	4%	8%	2%
70	3%	0%	2%	70	0%	5%	6%	2%
80	3%	0%	1%	80	3%	7%	12%	3%
90	3%	0%	1%	90	3%	12%	21%	6%
100	7%	0%	4%	100	6%	13%	0%	1%
110	6%	0%	3%	110	8%	5%	0%	1%
120	1%	0%	1%	120	15%	6%	0%	0%
130	0%	0%	0%	130	0%	15%	0%	1%
MPZ	47%	0%	24%	MPZ	0%	0%	0%	30%
NonPay	17%	88%	52%	NonPay	18%	28%	2%	34%

CO2 Injection Profile for Production Pattern #164							
Injector Well 177				**Injector Well 178**			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
ROZ Interval	4285-4399			ROZ Interval	4298-4420	perfed 4300-4380	
Depth (ROZ) (ft from top)				Depth (ROZ) (ft from top)			
10	11%	0%	6%	10	6%	15%	11%
20	23%	69%	46%	20	22%	15%	19%
30	66%	15%	40%	30	14%	10%	12%
40	0%	0%	0%	40	16%	18%	17%
50	0%	0%	0%	50	15%	12%	13%
60	0%	0%	0%	60	0%	5%	2%
70	0%	0%	0%	70	7%	11%	9%
80	0%	0%	0%	80	12%	13%	13%
90	0%	0%	0%	90	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%
120	0%	0%	0%	120	0%	0%	0%
130	0%	0%	0%	130	0%	0%	0%
MPZ	0	16%	8%	MPZ	8%	0%	4%
NonPay	0%	0	0	NonPay	0%	0%	0%

Injector Well 177				**Injector Well 178**			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
MPZ Interval	4164-4285			MPZ Interval	4172-4298	perfed 4300-4380	
Depth (MPZ) (ft from top)				Depth (MPZ) (ft from top)			
10	0%	0%	0%	10	0%	0%	0%
20	0%	0%	0%	20	0%	0%	0%
30	0%	0%	0%	30	0%	0%	0%
40	0%	0%	0%	40	0%	0%	0%
50	0%	0%	0%	50	0%	0%	0%
60	0%	16%	8%	60	0%	0%	0%
70	0%	0%	0%	70	0%	0%	0%
80	0%	0%	0%	80	0%	0%	0%
90	0%	0%	0%	90	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%
120	0%	0%	0%	120	2%	0%	1%
130	0%	0%	0%	130	6%	0%	3%
MPZ	100%	84%	92%	MPZ	92%	100%	96%
NonPay	0%	0	0	NonPay	0%	0%	0%

CO2 Injection Profile for Production Pattern #164							June 30, 3015
Injector Well 153			**Injector Well 154**				
Dates of Inj	2/25/2011	12/3/2012	Dates of Inj	2/28/2011	11/8/2011	7/6/2012	
ROZ Interval	4275-4396	uppr MPZ perf	ROZ Interval	4268-4401			ROZ
Depth (ROZ)	openhole	rest is opnhl	Depth (ROZ)	openhole		Remediated	Avg
(ft from top)			(ft from top)				
10	10%	0%	10	0%	0%	0%	4%
20	6%	0%	20	0%	0%	0%	16%
30	0%	0%	30	0%	0%	0%	13%
40	6%	0%	40	0%	0%	0%	4%
50	6%	0%	50	0%	0%	0%	3%
60	6%	0%	60	0%	0%	0%	1%
70	6%	0%	70	0%	0%	0%	2%
80	7%	0%	80	0%	0%	0%	3%
90	3%	0%	90	0%	0%	0%	0%
100	0%	0%	100	0%	0%	0%	0%
110	0%	0%	110	0%	0%	0%	0%
120	0%	0%	120	0%	0%	0%	0%
130	0%	0%	130	0%	0%	0%	0%
MPZ	38%	100%	MPZ	82%	72%	98%	53%
NonPay	11%	0%	NonPay	18%	28%	2%	1%

Injector Well 153			**Injector Well 154**				
Dates of Inj	2/25/2011	12/3/2012	Dates of Inj	2/28/2011	11/8/2011	7/6/2012	
MPZ Interval	4142-4275	uppr MPZ perf	MPZ Interval	4132-4268			MPZ
Depth (MPZ)	openhole	rest is opnhl	Depth (MPZ)	openhole			Avg
(ft from top)			(ft from top)				
10	0%	24%	10	6%	2%	3%	7%
20	0%	25%	20	6%	2%	5%	8%
30	3%	18%	30	6%	0%	15%	8%
40	5%	12%	40	13%	1%	17%	7%
50	8%	9%	50	13%	2%	11%	5%
60	4%	6%	60	3%	4%	8%	5%
70	1%	4%	70	0%	5%	6%	3%
80	5%	2%	80	3%	7%	12%	3%
90	6%	0%	90	3%	12%	21%	5%
100	0%	0%	100	6%	13%	0%	0%
110	0%	0%	110	8%	5%	0%	0%
120	0%	0%	120	15%	6%	0%	0%
130	0%	0%	130	0%	15%	0%	1%
MPZ	56%	0%	MPZ	0%	0%	0%	47%
NonPay	11%	0%	NonPay	18%	28%	2%	1%

