A Game Changing New Unconventional Play: the Science and Case History Based Economics of Depressuring the Upper Residual Oil Zone

L. Stephen Melzer, Melzer Consulting

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Studies on the origins and distributions of residual oil zones (ROZs) have set the stage for an exciting and expansive new production play dubbed herein as Depressuring the Upper Residual Oil Zone (DUROZ). What began as an attempt to extend existing San Andres field production to the zones beneath the oil/water contact has now spread to "greenfield" regions without an overlying main payzone (MPZ). The play requires an understanding that the San Andres formation was a huge (mega-) trap at the close of the Cretaceous Period and the oil was partially swept by water encroachment from the west during the early and mid-Tertiary era. The play takes advantage of the new horizontal drilling and completions strategies made commonplace with the unconventional (aka "shale") plays. It also gains benefit from the pressure depletable nature and better rock properties of the San Andres formation and its oil wet residual oil zones. Over 50 horizontal case histories are underway demonstrating the commercial promise of the depressuring play in ROZ reservoirs that are not capable of commercial exploitation of oil in either primary or secondary production. This paper documents the key concepts of the ROZ creation as well as including some of the producing statistics of the case histories underway on the northern shelf region of the Permian Basin. It also outlines the governing principles of the new play which afford the ability to expand the play to huge greenfield ROZ areas even at large distances from the immediately exploited area. The widely held and competing theories of why the oil being produced may not be residual oil are not thoroughly discussed herein but will be addressed in a future paper.

The Key to the Play: Formation of a ROZ

The concept begins with the understanding of the origins of residual oil zones (ROZs). According to Melzer, 2006[1,2] three different kinds of ROZs are possible owing their origins to tectonic adjustments in the basin after reservoir deposition, subsidence, oil generation and migration to a trap. That subsequent adjustment can occur due to a basinwide tilt (ROZ Type 1), leaking or breaching of reservoir seals (ROZ Type 2), or uplift on one side of a basin allowing water influx through the basin and out to surface (ROZ Type 3). Table 1 summarizes the ROZ type attributes.

Table 1: ROZ Type Attibutes

ROZ TYPE	Oil-Water Contact	Base of Oil Saturation	Other Characteristics
Regional Tilt (1)	Horizontal	Tilted	Wedge with thin side Updip
Breached Seal and Reaccumulation (2)	Horizontal	Horizontal	Stratified Tar Mats, Anomolously Low GOR
Hydrodynamic Tilt (3)	Tilted	Horizontal	Wedge with thin side in Direction of Flow (to Spill Point)

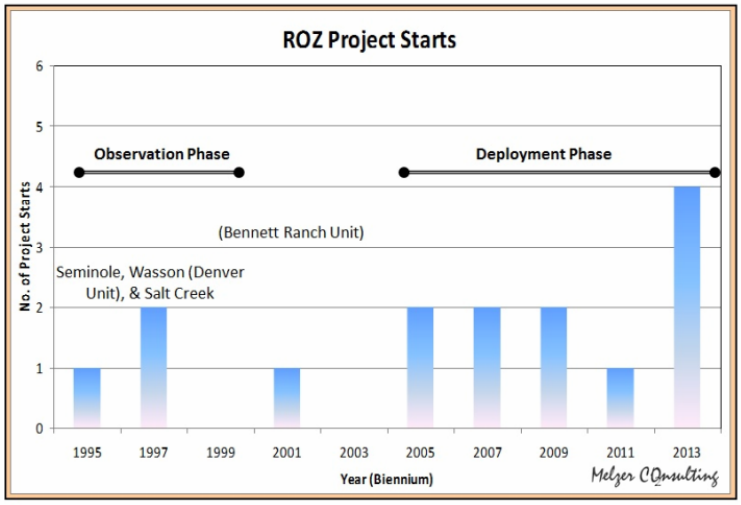
[1] Stranded Oil in the Residual Zone, U.S. Department of Energy Report, February 2006 http://www.melzerconsulting.com/pdf/ROZ_Melzer_Document_51.pdf

[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.

