A New Look at the Commercial Development of the Yeso Carbonate Formation in Eddy County, NM

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A New Look at the On-going Commercial Development of the Yeso Carbonate Formation in Eddy County, NM

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Outline

REPORT FIGURES

REPORT FIGURES (CONT'D)

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Introduction

The very recent evolution of the horizontal well revolution has created a modern unprecedented level of new drilling activity in the U.S. Most of the accounts have focused upon the so-called shales[3] such as the Eagle Ford, Marcellus, Bakken and Spraberry/Wolfcamp formations with the latter (Permian Basin) taking a strong and predominate role since 2014. The activity in the Spraberry/Wolfcamp lies within both the eastern sub-basin, the Midland Basin and the western one, called the Delaware Basin of the larger Permian Basin. The "shale" (aka basinal deposits) are surrounded by carbonate shelves that were concurrently developing when the deeper basin fine-grained materials were being deposited in their oxygen starved, deeper water setting. The shelf deposits were in a higher energy and carbonate rich environment dominated by coralline and shell clasts of shallow water environments. Several of these shelf formations such as the San Andres and Clear Fork became famous for their long-lived oil reservoirs and were responsible for the majority of oil production in the Permian Basin prior to the arrival of horizontal drilling and the shale revolution.

This horizontal drilling revolution, begun in the shales, has more recently spread to the shelf carbonates. The particular formations that have seen the bulk of the recent drilling are:

1) the New Mexico equivalent to the Glorieta and Clear Fork formations in Texas, called the Yeso formation, and
2) the younger San Andres formation which is seeing a rapidly accelerating pace of commercial drilling activity.

The fast-changing status of the San Andres horizontal drilling play has been summarized in a recent article[4]. The description and status of the Yeso play is summarized herein.

Geologic Setting and Trends

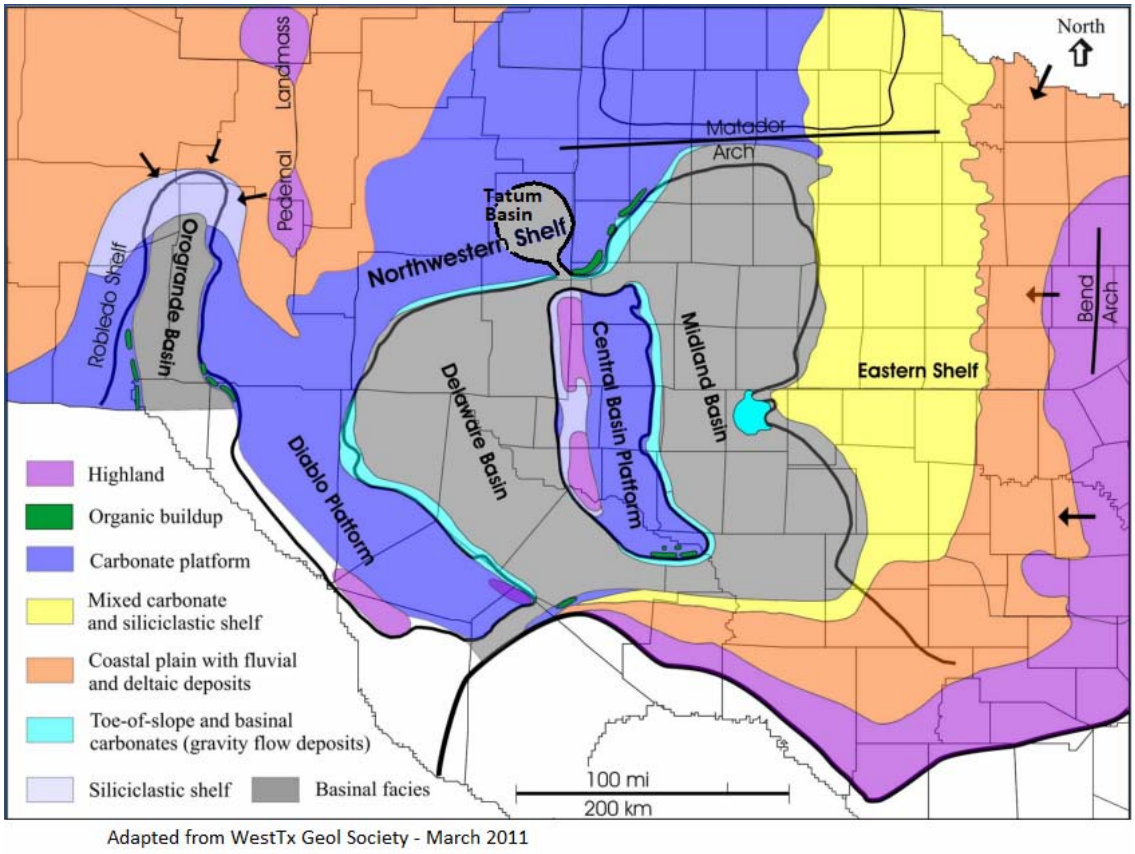
Fig. 1 provides the Permian Basin paleogeographic map of the Permian Basin at a time equivalent to the deposition of the Glorieta formation (see Fig 2). Note the position of the two large seas, i.e., the Delaware and Midland sub-basins. The Glorieta, as can be seen in the stratigraphic cross section in Fig. 2, lies between the deeper Yeso formation and the overlying San Andres formation. Drilling activity in the Yeso formation is confined to a narrow band on the north and northwest side of the Delaware sub-basin while the San Andres formation has taken on the look of a regional (resource) play[4] which is using as a base a mapping reference from a study characterizing the exploited portion of the reservoir which has been referred to aa the residual oil zone (ROZ)[5,6].

[3] We will use the term "shale" as a substitute for the tight ("mud") rocks long believed to be commercially unproduceable and now a worldwide target of horizontal drilling

[4] "Residual Oil Zones; the Second Resource Play in the Permian Basin," Melzer L.S. (2008), The American Oil & Gas Reporter, 2018 PBIOS Official Program Guide, October 2018, Vol 61, No. 10, October 2018

[5] A residual oil zone (ROZ) is most commonly defined as a remnant of a paleo oil entrapment which has been water flooded by natural processes in the geological past.

Fig. 1 – Permian Basin Paleogeography Around the Time of Deposition of the Glorieta Formation



The Yeso is also seeing extensive commercial horizontal drilling development but without the reference to the reservoir as a ROZ. The acquisition of the wealth of new reservoir data from the horizontals and the similarity of tectonic histories of the two formations has inspired a fresh look at the Yeso development and this first attempt to document the possibility of the Yeso as a ROZ analog to the San Andres. Some of the diagnostics for identifying ROZs and discriminating them from conventional zones with mobile oil are used herein.

Fig. 2 Illustrates the stratigraphic position of the Yeso formation, its overlying Glorieta and its underlying Abo formations. All are shelf carbonate formations with the Glorieta possessing some interbedded clastic material while the deeper Abo and shallower Yeso are limestones and dolomites with very little clastics.

Fig. 3 displays the carbonate shelf environment common to all three formations. Deeper water brings shales into play (beyond the outer ramp {F7} and into the deeper marine) while subareal exposure brings evaporites such as anhydrite into the formations and called “sabkha” just beyond the tidal flats (F1). In

[6] Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways in the Permian Basin San Andres Formation, Trentham, R.C., Melzer, L.S. & Vance. D. (2016), Research Partnership to Secure Energy for America and U.S. Dept of Energy Final Report, www.netl.doe.gov/file%20library/research/oil-gas/10123-17-final-report.pdf

the inner ramp, reservoir quality sediments dominate and form the ultimate reservoir rocks upon their deep burial and invaded with oil and gas migrating updip from the deeper marine shales.