CO2 Injection Profile for Production Pattern #165

Injector Well 177				Injector Well 176W (Not Used Due to Losses)			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	4/22/2010	3/8/2011	10/4/2012
ROZ Interval	4285-4399			ROZ Interval	4278-4421		new perfs in ROZ
Depth (ROZ)				Depth (ROZ)			
(ft from top)				(ft from top)			
10	11%	0%	6%	10	0%	0%	0%
20	23%	69%	46%	20	0%	1%	0%
30	66%	15%	40%	30	1%	0%	0%
40	0%	0%	0%	40	4%	6%	0%
50	0%	0%	0%	50	7%	9%	0%
60	0%	0%	0%	60	6%	11%	0%
70	0%	0%	0%	70	0%	9%	2%
80	0%	0%	0%	80	0%	4%	5%
90	0%	0%	0%	90	0%	4%	5%
100	0%	0%	0%	100	0%	3%	0%
110	0%	0%	0%	110	0%	4%	0%
120	0%	0%	0%	120	0%	2%	3%
130	0%	0%	0%	130	0%	6%	3%
MPZ	0	16%	8%	MPZ	55%	37%	3%
NonPay	0%	0	0%	NonPay	27%	4%	80%

Injector Well 177				Injector Well 176W			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	4/22/2010	3/8/2011	10/4/2012
MPZ Interval	4164-4285			MPZ Interval	4150-4278		
Depth (MPZ)				Depth (MPZ)			
(ft from top)				(ft from top)			
10	0%	0%	0%	10	0%	6%	0%
20	0%	0%	0%	20	6%	2%	0%
30	0%	0%	0%	30	1%	0%	0%
40	0%	0%	0%	40	0%	0%	0%
50	0%	0%	0%	50	0%	0%	0%
60	0%	16%	8%	60	3%	2%	0%
70	0%	0%	0%	70	7%	2%	0%
80	0%	0%	0%	80	4%	2%	0%
90	0%	0%	0%	90	2%	1%	0%
100	0%	0%	0%	100	9%	2%	0%
110	0%	0%	0%	110	16%	2%	0%
120	0%	0%	0%	120	4%	2%	0%
130	0%	0%	0%	130	3%	2%	0%
MPZ	100%	84%	92%	MPZ	18%	73%	21%
NonPay	0%	0	0%	NonPay	27%	4%	80%

CO2 Injection Profile for Production Pattern #165					
Injector Well 153			**Injector Well 152W**		
Dates of Inj	2/25/2011	12/3/2012	Dates of Inj	3/3/2011	
ROZ Interval	4275-4396	uppr MPZ perf	ROZ Interval	4291-4422	**ROZ**
Depth (ROZ)	openhole	rest is opnhl	Depth (ROZ)		**Avg**
(ft from top)			(ft from top)		
10	10%	0%	10	3%	**3%**
20	6%	0%	20	5%	**17%**
30	0%	0%	30	6%	**15%**
40	6%	0%	40	7%	**2%**
50	6%	0%	50	3%	**1%**
60	6%	0%	60	0%	**0%**
70	6%	0%	70	0%	**0%**
80	7%	0%	80	0%	**0%**
90	3%	0%	90	0%	**0%**
100	0%	0%	100	0%	**0%**
110	0%	0%	110	0%	**0%**
120	0%	0%	120	0%	**0%**
130	0%	0%	130	0%	**0%**
MPZ	38%	100%	MPZ	75%	**61%**
NonPay	11%	0%	NonPay	0%	**0%**

Injector Well 153			**Injector Well 152W**		
Dates of Inj	2/25/2011	12/3/2012	Dates of Inj	3/3/2011	
MPZ Interval	4142-4275	uppr MPZ perf	MPZ Interval	4132-4291	MPZ
Depth (MPZ)	openhole	rest is opnhl	Depth (MPZ)		Avg
(ft from top)			(ft from top)		
10	0%	24%	10	2%	9%
20	0%	25%	20	7%	11%
30	3%	18%	30	6%	8%
40	5%	12%	40	5%	6%
50	8%	9%	50	0%	3%
60	4%	6%	60	0%	5%
70	1%	4%	70	13%	6%
80	5%	2%	80	13%	5%
90	6%	0%	90	12%	4%
100	0%	0%	100	12%	4%
110	0%	0%	110	4%	1%
120	0%	0%	120	0%	0%
130	0%	0%	130	3%	1%
MPZ	56%	0%	MPZ	25%	39%
NonPay	11%	0%	NonPay	0%	0%

