Residual Oil Zones; the Second Resource Play in the Permian Basin

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The headlines today are, quite justifiably, all about the "shale play" investments and the huge impact they are having on America's energy supplies. One of the secondary stories is all about the amazing Permian Basin and its newly recognized status as a global super-basin. But, it wasn't that long ago that the Permian Basin was in the midst of a long standing declining trend and at its 50+ year low point of 840,000 bopd in mid-year '07. Move forward to mid-year 2018 and production has risen to a level never seen before in the history of the Permian Basin of 3,200,000 bopd. This has been an amazing accomplishment and a tribute to the American ethos. So much excitement and momentum has occurred in just those eleven years that it is quite easy to calculate that well over $200 billion of new drilling investment has poured into the Permian Basin in just over a decade. It seems that multi-billion dollar projects are announced each month.

Seventy percent of the new drilling during that 11-year period has been horizontal and almost all of it within its two sub-basins, the Delaware and Midland basins. But very quietly, the historically reliable producing carbonate shelf reservoirs have been making their mark too. Today, over 1,000 of the total of 20,000 new horizontal wells have landed in the San Andres and Yeso carbonates with the percentage gradually increasing from less than 2% in early 2012 to today's 5%.

This article focuses on the San Andres formation in particular and addresses the accelerating development of that horizontal well play which we are calling the second resource play after the shales. This San Andres resource play, however, can be thought of as a conventional reservoir with an unconventional (residual) oil in contrast to the unconventional reservoir ("shale") with a conventional oil. The difference will prove interesting as some valuable attributes of conventional rock should lend this San Andres play to a very long life.

History of the Adolescent Horizontal San Andres Play

If one ignores the few horizontal wells experimentally landed in the main pay intervals of the larger fields, Andrews County is commonly credited as the locale with the first San Andres horizontals. The earliest of those were 2010 step-outs just outside the long-established field boundaries like near the Shafter Lake and Fuhrman-Mascho fields. Shortly thereafter, a "tight oil" prospect was attempted in western Yoakum County where the first well, the Broken Spoke #2 State (actually just across the state border in Lea County, NM) was drilled in April and May of 2013. The mile-long lateral completed with a hydro-fracture by Manzano Resources as though it were the carbonate equivalent to a tight shale well. The well began initial production later that summer (2013) but was producing only large volumes of water for 30 days until it began to cut oil. The operator was hauling water until the production rose to >200 bopd at which time they decided to drill a disposal well. They began sustained production in late March 2014 and filed the completion report in May 2014 after disposing of a total of more than 80,000 barrels of water (more than its entire stimulation "load" volume). The well had begun cutting oil only after reaching a pump intake pressure of 1315 psi, down from an initial pressure of 2130 psi. The well has gone on to produce 150,000 barrels of oil. Fig. 1 recaps the

entire history (48 months) of oil production history of the discovery Broken Spoke well with a hyperbolic fit projecting a cumulative recovery of 250,000 bbls at 10 years and estimated ultimate recovery of 350,000 bbls. With the success of this Broken Spoke lateral, Manzano proceeded to drill six more wells in rapid succession. Table 1 shows the summary characteristics of the seven wells.

Those initial wells in Western Yoakum were all drilled in a regional "graveyard" area littered with dry and non-commercial vertical wells dating back to the 1950s. The excitement of the production from those initial horizontal wells gave cause to suspect that something new was occuring. Clearly, the wells were not completed in tight intervals as was originally supposed and the sustained fluid production with a delayed onset of oil cuts suggested something different was happening. As a result, folks began to refer back to the recent mapping of the San Andres residual oil zones[1] and comparing the production to the dewatering projects like the Hunton and Red Fork in Oklahoma, the observations of similar well response in the upper and middle Yeso laterals in Eddy County, NM. Other productive reservoirs like the Indian Basin also in Eddy County had shown a similar delayed onset of oil production but often explained in a variety of alternative ways. Two common attributes has been recognized to these reservoirs that they have either a mixed- or oil-wet character to the reservoir and lower salinity formation waters. Fig. 2 was developed to illustrate the mechanism of production and Fig. 3 as the explanation of the presence and geography of significant residual oil. A mechanism for later stage oil wetting was a part of the new theories.

Resource Play?

One of the first marks of defining a resource play is outlining a wide region in which similar characteristic of a reservoir are present. The construction of the ROZ fairways of Fig. 3 was based upon observations that a very broad area of a carbonate shelf existed during the San Andres period. Low stands of sea level during glacial times exposed a huge expanse of the West Texas and Southeast New Mexico shelf terrain. Interglacial periods then flooded the shelf and created intertidal and subtidal regions of carbonate materials that could later become reservoir quality rock. Deeper water (basinal) deposits could provide the organic hydrocarbon material that would become the source rock for oil and gas. All of these requirements were met in the area which is known as the Permian Basin today and in the rocks that have become known as the San Andres formation and its adjacent basinal shales. Later stages of deposition (post Grayburg) starved out the deeper water organics while earlier stages (Clearfork and Abo/Wichita Albany) had all the organics needed but offered more limited expanses of reservoir quality carbonate shelves.