Fig. 4 maps the locations of both vertical and horizontal wells drilled in the Glorieta, Yeso, and Abo formations which clearly indicate the position of the inner ramp carbonates. The inner ramp position is not a constant one through geologic time. It can be affected by subsidence or uplift of the basin, deposition and shallowing of the basin due to sediment accumulation over time and glacial and interglacial sea level changes. The shelf position bordering the Midland Basin was dramatically affected by the latter two factors while the Delaware Basin was a deeper basin and the position of the shelf remained in a more constant geographical position over the times of deposition of the Leonard Series. This created stacked reservoirs observed on the north and east sides of the Delaware Basin. The accumulation of basin fill material in the shallower Midland Basin, and even in the later stages of the Delaware Basin, began to move the shorelines basinward in what is often termed a prograding shelf. In the Delaware Basin, the progradation is only noticeable in Guadalupian time after deposition of the San Andres formation and as noted by the prograding position of the Capitan Reef (see Fig. 2).

Fig. 2 – NW Shelf Stratigraphic Section

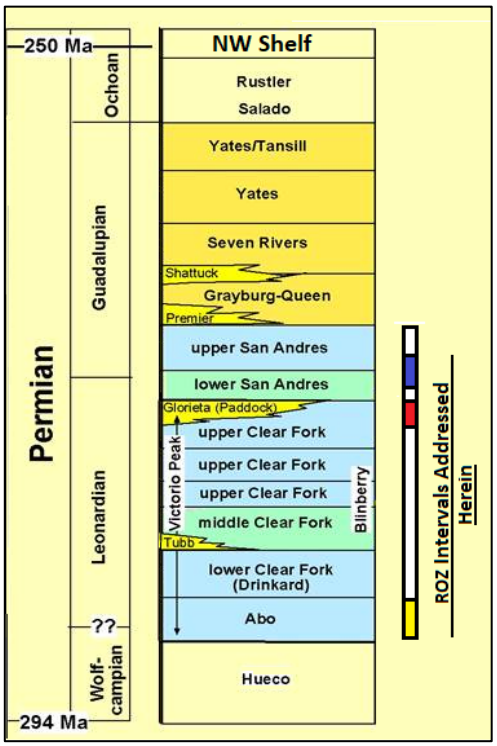
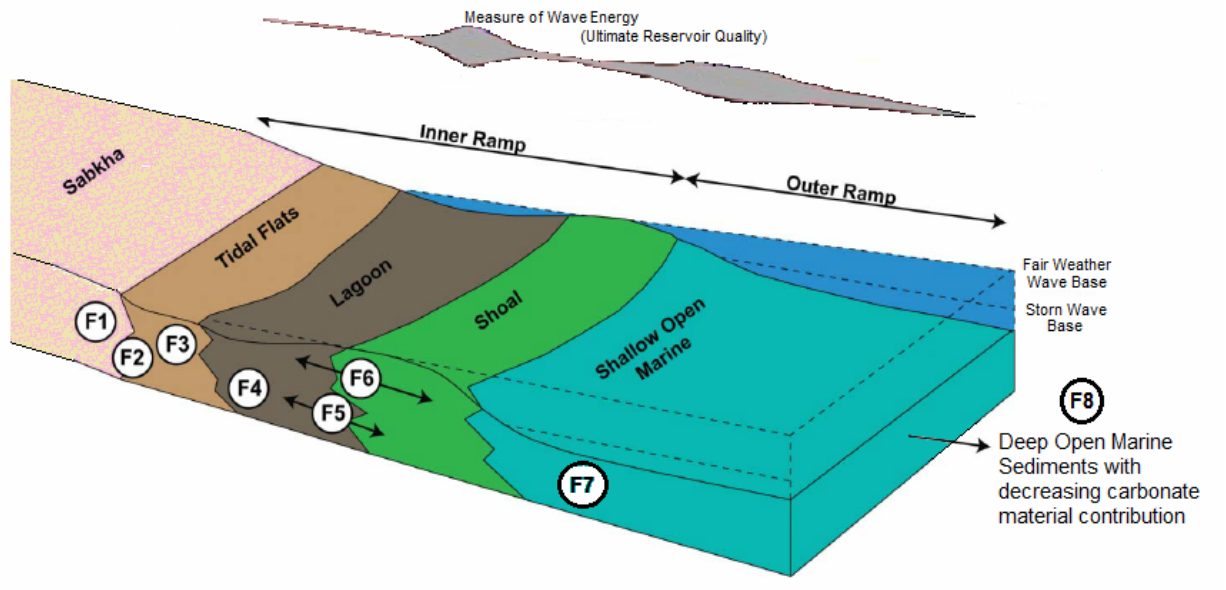


Fig. 3 – Generalized Shallow Shelf Environment (adapted from Sonnenberg (2000))



The westernmost termination of producing wells in Eddy County will be discussed in a following section. The effects of a significant later stage uplift of the basin occurred after oil entrapment in the Tertiary Epoch and will also be addressed later.

Yeso Reservoir Development History

As shown in Fig. 5, drilling activity began to "ramp up" in the late 1990's within the carbonate reservoirs in Eddy County. Most of the wells prior to 2012 were vertical and the steep rise after that is due to the horizontal well revolution.

The subject of this article, the Yeso play, was effectively isolated from rapid growth until the turn of the century. A few horizontals were drilled but the play underwent rapid acceleration with the onset of the horizontal revolution in 2012. Since then, almost 1,500 wells have been drilled in the Glorieta-Yeso in Eddy Co. A little over 400 of those wells were completed laterally, leading to a recovery of 33.1 million barrels of crude oil which is 20% of the entire cumulative oil the trend which began in the late 90's. The Eddy county horizontal carbonate shelf play is currently producing a steady 19,700 bopd, accounting for 60% of the daily oil for the combined vertical and horizontal wells.

The companires that have experienced the greatest success in the play have come from Apache and COG Operating. As the most active operator, Apache, has drilled over 310 new Yeso wells since 2012, 80 of those being horizontal. During this same timeframe, COG has drilled just over 600 Yeso wells, 190 of which are horizontal. Both of these operators are continuing the development of the play with some of the best wells being the most recent ones suggesting techniques are improving as new lessons are learned.

Fig. 4 – Map with Leonard Series Producing Wells Illustrating the Carbonate Shelf Trends

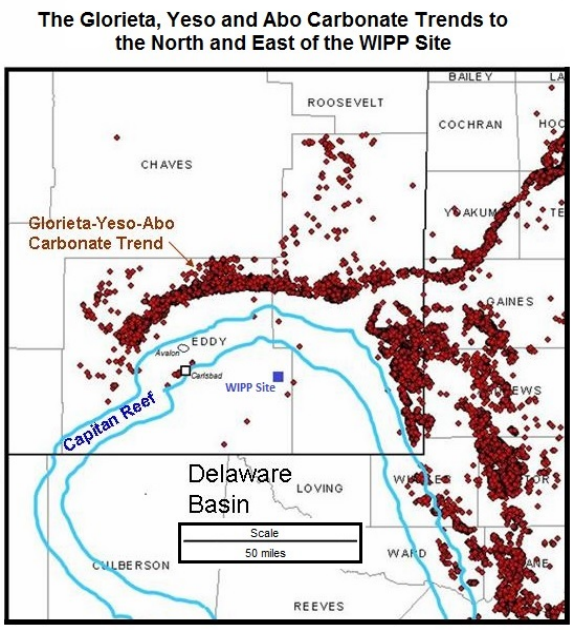


Fig. 5 – Recent Accelerating Production Growth – Glorieta, Yeso Formations

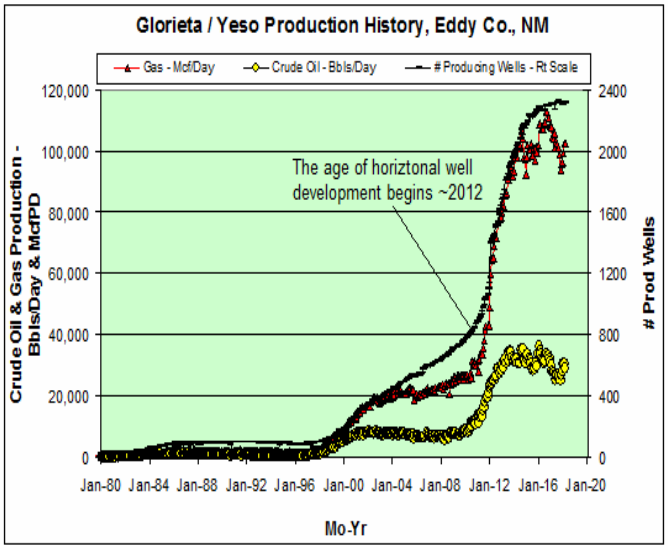


Fig. 6 provides examples of the recent well results. The production history is provided for six recent (2014) horizontal wells in T 17S R31E in the heart of eastern Eddy County Yeso play. This is a part of the Cedar Lake field in eastern Eddy and recognized as one of the most successful fields within the Glorieta-Yeso carbonate trend. New Mexico Oil Conservation Division (NMOCD) records shows a total of 215 wells have been drilled in the Cedar Lake field since the late 90's. Seventy-four of those have been laterally drilled and completed beginning in 2012. The Cedar