CO2 Injection Profile for Production Pattern #189

Injector Well 179				Injector Well 178			
Dates of Inj	9/23/2011	10/20/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
ROZ Interval	4287-4434			ROZ Interval	4298-4420	›erfed 4300-4380	
Depth (ROZ)	145 openhole for the rest			Depth (ROZ)			
(ft from top)				(ft from top)			
10	47%	0%	24%	10	6%	15%	11%
20	0%	0%	0%	20	22%	15%	19%
30	0%	0%	0%	30	14%	10%	12%
40	0%	0%	0%	40	16%	18%	17%
50	0%	0%	0%	50	15%	12%	13%
60	0%	0%	0%	60	0%	5%	2%
70	0%	0%	0%	70	7%	11%	9%
80	0%	0%	0%	80	12%	13%	13%
90	0%	0%	0%	90	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%
120	0%	0%	0%	120	0%	0%	0%
130	0%	0%	0%	130	0%	0%	0%
MPZ	36%	12%	24%	MPZ	8%	0%	4%
NonPay	17%	88%	52%	NonPay	0%	0%	0%

Injector Well 179				Injector Well 178			
Avg Rate				Avg Rate			
Dates of Inj	9/23/2011	10/20/2012	Avg	Dates of Inj	8/25/2011	9/10/2012	Avg
MPZ Interval	4150-4287			MPZ Interval	4172-4298	›erfed 4300-4380	
Depth (MPZ)				Depth (MPZ)			
(ft from top)				(ft from top)			
10	0%	4%	2%	10	0%	0%	0%
20	0%	8%	4%	20	0%	0%	0%
30	2%	0%	1%	30	0%	0%	0%
40	4%	0%	2%	40	0%	0%	0%
50	4%	0%	2%	50	0%	0%	0%
60	4%	0%	2%	60	0%	0%	0%
70	3%	0%	2%	70	0%	0%	0%
80	3%	0%	1%	80	0%	0%	0%
90	3%	0%	1%	90	0%	0%	0%
100	7%	0%	4%	100	0%	0%	0%
110	6%	0%	3%	110	0%	0%	0%
120	1%	0%	1%	120	2%	0%	1%
130	0%	0%	0%	130	6%	0%	3%
140	0%	0%	0%	140	0%	0%	0%
150	0%	0%	0%	150	0%	0%	0%
MPZ	47%	0%	24%	MPZ	92%	100%	96%
NonPay	17%	88%	52%	NonPay	0%	0%	0%

CO2 Injection Profile for Production Pattern #189 — June 30, 3015

Injector Well 205W				Injector Well 204							
Dates of Inj	5/7/2010	12/9/2011	12/6/2012	Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Perod	
ROZ Interval	4329-4428			ROZ Interval	4291-4420						ROZ
Depth (ROZ)				Depth (ROZ)	ROZ only			MPZ/ROZ open			Avg
(ft from top)				(ft from top)							
10	0%	0%	0%	10	5%	0%	3%	0%	2%	1%	9%
20	0%	0%	0%	20	14%	2%	8%	0%	6%	3%	5%
30	0%	0%	0%	30	10%	11%	11%	16%	6%	11%	6%
40	0%	0%	0%	40	8%	13%	10%	18%	21%	19%	9%
50	0%	0%	0%	50	22%	19%	20%	0%	0%	0%	3%
60	0%	0%	0%	60	13%	16%	15%	0%	0%	0%	1%
70	0%	0%	0%	70	10%	15%	13%	0%	0%	0%	2%
80	0%	0%	0%	80	17%	16%	16%	0%	0%	0%	3%
90	0%	0%	0%	90	0%	8%	4%	0%	0%	0%	0%
100	0%	0%	0%	100	0%	0%	0%	0%	0%	0%	0%
110	0%	0%	0%	110	0%	0%	0%	0%	0%	0%	0%
120	0%	0%	0%	120	0%	0%	0%	0%	0%	0%	0%
130	0%	0%	0%	130	0%	0%	0%	0%	0%	0%	0%
MPZ	100%	74%	100%	MPZ	0%	0%	0%	66%	65%	66%	48%
NonPay	0%	26%	0%	NonPay	0%	0%	0%	0%	0%	0%	13%