One of the haunting questions for any resource play is why certain areas are more prone to successful wells than others? Taking a dual approach is best: 1), using simple regional statistics to individually characterize areas then 2) test against good scientific reasons for the observed variability? For example, is the predictability and presence of the entrained gas a key? Is the degree of natural water flood sweep a key? What could

[1] 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

one look to for optimizing the areas for high grading and optimally selecting the best landing depths for maximizing the oil cuts?

Statistical Status and Emergent Trends in the Play

Fig. 4 charts the oil and gas production from the horizontal San Andres wells from the first wells in 2012 to mid-year 2018. Note the 130+% increase in average daily oil production from 18 months ago. Table 2 summarizes the current status of the play in the key six county regions and in terms of the number of wells, average daily and cumulative oil and gas production, and gas-oil ratio.

One can draw several conclusions from the study. The horizontal San Andres play has grown from one producing no oil in early 2012 to producing 35,000 bopd and 32 mmcfpd in May of 2018 (6 years). The play has amassed over 27 million barrels of crude oil. The latest annual growth rate is 37% for the number of wells drilled, 40% for average daily oil, and 60% for cumulative oil.

The play has spread out geographically now to a regional one with significant well investments in six counties. Andrews County started first but Yoakum County now leads the way with 37% of the wells (to 34% for Andrews). Gaines County is coming on fast with 16% of wells (76) while having 52 wells just 6-months ago.

There are two categories of gas-oil ratios for play wells: Andrews and Gaines Counties with 500 cubic feet per barrel while the other four counties average over 1200. Curve fitting production versus time suggests that many wells (using a 1-mile lateral standard) are projecting over 300,000 for their estimated ultimate recovery (EURs). Western Yoakum County has a few wells that project to recover in excess of 400,000 barrels.

In checking with the most active companies, it is very clear that well completion strategies are still developing. Approaches used to select landing depths, how to complete the wells in terms of number of stages, size of stimulation jobs, and whether to use scale inhibitor flushes with each stage are still evolving. Hydro-fracture jobs all use lower rates and volumes than the shales with many using rates as low as 10-20 barrels per minute. There also seems to be a growing consensus that the vertical profile of porosity (and permeability) is important to the size and rate of hydro-fracturing stimulation used with the landing depth biased to the upper, gassier intervals as noted from the mud logs.

Open-hole completions have been used successfully in analog plays such as the Hunton carbonate in Oklahoma and are mechanically possible in the San Andres but have not proven commercially successful in the San Andres as yet.

The produced gas can vary in composition very widely. It is always sour (along with the oil) but the H_2S composition ranges widely with several wells reporting in excess of 1000 ppm H_2S. CO_2 can also vary widely from less than 3% to greater than 10%. Methane composition also varies dramatically with many wells reporting less than the ethane percentages. BTU content is very high, often in spite of the low methane and high CO_2 content and trends upward with increasing time and decreasing reservoir pressure. This was also quite true in the Hunton so-called dewatering play where some late stage (>10 year-old) wells reporting content > 1600 btus. The delayed onset of oil production often observed, the increasing BTU content, changing gas composition with increasing yields

of ethane, propane and higher NGL hydrocarbons, and low crude oil decline rates are consistent with the concept of the play being an oil-wet conventional reservoir play but with a residual oil left behind after the natural, paleo oil water flood

Water salinities vary widely but are almost always less than standard main pay zone connate waters. The degree of ***natural*** water flood flushing is believed to be responsible for the low and regionally variable water salinities as well as the retained gas and composition. The waters are saturated with sulfates causing high sulfate scaling tendencies.

Play Summary and Conclusions

There is still much confusion regarding the nature of the horizontal well San Andres play. Many operators still profess to be producing mobile oil. However, the horizontal San Andres play is developing in many of the areas recently mapped as being a huge paleo oil trap that was flushed of its mobile oil in the geological past. But, like man's water floods, mother-nature bypassed a percentage of the oil leaving a residual oil target that has never been depressured.

The "greenfield" areas can have thin shingles of "attic" mobile oil that, by themselves, are not commercial but when commingled with the upper ROZ intervals can provide excellent economics. The natural water flood sweep can be areally and vertically variable which adds risk to the ultimate oil cuts and gas-oil ratios but appears to correlate with the carbonate facies, water salinities, and the degree of diagenesis the facies have undergone during the sweep. A 12-18% oil cut appears to be the P-50 value thus far. Lateral landing depths and completion strategies are beginning to take those variables into account making the play a regional one but one needing some regional fine-tuning considering the above factors.