Lake horizontal wells have produced a cumulative amount of 8.5 MM bbls, 45% of the field's total. Some of these wells have gone on to produce more than 250,000 bbls in less than 4 years.

Fig. 7 provides a map of our study region within the Cedar Lake field. Note the intensity of drilling in a "fairway" through the heart of the Township. This follows the same trend of drilling in the deeper Abo formation which has not seen the explosion of horizontal drilling and will be discussed in a later section.

Fig. 6 – Production History of Six (Mile-long) Laterals in the Heart of the Yeso Trend in Eastern Eddy County (T 17S R31E), NM

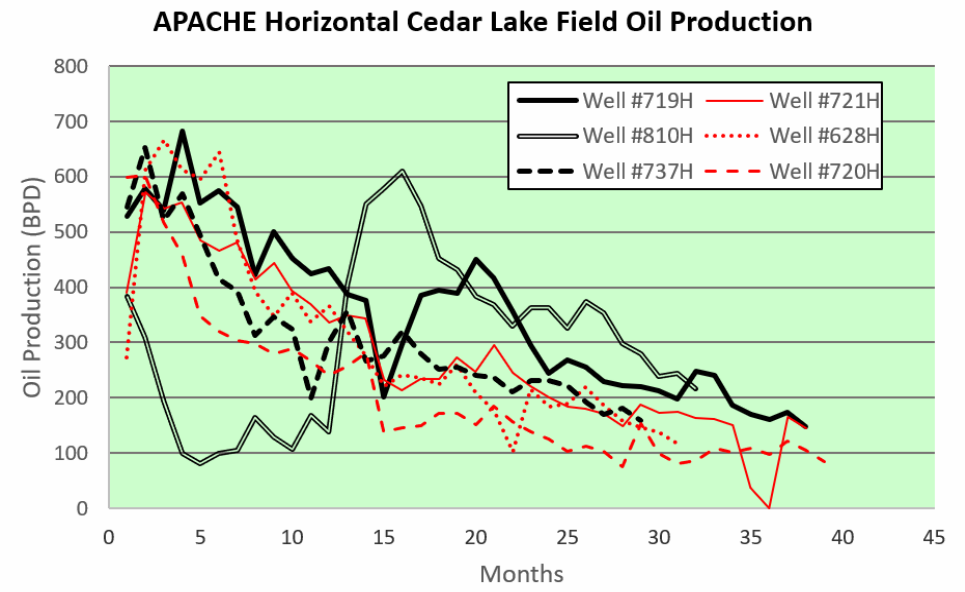
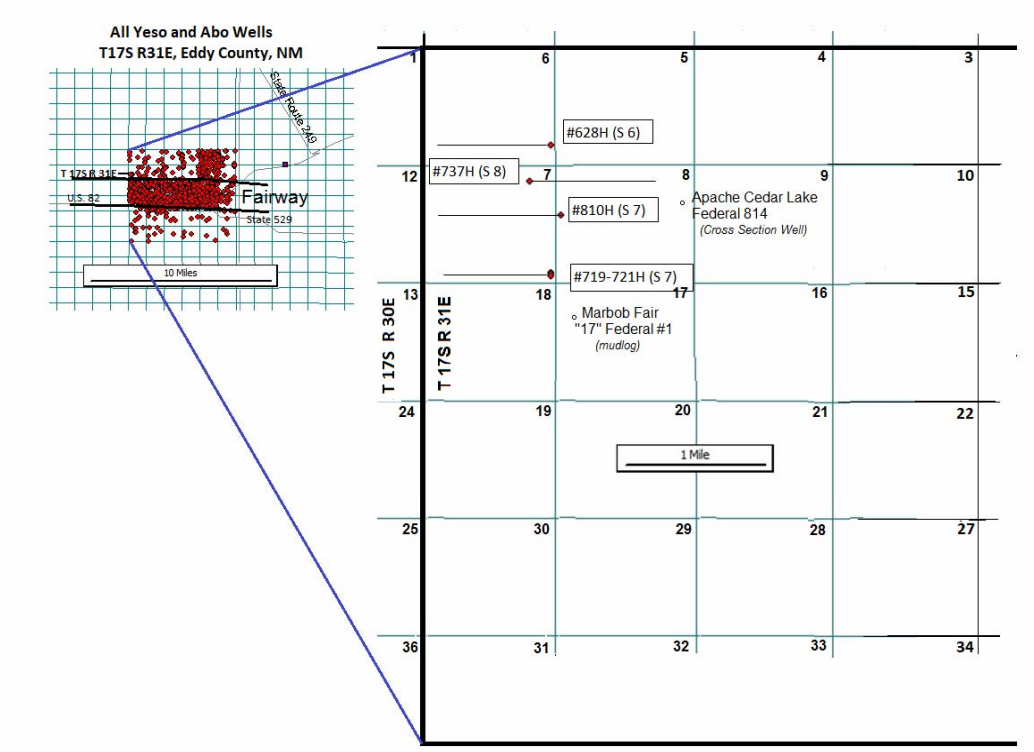
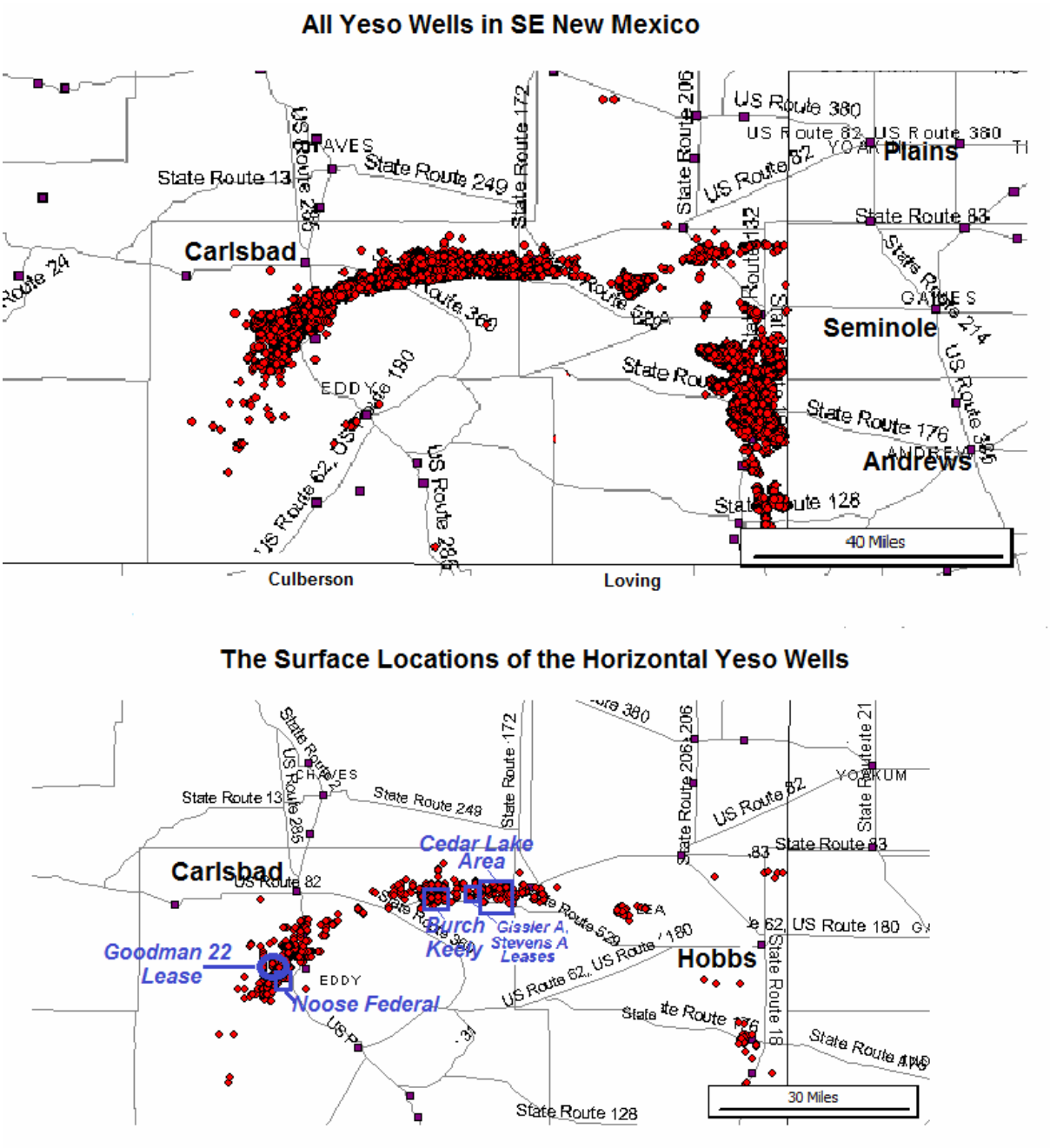