Injector Well 205W				Injector Well 204							
Avg Rate				Avg Rate							
Dates of Inj	5/7/2010	12/9/2011	12/6/2012	Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Perod	MPZ
MPZ Interval	4181-4329			MPZ Interval	4181-4291						Avg
Depth (MPZ)				Depth (MPZ)	ROZ only			MPZ/ROZ open			
(ft from top)				(ft from top)							
10	1%	3%	0%	10	0%	0%	0%	19%	0%	10%	3%
20	2%	3%	0%	20	0%	0%	0%	9%	4%	6%	3%
30	4%	7%	0%	30	0%	0%	0%	7%	7%	7%	2%
40	7%	6%	47%	40	0%	0%	0%	2%	7%	4%	13%
50	6%	3%	0%	50	0%	0%	0%	2%	16%	9%	3%
60	5%	3%	4%	60	0%	0%	0%	2%	15%	8%	4%
70	5%	8%	7%	70	0%	0%	0%	13%	6%	10%	5%
80	13%	9%	3%	80	0%	0%	0%	9%	2%	6%	3%
90	24%	13%	4%	90	0%	0%	0%	3%	2%	3%	2%
100	10%	4%	7%	100	0%	0%	0%	1%	2%	1%	3%
110	1%	3%	8%	110	0%	0%	0%	1%	2%	1%	3%
120	2%	2%	6%	120	0%	0%	0%	0%	1%	0%	2%
130	4%	7%	4%	130	0%	0%	0%	0%	0%	0%	2%
140	2%	0%	8%	140	0%	0%	0%	0%	0%	0%	2%
150	13%	0%	0%	150	0%	0%	0%	0%	0%	0%	0%
MPZ	0%	0%	0%	MPZ	100%	100%	100%	33%	35%	34%	38%
NonPay	0%	26%	0%	NonPay	0	0	0	0%	0%	0%	13%

CO2 Injection Profile for Production Pattern #191

Injector Well 177				Injector Well 176W (Not Used Due to Losses)			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	4/22/2010	3/8/2011	10/4/2012
ROZ Interval	4285-4399			ROZ Interval	4278-4421		new perfs in ROZ
Depth (ROZ)				Depth (ROZ)			
(ft from top)				(ft from top)			
10	11%	0%	6%	10	0%	0%	0%
20	23%	69%	46%	20	0%	1%	0%
30	66%	15%	40%	30	1%	0%	0%
40	0%	0%	0%	40	4%	6%	0%
50	0%	0%	0%	50	7%	9%	0%
60	0%	0%	0%	60	6%	11%	0%
70	0%	0%	0%	70	0%	9%	2%
80	0%	0%	0%	80	0%	4%	5%
90	0%	0%	0%	90	0%	4%	5%
100	0%	0%	0%	100	0%	3%	0%
110	0%	0%	0%	110	0%	4%	0%
120	0%	0%	0%	120	0%	2%	3%
130	0%	0%	0%	130	0%	6%	3%
140	0%	0%	0%	140	0%	14%	3%
150	0%	0%	0%	150	0%	0%	0%
MPZ	0	16%	8%	MPZ	55%	23%	0%
NonPay	0%	0	0%	NonPay	27%	4%	80%

Injector Well 177				Injector Well 176W			
Avg Rate				Avg Rate			
Dates of Inj	9/21/2011	12/1/2012	Avg	Dates of Inj	4/22/2010	3/8/2011	10/4/2012
MPZ Interval	4164-4285			MPZ Interval	4150-4278		
Depth (MPZ)				Depth (MPZ)			
(ft from top)				(ft from top)			
10	0%	0%	0%	10	0%	6%	0%
20	0%	0%	0%	20	6%	2%	0%
30	0%	0%	0%	30	1%	0%	0%
40	0%	0%	0%	40	0%	0%	0%
50	0%	0%	0%	50	0%	0%	0%
60	0%	16%	8%	60	3%	2%	0%
70	0%	0%	0%	70	7%	2%	0%
80	0%	0%	0%	80	4%	2%	0%
90	0%	0%	0%	90	2%	1%	0%
100	0%	0%	0%	100	9%	2%	0%
110	0%	0%	0%	110	16%	2%	0%
120	0%	0%	0%	120	4%	2%	0%
130	0%	0%	0%	130	3%	2%	0%
140	0%	0%	0%	140	0%	0%	0%
150	0%	0%	0%	150	0%	0%	0%
160	0%	0%	0%	160	0%	0%	0%
MPZ	100%	84%	92%	MPZ	18%	73%	21%
NonPay	0%	0	0%	NonPay	27%	4%	80%