The play is dramatically overshadowed by the multiple Wolfcamp "bench" shale plays in the Delaware and Midland sub-basins but has grown to produce over 37,000 bopd in six counties on the Central Basin Platform and Northwest Shelf areas. The average daily oil production growth rate has been 130+% in the last 18 months. To date, thirty different operators are involved in the play, mostly funded by private equity financing.

The wells target the upper sections of a conventional reservoir dubbed the residual oil zone. They are located where the entire reservoir quality reservoir has been naturally waterflooded. Where there was closure atop the ROZ interval providing retained mobile oil, sixteen main pay zone CO_2 floods have been deepened into the ROZ intervals below the oil/water contacts – some as much as 300 feet. One CO_2 enhanced oil recovery (EOR) project is underway in a greenfield fairway of the ROZ – all proving the viability of EOR in the ROZ. The applicability of converting the horizontally developed depressured areas to an EOR project will likely be tested in the coming years.

Table 1 - Onset of Oil Production in Greenfield (DUROZ) Horizontals, Western Yoakum County, TX

FIRST OF THE STEWARD (nee MANZANO) DUROZ WELLS: WEST YOAKUM CO., TX							
Well	Spud Date	Date of First Production	Date of First Oil	Initial Intake Pressure	First Oil Cut Intake Pressure	Lateral Length	Days Until First Production
What A Melon 1H	3/6/2013	3/13/2014	4/8/2014	1745	1225	1 mile	26
Broken Spoke 1H	4/8/2013	3/27/2014	4/27/2014	2120	1315	1 mile	31
What A Melon 4H	8/14/2014	9/27/2014	10/3/2014	1700	1270	1 mile	6
Mad Jack 522 1H	9/2/2014	10/22/2014	11/23/2014	1975	1090	1.5 mile	32
Greasy Bend 584 2H	9/30/2014	11/10/2014	12/2/2014	2030	1200	1 mile	22
Dog Bar 11 Fee 2H	10/17/2014	12/9/2014	1/9/2015	2225	1150	1 mile	31
Road Dirt 534 3H	10/30/2014	1/16/2015	2/10/2015	2053	1260	1 mile	25
Cousin Willard 450 4H	11/14/2014	2/5/2015	3/6/2015	2110	1635	1 mile	29
Smashed Nickel 3H	12/1/2014	3/21/2015	4/15/2015	2040	N/A	1.5 mile	25