Fig. 7 – Map of a Portion of the Intensely Developed Yeso Trend in Eastern Eddy County., NM



Yeso horizontal drilling activity has not been limited to one particular area. Drilling has occurred all along the Yeso carbonate shelf in Eddy County (Fig. 8). Percussion Petroleum has recently seen commercial success with their lease in the western part of the trend, the Goodman 22. Four new wells have been drilled on the lease and have produced a cumulative 393,000 barrels of oil in a six-month period, with a current daily of almost 500 bbls/day per well.

Fig. 8 – The NM Yeso Play Map Comparing all Wells and Just the Horizontal Wells



As inferred earlier, horizontal well technology is still evolving. It is fair to say that new drilling and well completion techniques are still being investigated and improved upon. Variables such as lateral length, depth at which the laterals are landed, and size and better rate control of the hydraulic fracturing program, are all considered keys to success in the play. While strategies for drilling and completion have a great impact on success, a more complete understanding of the reservoir rock and composition of the oils is also needed.

Table 1 provides examples of some of the latest drilling parameters, production results and completion designs.

Table 1 – Horizontal Well Landing Depths, Production, and Stimulation Designs for a Sampling of Recent Yeso

Selected Horizontal Wells targeting the Glor-Yeso in Eddy Co. NM

Lease Name	Operator Name	Well No.	Date of First Production	Initial Oil Potential (BPD)	Landing Depth	Lateral Length	Cum. Oil (Bbls)	Current Daily (BPD)	Cum. Gas (Mcf)	Daily Gas (Mcf/d)	Cum GOR (cf/Bbl)	Frac Volume (bbl)	Stages	Shots per Stage
CEDAR LAKE FEDERAL CA	APACHE CORPORATION	110H	8/1/2014	127	5255'	1 mile	63,794	48	362,388	290	5681	72,210	14	45
CEDAR LAKE FEDERAL CA	APACHE CORPORATION	719H	3/1/2015	520	4835'	1 mile	385,072	161	841,389	645	2185	73,950	14	
CEDAR LAKE FEDERAL CA	APACHE CORPORATION	720H	3/1/2015	549	5365'	1 mile	234,473	87	569,851	226	2430	54,190	14	
CEDAR LAKE FEDERAL CA	APACHE CORPORATION	302H	12/1/2017	295	5285'	1 mile	67,052	387	88,611	516	1322			
BURCH KEELY	COG OPERATING, LLC	963H	8/1/2016	88	4840'	2145'	68,794	25	156,217	53	2271	52,682		
BURCH KEELY	COG OPERATING, LLC	952H	3/1/2012	440	4950'	1 mile	115,612	87	281,203	287	2432	113,657		
NOOSE FEDERAL COM	COG OPERATING, LLC	009H	8/1/2014	475	2960'	4180'	217,259	83	345,451	183	1590	36,681		
STEVENS A	BURNETT OIL COMPANY, INC.	016H	4/1/2008	18	4710'	0.5 mile	253,884	19	619,813	274	2441			
GISSLER A	BURNETT OIL COMPANY, INC.	28H	12/1/2006	83	4750'	0.25 mile	261,653	23	403,284	65	1541			
GOODMAN 22	PERCUSSION PETROLEUM OPERATING, LLC	004H	1/1/2018	1170	2695'	1 mile	100,429	548	109,747	581	1093			

Fig. 8 displays a west-to-east stratigraphic cross section through the horizontal drilling area of the play. Note the porosity trend observed in the Glorieta/Upper Yeso highlighted in yellow. This enhanced porosity is continuous through the geographic middle ("fairway") of the productive trend of the Yeso in Eddy County and represents the heart of the inner ramp of the carbonate shelf as was depicted in Fig. 3. This fairway of reservoir continuity opens the possibility that meteorically-derived surface water could have entered the formation updip, just beyond the western reaches of the productive trend as shown in Fig. 4 and moved through the formation to the east into Lea County whereupon it found a pathway through the Permian Basin to an eastern discharge point. The analog to this possibility is the San Andres residual oil zone work as mapped in recent research and reported in the aforementioned RPSEA report[6].

The same wells used in Fig. 8 are displayed in a structural cross section in Fig 9. The striking feature of the cross section is the uplifted nature of the formations in the west. Note that the porosity trend in Fig. 8 is at a depth of 5500' and a mean sea level (MSL) elevation of -1400' in the eastern-most well. Forty miles to the west the porosity trend is at a depth of 2300' and a MSL elevation of +1100'. This 60 feet/mile dip was created by an early Tertiary Period uplift due to the Laramide and Basin and Range tectonics mentioned in the earlier section of this report. The extensive work done on the shallower San Andres formation shows exactly the same features with the late stage uplift given credit to the meteorically derived water influx and natural water flow (sweep) through the Permian Basin from west to east. San Andres outcrops are given credit for the water influx into the San Andes but there is some evidence that the water influx into the Glorieta/Yeso formations could be from the same source waters present in the Indian Basin's Pennsylvanian formation to the northwest of Carsbad. Another source possibility is a transmissive Huapache Fault responsible, at least in part, for the Carlsbad Caverns (see Fig

10 for the location of the fault) and source of surface water for percolation into the subsurface formations.