CO2 Injection Profile for Production Pattern #191							June 30, 3015
Injector Well 203		**Injector Well 202**					
Dates of Inj	9/19/2011	Dates of Inj	3/31/2010	2/18/2011	5/22/2012		
ROZ Interval	4295-4371	ROZ Interval	4306-4431				ROZ
Depth (ROZ)	perfed 4297-4365	Depth (ROZ)					Avg
(ft from top)		(ft from top)					
10	16%	10	1%	5%	13%		12%
20	6%	20	3%	5%	0%		17%
30	23%	30	0%	10%	0%		21%
40	36%	40	0%	0%	0%		12%
50	5%	50	0%	0%	0%		2%
60	3%	60	0%	0%	0%		1%
70	1%	70	0%	0%	0%		0%
80	10%	80	0%	0%	0%		3%
90	0%	90	0%	0%	0%		0%
100	0%	100	0%	0%	0%		0%
110	0%	110	0%	0%	0%		0%
120	0%	120	0%	0%	0%		0%
130	0%	130	0%	0%	0%		0%
140	0%	140	0%	0%	0%		0%
150	0%	150	0%	0%	0%		0%
MPZ	0%	MPZ	78%	42%	86%		31%
NonPay	0%	NonPay	18%	39%	2%		1%

Injector Well 203		**Injector Well 202**				
Avg Rate		Avg Rate				
Dates of Inj	9/19/2011	Dates of Inj	3/31/2010	2/18/2011	5/22/2012	
MPZ Interval	4180-4295	MPZ Interval	4173-4306			MPZ
Depth (MPZ)		Depth (MPZ)				Avg
(ft from top)		(ft from top)				
10	0%	10	1%	1%	2%	1%
20	0%	20	1%	1%	2%	1%
30	0%	30	8%	1%	2%	1%
40	0%	40	8%	2%	1%	0%
50	0%	50	9%	2%	1%	0%
60	0%	60	9%	3%	5%	4%
70	0%	70	3%	2%	6%	2%
80	0%	80	13%	1%	7%	2%
90	0%	90	8%	1%	9%	3%
100	0%	100	3%	2%	8%	3%
110	0%	110	4%	2%	7%	2%
120	0%	120	7%	12%	14%	5%
130	0%	130	6%	13%	23%	8%
140	0%	140	0%	0%	0%	0%
150	0%	150	0%	0%	0%	0%
160	0%	160	0%	0%	0%	0%
MPZ	100%	MPZ	4%	19%	13%	68%
NonPay	0%	NonPay	18%	39%	2%	1%

CO2 Injection Profile for Production Pattern #211

Injector Well 227R		Injector Well 226				Injector Well 205W			
Dates of Inj	10/3/2011	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	5/7/2010	12/9/2011	12/6/2012
ROZ Interval	4312-4437	ROZ Interval	4298-4414			ROZ Interval	4329-4428		
Depth (ROZ)		Depth (ROZ)				Depth (ROZ)			
(ft from top)		(ft from top)				(ft from top)			
10	0%	10	4%	2%	3%	10	0%	0%	0%
20	0%	20	1%	7%	4%	20	0%	0%	0%
30	0%	30	0%	0%	0%	30	0%	0%	0%
40	0%	40	0%	0%	0%	40	0%	0%	0%
50	0%	50	8%	0%	4%	50	0%	0%	0%
60	0%	60	0%	0%	0%	60	0%	0%	0%
70	0%	70	0%	0%	0%	70	0%	0%	0%
80	0%	80	0%	0%	0%	80	0%	0%	0%
90	0%	90	0%	0%	0%	90	0%	0%	0%
100	0%	100	0%	0%	0%	100	0%	0%	0%
110	0%	110	0%	0%	0%	110	0%	0%	0%
120	0%	120	0%	0%	0%	120	0%	0%	0%
130	0%	130	0%	0%	0%	130	0%	0%	0%
MPZ	100%	MPZ	87%	91%	89%	MPZ	100%	74%	100%
NonPay	0%	NonPay	0%	0%	0%	NonPay	0%	26%	0%

Injector Well 227R		Injector Well 226				Injector Well 205W			
Dates of Inj	10/3/2011	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	5/7/2010	12/9/2011	12/6/2012
MPZ Interval	4184-4312	MPZ Interval	4150-4298			MPZ Interval	4181-4329		
Depth (MPZ)		Depth (MPZ)				Depth (MPZ)			
(ft from top)		(ft from top)				(ft from top)			
10		10	8%	32%	20%	10	1%	3%	0%
20	47%	20	9%	15%	12%	20	2%	3%	0%
30	35%	30	2%	5%	4%	30	4%	7%	0%
40	16%	40	3%	3%	3%	40	7%	6%	47%
50	2%	50	6%	7%	6%	50	6%	3%	0%
60	0%	60	13%	9%	11%	60	5%	3%	4%
70	0%	70	17%	12%	15%	70	5%	8%	7%
80	0%	80	6%	3%	4%	80	13%	9%	3%
90	0%	90	6%	0%	3%	90	24%	13%	4%
100	0%	100	11%	1%	6%	100	10%	4%	7%
110	0%	110	5%	4%	4%	110	1%	3%	8%
120	0%	120	4%	2%	3%	120	2%	2%	6%
130	0%	130	0%	0%	0%	130	4%	7%	4%
140	0%	140	0%	0%	0%	140	2%	0%	8%
150	0%	150	0%	0%	0%	150	13%	0%	0%
MPZ	0%	MPZ	9%	7%	8%	MPZ	0%	0%	0%
NonPay	0%	NonPay	0%	0%	0%	NonPay	0%	26%	0%