The studies performed over the last several years have demonstrated that Type 3 is the controlling style in the San Andes formation of the northwest shelf and Central Basin Platform. They also explain the ubiquitous shows in the Formation that have so often frustrated operators with completions by making non-commercial quantities of oil when excellent shows were observed and noted as being equivalent to the shows of oil present in producing intervals (main payzones).

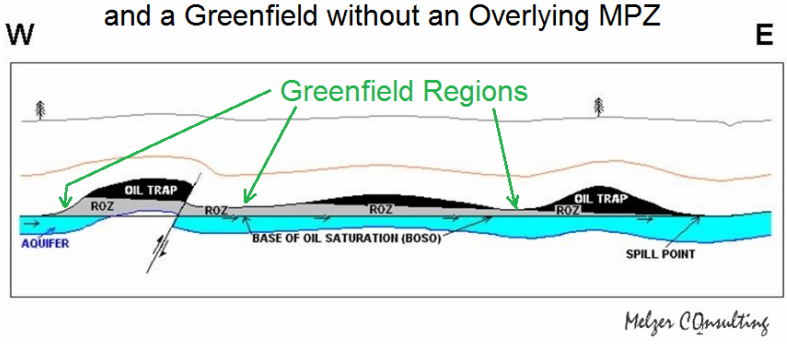
Perhaps the best way to think about the origins of a ROZ is to recognize that they originate because they were the lower portion of a paleo oil trap that has been naturally waterflooded. And, just as in man's waterfloods, the natural waterflood has left significant oil behind. As can be shown in many situations, the same percentage of by-passed oil can be present in the swept zones of both natural and man's waterfloods. That naturally by-passed oil was recognized in the 1980's by several major oil companies and is currently being exploited with the oil being mobilized by injection (enhanced oil recovery) techniques such as CO_2. This process works in the same fashion as CO_2 EOR has succeeded after man's waterfloods. Already, the ROZ CO_2 flooding concept has advanced beyond the theory stage as more than a dozen CO_2 EOR projects are underway in the residual oil zones of Permian Basin carbonate reservoirs. These ROZ projects have emerged out of the observation phase and clearly moved into the deployment phase (Figure 1).

Figure 1: Residual Oil Zone Flooding: Project History



All of projects in Figure 1 involve CO_2 EOR methods and all but one are flooding the San Andres Dolomite formation. The ROZ type involved is the laterally swept (Type 3) which, as Figure 2 illustrates, can be with or without an overlying main payzone (MPZ). The next phase of ROZ development is now maturing into demonstrations of commerciality of oil recovery in what are being called greenfields – in regions without pre-existing production.

Figure 2: Type 3 Residual Oil Zones
Lateral Sweep with ROZs formed beneath a Field and a Greenfield without an Overlying MPZ

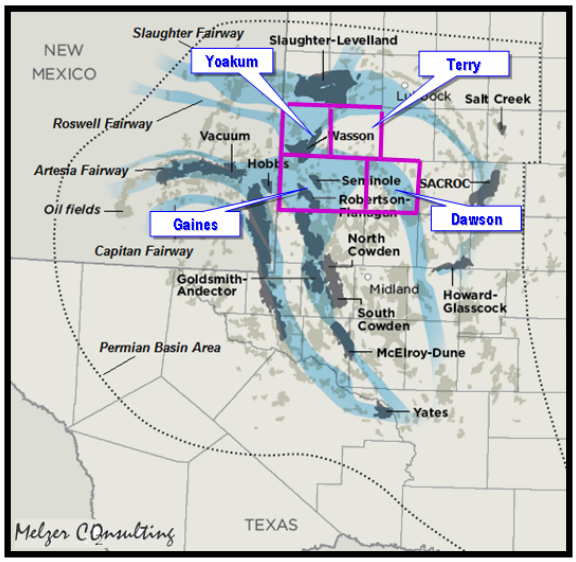


The continuing ROZ studies are attempting to identify and map the Greenfield regions of sweep wherein the mobile oil was entirely swept out leaving only the residual oil. These regions of Greenfield ROZs offered no closure atop the paleo trap and are aligned in what have been termed fairways. These

fairways represent the high energy (near-shore) facies wherein oil was entrapped early in the evolution of an oil basin. Figure 3 is the latest version of the fairway map.