Fig. 9 – Stratigraphic Cross Section of the Yeso Play (Datum – Top of Glorieta Formation)

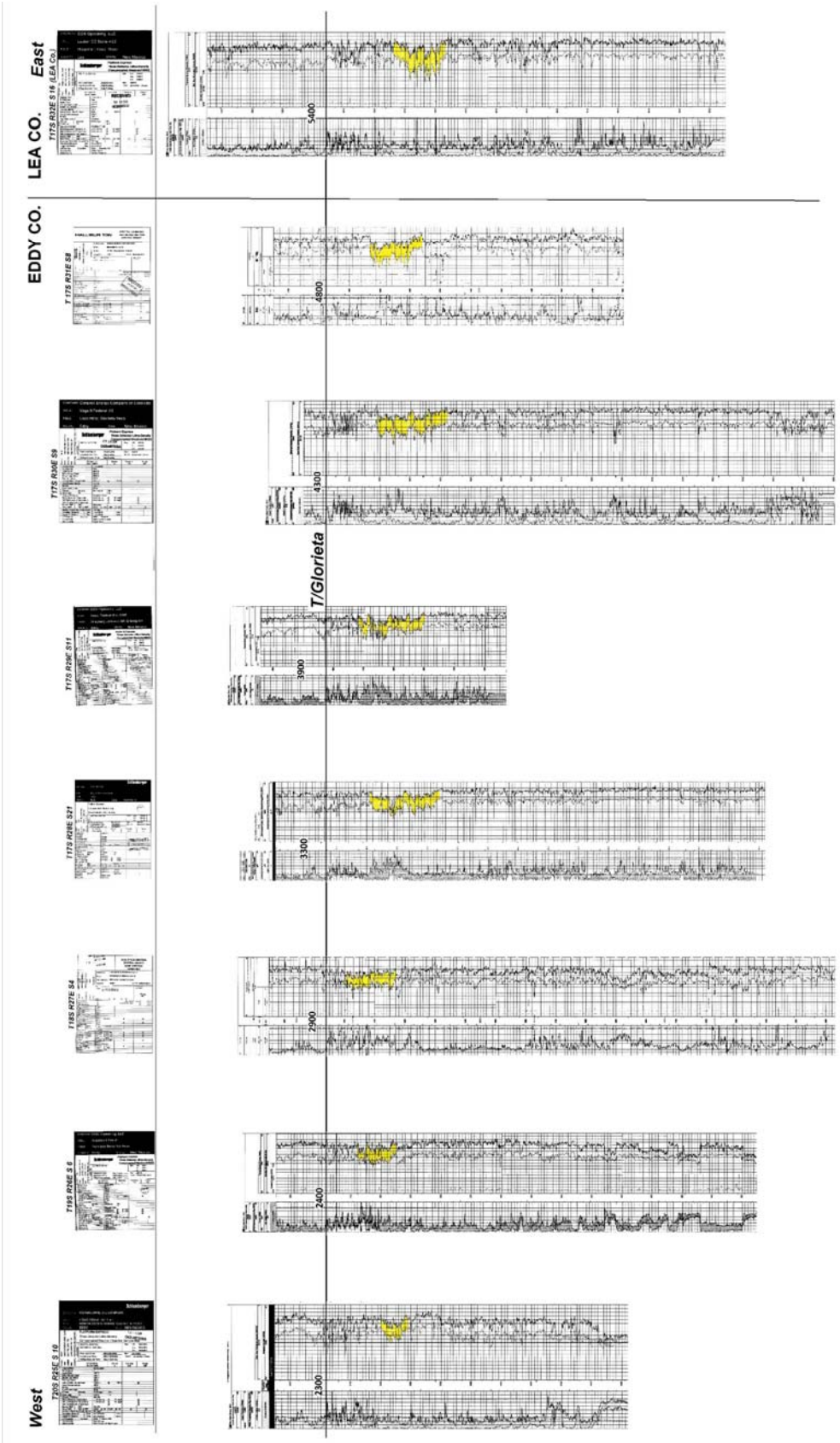
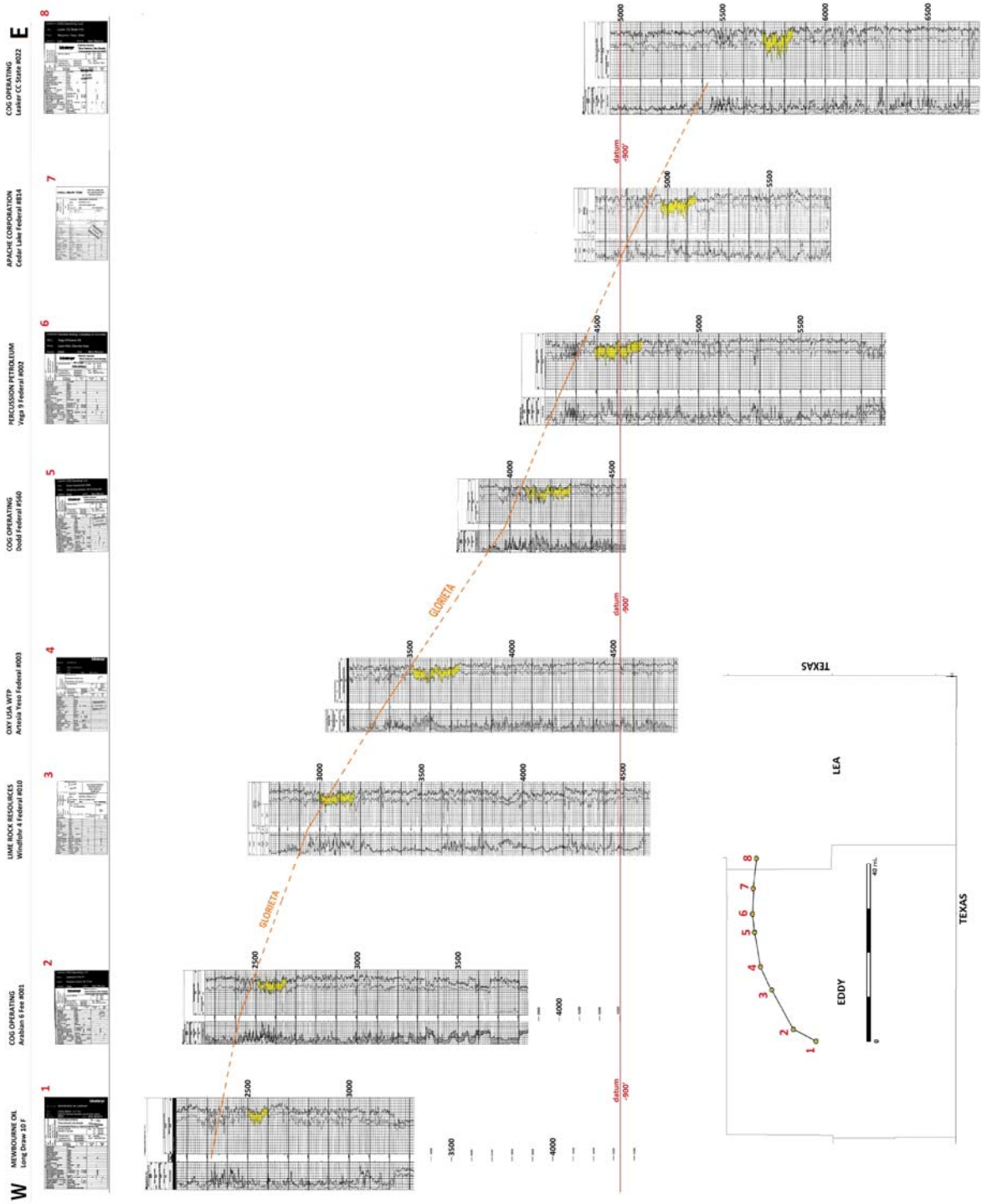