CO2 Injection Profile for Production Pattern #211

June 30, 3015

Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Perod	
ROZ Interval	4291-4420						ROZ
Depth (ROZ)	ROZ only			MPZ/ROZ open			Avg
(ft from top)							
10	5%	0%	3%	0%	2%	1%	1%
20	14%	2%	8%	0%	6%	3%	2%
30	10%	11%	11%	16%	6%	11%	3%
40	8%	13%	10%	18%	21%	19%	5%
50	22%	19%	20%	0%	0%	0%	1%
60	13%	16%	15%	0%	0%	0%	0%
70	10%	15%	13%	0%	0%	0%	0%
80	17%	16%	16%	0%	0%	0%	0%
90	0%	8%	4%	0%	0%	0%	0%
100	0%	0%	0%	0%	0%	0%	0%
110	0%	0%	0%	0%	0%	0%	0%
120	0%	0%	0%	0%	0%	0%	0%
130	0%	0%	0%	0%	0%	0%	0%
MPZ	0%	0%	0%	66%	65%	66%	89%
NonPay	0%	0%	0%	0%	0%	0%	0%

Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Perod	
MPZ Interval	4181-4291						MPZ
Depth (MPZ)	ROZ only			MPZ/ROZ open			Avg
(ft from top)							
10	0%	0%	0%	19%	0%	10%	10%
20	0%	0%	0%	9%	4%	6%	16%
30	0%	0%	0%	7%	7%	7%	11%
40	0%	0%	0%	2%	7%	4%	18%
50	0%	0%	0%	2%	16%	9%	4%
60	0%	0%	0%	2%	15%	8%	6%
70	0%	0%	0%	13%	6%	10%	8%
80	0%	0%	0%	9%	2%	6%	3%
90	0%	0%	0%	3%	2%	3%	2%
100	0%	0%	0%	1%	2%	1%	4%
110	0%	0%	0%	1%	2%	1%	3%
120	0%	0%	0%	0%	1%	0%	2%
130	0%	0%	0%	0%	0%	0%	1%
140	0%	0%	0%	0%	0%	0%	2%
150	0%	0%	0%	0%	0%	0%	0%
MPZ	100%	100%	100%	33%	35%	34%	11%
NonPay	0	0	0	0%	0%	0%	0%

CO2 Injection Profile for Production Pattern #212											
Injector Well 225						**Injector Well 226**				**Injector Well 203**	
Dates of Inj	2/17/2011	6/28/2011	7/10/2012	9/4/2012	11/30/2012	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
ROZ Interval					use this one	ROZ Interval	4298-4413			ROZ Interval	4295-4370
Depth (ROZ)	ıole MPZ and ROZ open				perf ROZ closed MPZ	Depth (ROZ)				Depth (ROZ)	perfed 4297-4365
(ft from top)						(ft from top)				(ft from top)	
10	0%	0%	0%	0%	79%	10	4%	2%	3%	10	16%
20	0%	0%	0%	0%	21%	20	1%	7%	4%	20	6%
30	0%	0%	0%	0%	0%	30	0%	0%	0%	30	23%
40	0%	0%	0%	0%	0%	40	0%	0%	0%	40	36%
50	0%	0%	0%	0%	0%	50	8%	0%	4%	50	5%
60	0%	0%	0%	0%	0%	60	0%	0%	0%	60	3%
70	0%	0%	0%	0%	0%	70	0%	0%	0%	70	1%
80	0%	0%	0%	0%	0%	80	0%	0%	0%	80	10%
90	0%	0%	0%	0%	0%	90	0%	0%	0%	90	0%
100	0%	0%	0%	0%	0%	100	0%	0%	0%	100	0%
110	0%	0%	0%	0%	0%	110	0%	0%	0%	110	0%
120	0%	0%	0%	0%	0%	120	0%	0%	0%	120	0%
MPZ	58%	100%	100%	100%	0%	MPZ	87%	91%	89%	MPZ	0%
NonPay	42%	0%	0%	0%	0%	NonPay	0%	0%	0%	NonPay	0%