Figure 1: Broken Spoke 2 “Discovery Well” Oil Production with Hyperbolic Fit

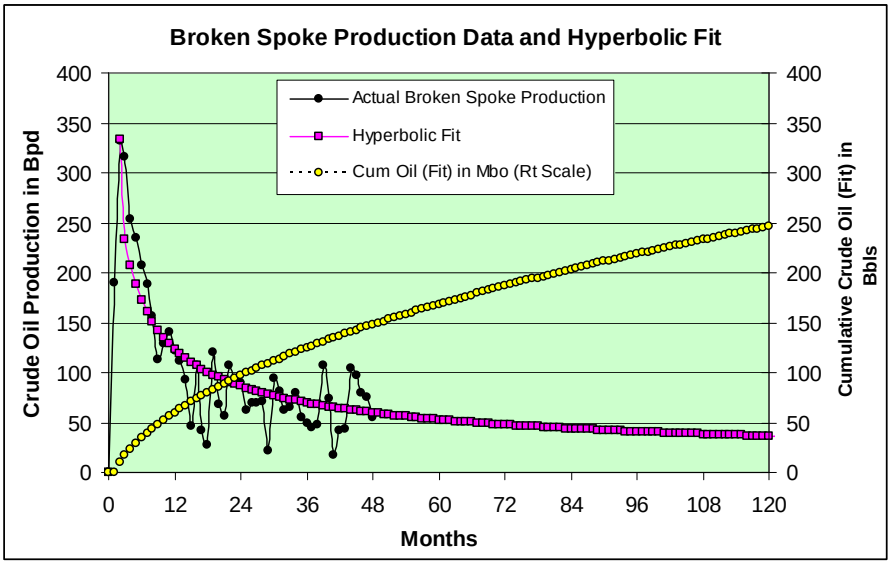

Figure 2: The Reservoir Depressuring Process in an Oil- or Mixed-wet Reservoir

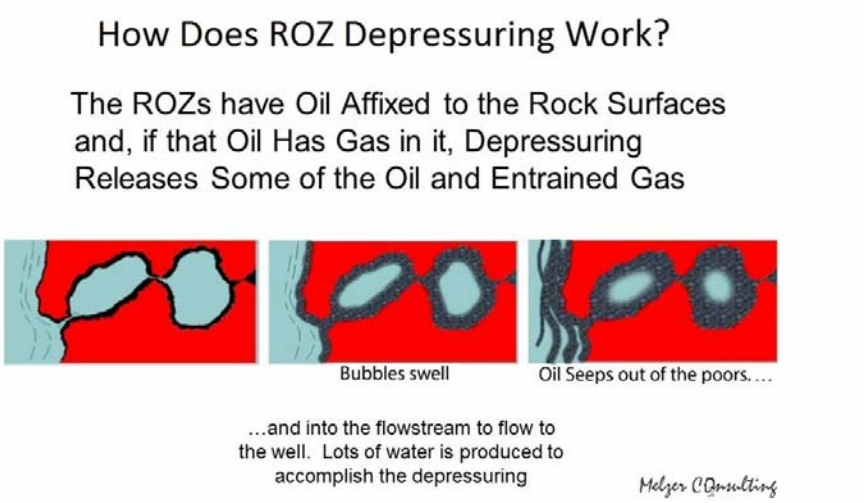

Figure 3: The Six-County Study Area with the Horizontal Well and Mapping of the San Andres Residual Oil Zones

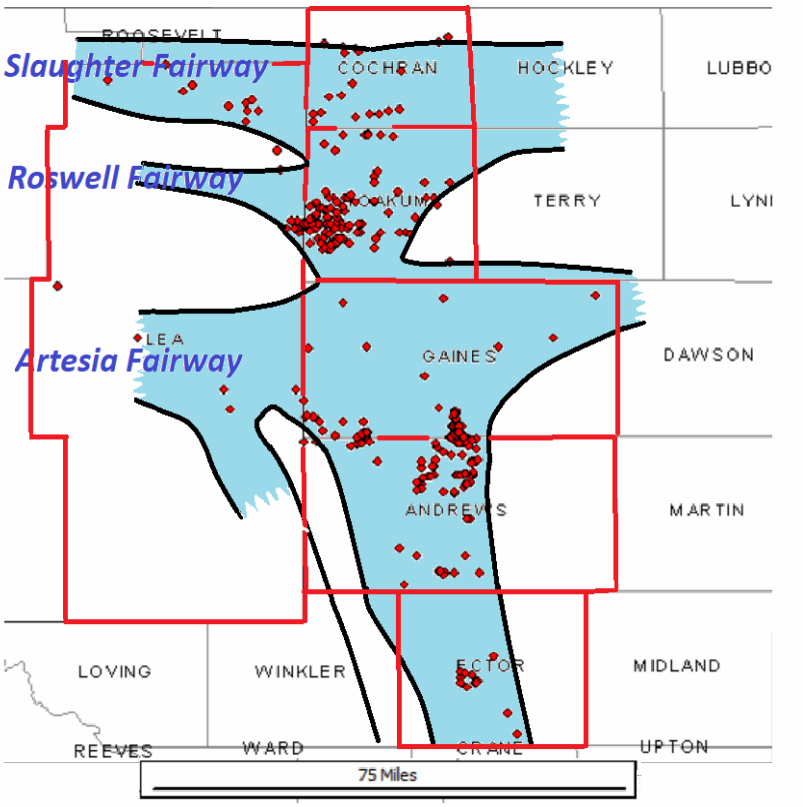

Table 2 – Horizontal San Andres Play Table of Statistics – Jul '18

Data as of Jul '18 Melzer CO2nsulting	Yoakum	Andrews	Gaines	Cochran	Lea	Ector	6-Counties
# Wells	157	156	61	17	21	21	433
% of Total Wells	36.3%	36.0%	14.1%	3.9%	4.8%	4.8%	100.0%
Current Daily Oil (Bo/D)	21,301	8,310	3,626	995	1,719	1,541	37,492
% of Daily Oil/D	56.8%	22.2%	9.7%	2.7%	4.6%	4.1%	100.0%
Current Crude Oil/Well (Bo/D)	21,301	53	48	59	103	73	
Cum Oil Jan '11 - May '18 (MBo)	11,799	10,551	1,772	472	830	1,441	26,866
Percent of Cum Oil	43.9%	39.3%	6.6%	1.8%	3.1%	5.4%	100.0%
Current Daily Gas (Mcf/D)	26,116	4,274	1,905	1,371	1,500	2,096	37,262
Percent of Daily Gas	70.1%	11.5%	5.1%	3.7%	4.0%	5.6%	100.0%
Cum Gas Jan '11 - May '18 (MMcf)	12,935	4,728	807	467	866	1,674	21,477
Percent of Cum Gas	60.2%	22.0%	3.8%	2.2%	4.0%	7.8%	100.0%
GOR (CF/Bbl)	1,226	514	525	1,379	1,211	1,382	-

Fig. 4 – Growth of Oil, Gas Production and Number of San Andres Horizontal Wells