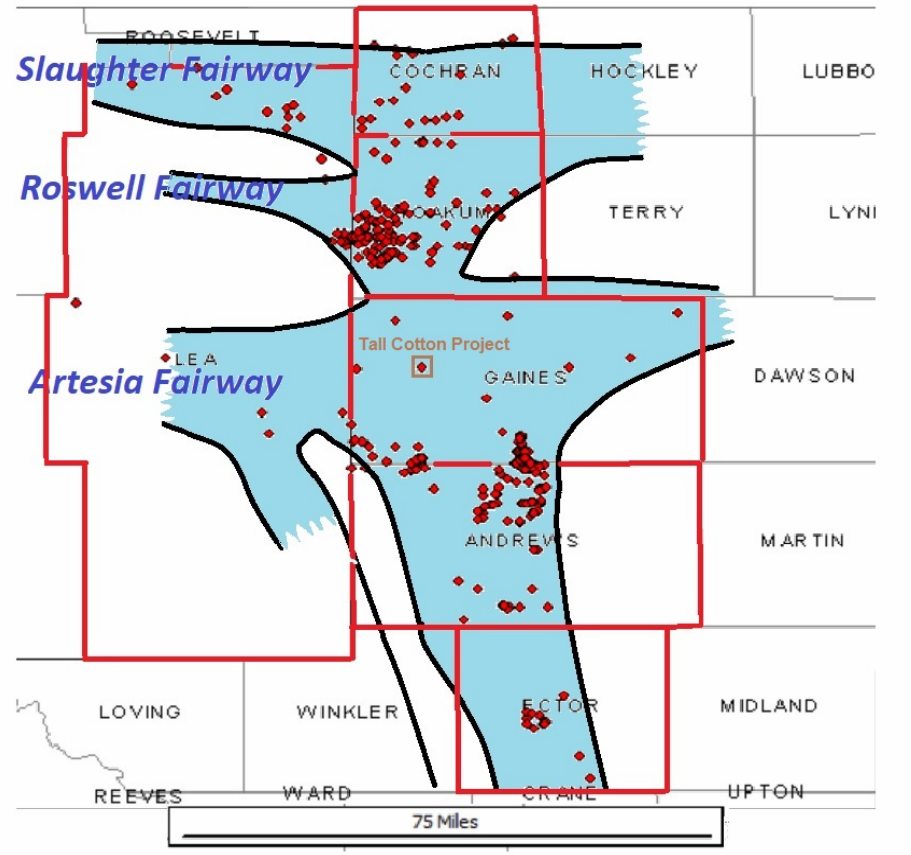
Fig. 10 – Structural Cross Section of the Yeso Play (Datum – Minus 900 Feet Mean Sea Level)



Permian Basin Carbonate Reservoirs and Residual Oil Zones

The post-2012 time frame for increased drilling in the Eddy County Yeso Formation was accompanied by a similarly expanding trend of drilling in the San Andres formation in several Texas Counties and northeastern Lea County. The San Andres play activity corresponds to the location of newly mapped residual oil zone fairways as is depicted in Figure 10. The Tall Cotton CO_2 EOR project, commonly referred to as the first "Greenfield" ROZ EOR project in the world, is also noted in western Gaines County. These ROZs represent intervals wherein the oil present is immobile and requires either CO_2 or reservoir depressuring to make the oil move to producing wells. The knowledge about these zones all started in the late 1990s with research related specifically to CO_2 EOR. Sixteen CO_2 EOR ROZ projects are now underway wherein the main pay zone reservoirs being flooded were drilled deeper into the ROZs. But, more recently, reservoir depressuring wells utilizing horizontal drilling have advanced in these ROZ intervals which are especially noteworthy in western Yoakum and northern Andrews Counties, Texas. The similar commercial successes in the San Andres and the horizontal activity in the Yeso formation in Eddy Cunty, NM have led some professionals, familiar with ROZs and their geologic origins, to suggest that residual oil zones (ROZs) may also present in the Yeso formation. In both plays, some moveable (primary) oil is occasionally present but immobile (ROZ) oil likely constitutes much of the produced volumes. The newer wells are typically Glorieta/Yeso completions producing sour oil which is a classic diagnostic for oil produced in a Permian Basin ROZ environment. We will further examine the evidence for ROZs in the Yeso and the deeper Abo formations with the goal of understanding whether the analog San Andres ROZ is a model for explaining some of the exciting production in the Yeso horizontal wells.

Fig. 11 – Location of Horizontal Wells in the San Andres Play Mapped Upon the ROZ Fairways[6]



Before we dissect the carbonate analogs of the San Andres and Abo formations, we should examine the status of the production of horizontal wells in the Yeso and San Andres plays. Fig. 12 compares the growth of horizontal wells in both plays. Fig. 13 illustrates the crude oil production growth.

Fig. 12 – Production Well Counts for the Yeso and San Andres Plays

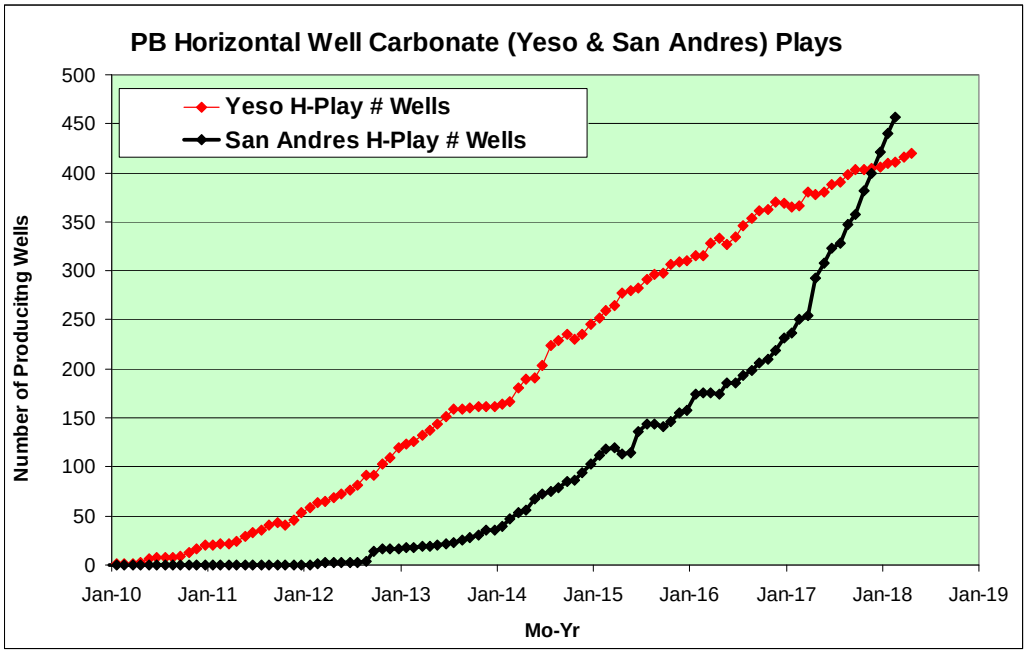
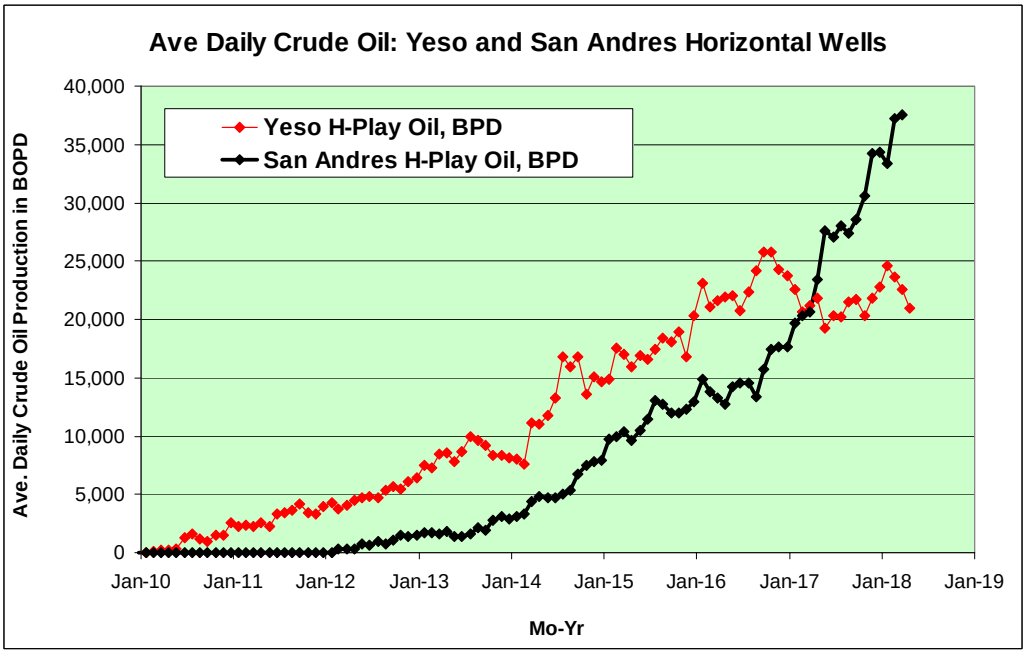