Injector Well 225						**Injector Well 226**				**Injector Well 203**	
Dates of Inj	2/17/2011	6/28/2011	7/10/2012	9/4/2012	11/30/2012	Dates of Inj	8/25/2011	9/10/2012	Avg	Dates of Inj	9/19/2011
MPZ Interval						MPZ Interval	4150-4298			MPZ Interval	4180-4295
Depth (MPZ)	ıole MPZ and ROZ open				perf ROZ closed MPZ	Depth (MPZ)				Depth (MPZ)	perfed 4297-4365
(ft from top)						(ft from top)				(ft from top)	
10	3%	4%	36%	61%	0%	10	8%	32%	20%	10	0%
20	3%	3%	45%	16%	0%	20	9%	15%	12%	20	0%
30	3%	4%	19%	12%	0%	30	2%	5%	4%	30	0%
40	3%	6%	0%	4%	0%	40	3%	3%	3%	40	0%
50	4%	8%	0%	8%	0%	50	6%	7%	6%	50	0%
60	7%	9%	0%	0%	0%	60	13%	9%	11%	60	0%
70	8%	9%	0%	0%	0%	70	17%	12%	15%	70	0%
80	7%	10%	0%	0%	0%	80	6%	3%	4%	80	0%
90	7%	16%	0%	0%	0%	90	6%	0%	3%	90	0%
100	13%	33%	0%	0%	0%	100	11%	1%	6%	100	0%
110	0%	0%	0%	0%	0%	110	5%	4%	4%	110	0%
120	0%	0%	0%	0%	0%	120	4%	2%	3%	120	0%
MPZ	0%	0%	0%	0%	100%	MPZ	9%	7%	8%	MPZ	100%
NonPay	42%	0%	0%	0%	0%	NonPay	0%	0%	0%	NonPay	0%

CO_2 Injection Profile for Production Pattern #212

June 30, 3015

Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Period	
ROZ Interval	4291-4420						ROZ
Depth (ROZ)	ROZ only			MPZ/ROZ open			Avg
(ft from top)							
10	5%	0%	3%	0%	0%	0%	25%
20	14%	2%	8%	0%	2%	1%	8%
30	10%	11%	11%	0%	6%	3%	7%
40	8%	13%	10%	16%	6%	11%	12%
50	22%	19%	20%	18%	21%	19%	7%
60	13%	16%	15%	0%	0%	0%	1%
70	10%	15%	13%	0%	0%	0%	0%
80	17%	16%	16%	0%	0%	0%	3%
90	0%	8%	4%	0%	0%	0%	0%
100	0%	0%	0%	0%	0%	0%	0%
110	0%	0%	0%	0%	0%	0%	0%
120	0%	0%	0%	0%	0%	0%	0%
	4181-4291						
MPZ	0%	0%	0%	66%	65%	65%	38%
NonPay	0%	0%	0%	0%	0%	0%	0%

Injector Well 204							
Dates of Inj	8/24/2009	9/24/2009	Avg 1st period	2/16/2011	7/16/2012	Avg 2nd Perod	
MPZ Interval	4181-4291						MPZ
Depth (MPZ)	ROZ only			MPZ/ROZ open			Avg
(ft from top)							
10	0%	0%	0%	19%	0%	10%	7%
20	0%	0%	0%	9%	4%	6%	5%
30	0%	0%	0%	7%	7%	7%	3%
40	0%	0%	0%	2%	7%	4%	2%
50	0%	0%	0%	2%	16%	9%	4%
60	0%	0%	0%	2%	15%	8%	5%
70	0%	0%	0%	13%	6%	10%	6%
80	0%	0%	0%	9%	2%	6%	3%
90	0%	0%	0%	3%	2%	3%	1%
100	0%	0%	0%	1%	2%	1%	2%
110	0%	0%	0%	1%	2%	1%	1%
120	0%	0%	0%	0%	1%	0%	1%
MPZ	100%	100%	100%	33%	35%	34%	61%
NonPay	0	0	0	0%	0%	0%	0%

CO2 Injection Profile for Production Pattern #213

Injector Well 225W					
Avg Rate	Openhole	Openhole	Openhole	Openhole	Cased and Perfed
Dates of Inj	2/17/2011	6/28/2011	7/10/2012	9/4/2012	11/30/2012
ROZ Interval					
Depth (ROZ)					
(ft from top)					
10	0%	0%	0%	0%	79%
20	0%	0%	0%	0%	21%
30	0%	0%	0%	0%	0%
40	0%	0%	0%	0%	0%
50	0%	0%	0%	0%	0%
60	0%	0%	0%	0%	0%
70	0%	0%	0%	0%	0%
80	0%	0%	0%	0%	0%
90	0%	0%	0%	0%	0%
100	0%	0%	0%	0%	0%
110	0%	0%	0%	0%	0%
120	0%	0%	0%	0%	0%
130	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%
MPZ	58%	99%	64%	39%	0%
NonPay	42%	1%	36%	61%	0%