Fig. 13 – Daily Ave. Crude Oil Production Comparisons for the Yeso and San Andres Plays

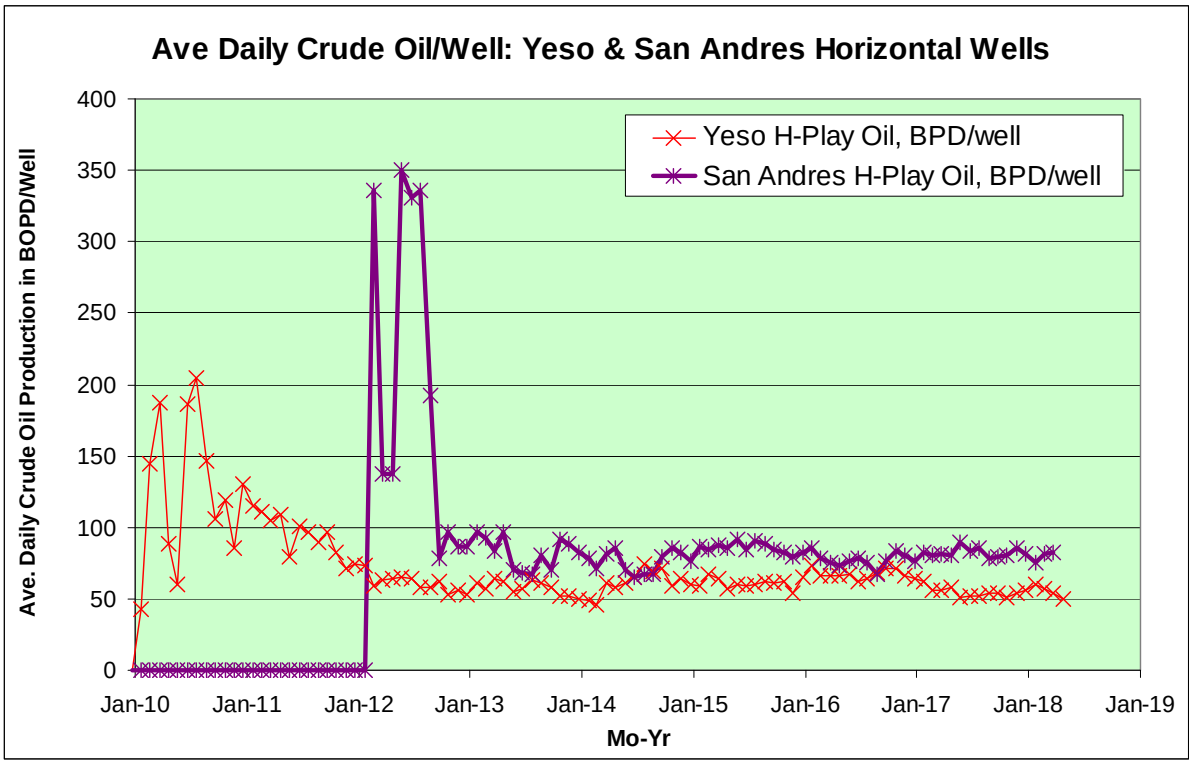


While the well and production numbers look very similar for the two plays, the Yeso seems to show a tailing off of drilling and production in the last 18 months. But, at the time of this writing, several new wells have been brought on line in the western portion of the Yeso trends which will display a return of growth. Meanwhile, the San Andres ROZ play continues its rapidly accelerating growth.

Fig. 14 compares the similarities of the average wells in the two plays by using the parameter of crude oil production per well. Several observations are possible using this metric:

1) the decline curves of these horizontal two carbonate plays are quite gentle, and
2) the 'stabilized' level of average production per well is quite similar between the two plays. The San Andres Play average is higher post-January 2017 due to its faster addition of new wells.

Fig. 14 – Average Daily Crude Oil Production per Horizontal Well: Yeso & San Andres Plays



Quick Review of Principles of Laterally Swept ROZs

The aforementioned RPSEA report[6] provides the detail on the science of laterally swept (Type 3) ROZs. A source of meteorically-sourced water infiltrates a paleo oil trap due to an uplift exposing the formation to surface water. If the reservoir has sufficient continuity to allow movement to an downgradient discharge point, a natural water flood ensues. Alternation of the rock occurs along the way due to the active anaerobic microbial processes that can also modify the oil if the degree of water sweep is high. The process has been studied extensively for carbonates where the presence of sulfur (anhydrites), oil (paleotrap), and water movement can all be present. Disseminated anhydrite is especially important in the ramp carbonates and can help alter the porosity from single digits to as high as 16% since the dolomitic process is a porosity enhancement one. The permeabilities are also increased. This process

provides the "bow shaped" character of these Type 3 ROZs on the porosity and resistivity logs as can be observed in the Glorieta-Upper Yeso interval in Figures 8 and 9. Note too that the reservoir continuity required for the water sweep is also observed in the cross sections.

With the observation that the lateral continuity is present through the Yeso play region, the question to pose is where does the sweep water find a path to its discharge point? It is the writers' opinion that it must find a transmissive fault to cross the San Simon channel separating the Yeso carbonate shelf from the Northwest or Central Basin Platform Shelves. Type 3 ROZs have been documented in the San Andres formation there. Additionally, stacked ROZs have been documented as deep as the Clearfork formation on the west side of the Central Basin Platform.

Reservoir Aspects and Type Log Example

Several significant reservoir and fluid diagnostics have been recently identified that, taken in full, suggest the presence of a residual oil zone of the type found in the Permian Basin carbonate reservoirs. When keeping in mind that the ROZs are laterally flooded by natural water floods, both the reservoirs and fluids can be altered by microbial processes. As mentioned in the last section, those are typically porosity enhancement processes and, with significant pore volumes of sweep, have modified the oil to remove some of the lighter-end components and make the oil more viscous and less mobile. Research is still immature but the important diagnostics to look for to identify a laterally swept ROZ are the following:

1. Inner Ramp carbonate facies and laterally correlatable porosity zones,
2. A 'bow' shape porosity and resistivity log characteristic,
3. Where main payzones are present, tilted oil-water contacts,
4. The presence of H_2S in the gas and oil (microbially released),
5. Sulfur-rich formation waters,
6. Lower water salinities when compared to the commonly recorded connate waters in the main pay zones that remain isolated from the lateral sweep,
7. Laterals that produce large quantities of water and often illustrate a delayed onset of oil and gas production upon reservoir depressuring, and
8. Gentle oil decline curves indicating large reservoirs with considerable lateral reservoir continuity.

The very new industry insights illustrating the critical attributes for commercially successful reservoir depressuring using horizontal wells are often the same as the ones for enhanced oil recovery. However, some important differences are notable as well. For one, at 5000' depths in the San Andres formation, CO_2 EOR can work with lower GOR oils than can be successful in reservoir depressuring. Current work suggests the 300 ft^3/bbl is an appropriate criterion for commercial depressuring at 5000' depth laterals; CO_2 EOR can retain miscible conditions and be effective with much lower GOR values.