Injector Well 224		
Avg Rate		
Dates of Inj	6/29/2011	
ROZ Interval	4298-4426	
Depth (ROZ)	perf 4163-73, opnhl below	perf 4300-40,4360-4400
(ft from top)		
10	0%	14%
20	0%	10%
30	0%	14%
40	0%	17%
50	0%	0%
60	0%	0%
70	0%	9%
80	0%	18%
90	0%	18%
100	0%	0%
110	0%	0%
120	0%	0%
130	0%	0%
140	0%	0%
MPZ	80%	0%
NonPay	20%	0%

Injector Well 225W					
Dates of Inj					
MPZ Interval					
Depth (MPZ)					
(ft from top)					
10	3%	3%	45%	16%	0%
20	3%	3%	19%	12%	0%
30	3%	4%	0%	4%	0%
40	3%	6%	0%	8%	0%
50	4%	8%	0%	0%	0%
60	7%	9%	0%	0%	0%
70	8%	9%	0%	0%	0%
80	7%	10%	0%	0%	0%
90	7%	16%	0%	0%	0%
100	13%	33%	0%	0%	79%
110	0%	0%	0%	0%	0%
120	0%	0%	0%	0%	0%
130	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%
MPZ	0%	0%	0%	0%	21%
NonPay	42%	1%	36%	61%	0%

Injector Well 224		
Dates of Inj	6/29/2011	
MPZ Interval	4162-4298	
Depth (MPZ)		
(ft from top)		
10	4%	0%
20	8%	0%
30	11%	0%
40	2%	0%
50	6%	0%
60	19%	0%
70	17%	0%
80	14%	0%
90	0%	0%
100	0%	0%
110	0%	0%
120	0%	0%
130	0%	0%
140	0%	0%
150	0%	0%
160	0%	0%
MPZ	0%	100%
NonPay	20%	0%

CO2 Injection Profile for Production Pattern #213						June 30, 3015
Injector Well 203		**Injector Well 202**				
Avg Rate		Avg Rate				
Dates of Inj	9/19/2011	Dates of Inj	3/31/2010	2/18/2011	5/22/2012	
ROZ Interval	4298-4420	ROZ Interval	4306-4431			ROZ
Depth (ROZ)	perfed 4297-4365	Depth (ROZ)				Avg
(ft from top)		(ft from top)				
10	16%	10	1%	5%	13%	31%
20	6%	20	3%	5%	0%	9%
30	23%	30	0%	10%	0%	9%
40	36%	40	0%	0%	0%	13%
50	5%	50	0%	0%	0%	1%
60	3%	60	0%	0%	0%	1%
70	1%	70	0%	0%	0%	3%
80	10%	80	0%	0%	0%	7%
90	0%	90	0%	0%	0%	4%
100	0%	100	0%	0%	0%	0%
110	0%	110	0%	0%	0%	0%
120	0%	120	0%	0%	0%	0%
130	0%	130	0%	0%	0%	0%
140	0%		0%	0%	0%	0%
MPZ	0%	MPZ	78%	42%	86%	21%
NonPay	0%	NonPay	18%	39%	2%	0%

Injector Well 203		**Injector Well 202**				
Dates of Inj	9/19/2011	Dates of Inj	3/31/2010	2/18/2011	5/22/2012	
MPZ Interval		MPZ Interval	4173-4306			MPZ
Depth (MPZ)		Depth (MPZ)				Avg
(ft from top)		(ft from top)				
10	0%	10	1%	1%	2%	0%
20	0%	20	1%	1%	2%	1%
30	0%	30	8%	1%	2%	0%
40	0%	40	8%	2%	1%	0%
50	0%	50	9%	2%	1%	0%
60	0%	60	9%	3%	5%	1%
70	0%	70	3%	2%	6%	1%
80	0%	80	13%	1%	7%	2%
90	0%	90	8%	1%	9%	2%
100	0%	100	3%	2%	8%	22%
110	0%	110	4%	2%	7%	2%
120	0%	120	7%	12%	14%	3%
130	0%	130	6%	13%	23%	6%
140	0%	140	0%	0%	0%	N/A
150	0%	150	0%	0%	0%	N/A
160	0%	160	0%	0%	0%	N/A
MPZ	100%	MPZ	4%	19%	13%	58%
NonPay	0%	NonPay	18%	39%	2%	0%

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