In many cases, older published reports can offer insights to the presence of ROZs. Two great examples of this were reports by William LeMay and Pat Gratton[7] citing detailed work done on the deeper Abo formation in Eddy and Lea Counties, New Mexico (see Fig. 2 stratigraphic section). Fig. 14 displays the Abo carbonate reef trend showing the titled oil/water contacts. We interpret these to be caused by a deeper west-to-east lateral sweep proposed herein in the Glorieta-Yeso and documented in the San

[7] LeMay, W.J. (1960), Southwestern Federation of Geological Societies Transactions, Oct 12-14, 1960;

Gratton, J.F. & LeMay, W.J. (1968), "San Andres Oil East of The Pecos," Twenty-second Annual Meeting of the New Mexico Geological Society, at Hobbs, New Mexico, May 10, 1968.

Andres formation so thoroughly referenced in the mapping within the RPSEA research reported on in 2007.[6] Note also the indications in Fig. 15 where the authors illustrate a transition (or residual oil) zone below the oil/water contact. Fig. 16 provides a closer look at the titled contact studied in the Empire Abo field in the middle of the Glorieta-Yeso horizontal play.

Abo equivalents to the Yeso carbonate ramp observations are not documented in the literature at least to our findings. However, one should expect the inner and outer reservoir ramp facies to be present. We do expect the ROZ porosity trend ("fairway of sweep") to be much narrower and like that of the Glorieta-Yeso fairway and unlike the corresponding and regionally broad San Andres shelf reservoirs as is hinted in Fig. 15.

Fig. 15 – Reef Trend Abo fields displaying tilted Oil/Water Contacts (after Lemay)

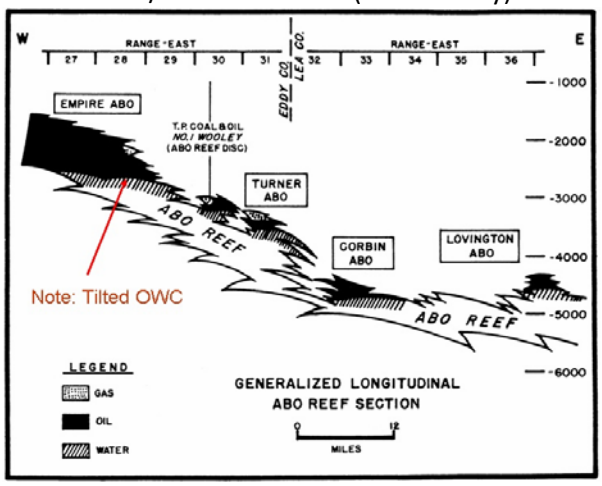
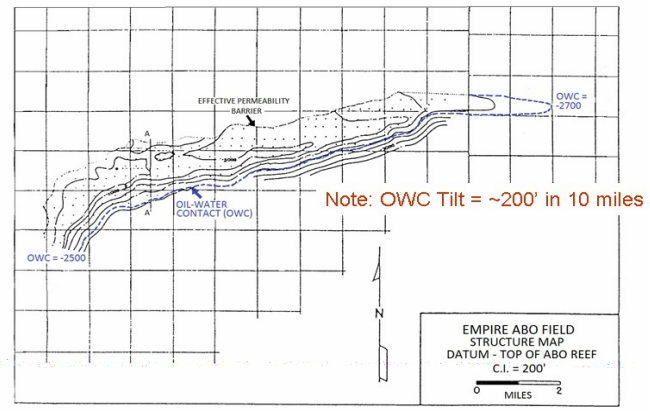
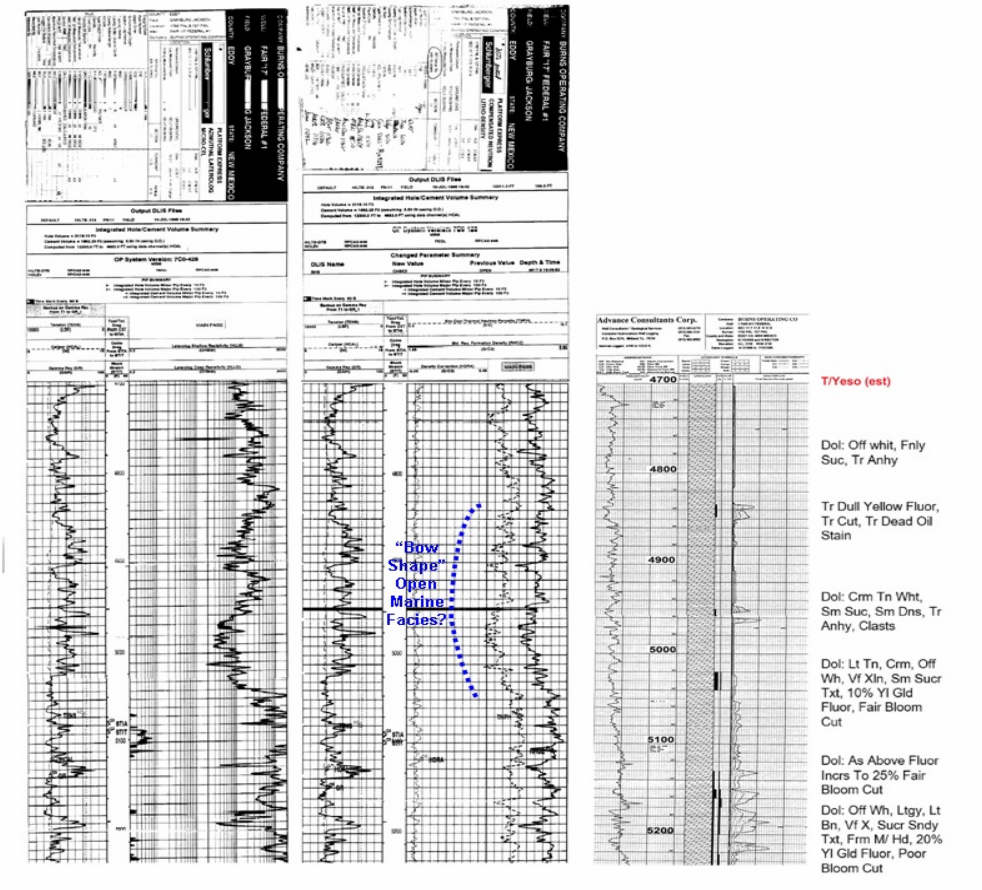


Fig. 16 – Closer Look at the Titled Oil/Water contact at the Empire Abo Field, (after Lemay)



In examining several of the mud and wireline logs acquired in recent years as a direct result of the accelerated drilling activity, we illustrate a type log in Section 17 of Township 17, Range 31E ~25-miles north of the WIPP site. Fig. 17 displays the upper section of the Yeso formation.

Fig. 17 – Example Mud and Wireline logs in the Upper Yeso Formation in eastern Eddy County, NM



SUMMARY

Several of the critical evidentiary requirements for the presence of a ROZ fairway in the Glorieta-Upper Yeso formation in Eddy County, New Mexico have been documented. Many of those same reservoir attributes have also been documented by several New Mexico researchers in the deeper Abo formation. Those common attributes are 1) documented tilted oil/water contacts, 2) typical logs illustrating the reservoir quality carbonate ramp facies and bow shape log character, 3) presence of anhydrite in sample descriptions, 4) sour nature of the oil and gas, and 5) excellent gas/oil ratio which should qualify the oil both as a horizontal well depressuring target and miscible with CO_2 for EOR. Oil gravities of 32-38^{o} API are widely documented and anecdotal documentation of delayed onset of oil production usually attributable to the depressurizing process needed to produce the residual oil during the depressuring of ROZ reservoirs.

Horizontal well completions in the Yeso formation are just 4-6 years old but indications are that decline curves would suggest the presence of large volume, conventional ROZ reservoirs like those being exploited in Yoakum County in the San Andres formation. The presence of sour oil and gas is pervasive in ROZs and is the case in the Yeso play. More work can be done to determine if presence of water salinities below connate salinities is present and if suppressed methane composition in the in the casinghead gas is observed. Both are excellent indicators of the lateral sweep associated with type 3 ROZs.