Also part of the on-going ROZ studies is a four-county assessment of the size of the San Andres formation ROZ "prize." The counties are outlined in Figure 3 and consist of Gaines, Yoakum, Terry and Dawson counties. A total of 107 billion barrels of oil in place has been quantified of which 66 billion was deemed to be economically producible using CO_2 EOR technology at $90/barrel. These oil resources are specifically the Greenfield resources and have purposely not included the brownfield resources below the producing fields.

Figure 3: Current Status of the Mapping of Active Major CO_2 EOR Projects in the Permian Basin and Residual Oil Zone Fairways



The commercial excitement of ROZs has now spread to the greenfield areas. Within the list of the on-going ROZ projects, one is a partial greenfield and another is entirely a greenfield project which began injection in November 2014. Both are CO_2 EOR demonstrations**.**

The Specifics of the DUROZ play

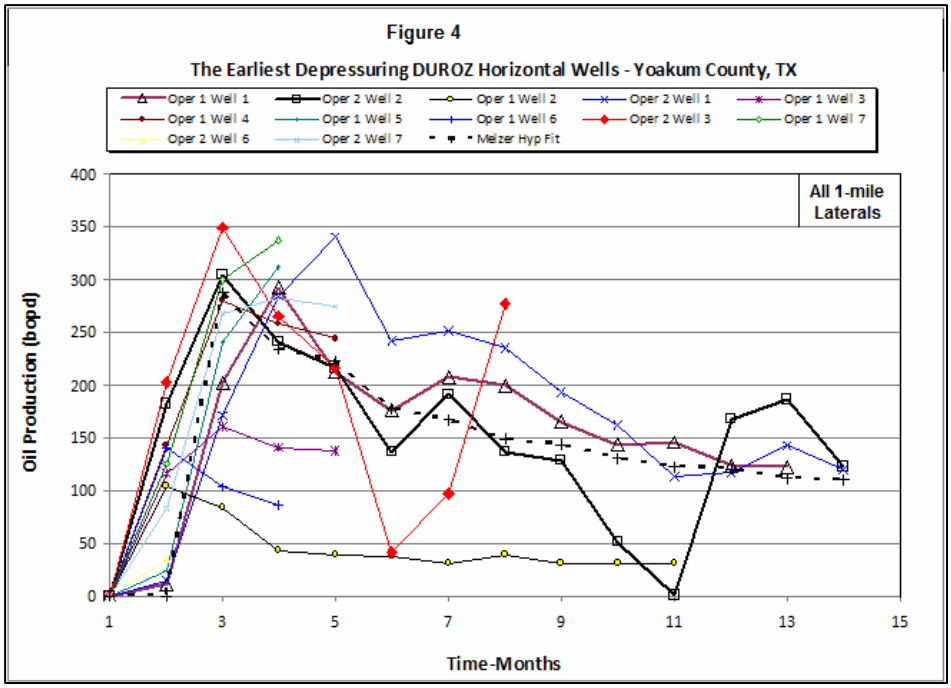
CO_2 EOR exploitation requires a producer with the technical and personnel expertise that only a few companies have sought. Further, CO_2 supplies have been tight for almost a decade in the Permian Basin and several operators have been longing for a method other than CO_2 EOR for extending the lives of mature oil fields or for producing the ROZs. It has just become obvious today that horizontal well technology, whose first carbonate application was designed to exploit the transition zone beneath the main payzones in existing fields, is now allowing an alternative to EOR. It has been extended to greenfield regions away from fields and has demonstrated the technical and economic viability of depresssuring the zone. The method provides for the creation of a large drainage volume via the horizontal and staged hydrofrac which allow the gas in solution within the residual oil to exsolve and render the oil mobile. One of the key elements for success of the method is, of course, having sufficient gas in solution in the residual oil. The technique works best where the oil has not seen depressuring and one advantage of Mother Nature's water flood is that the pore fluids were never depressured. This is in contrast to main payzones that were at least partially depressured during the primary production phase prior to the waterflooding phase.

Similar attempts at producing the ROZ intervals from vertical wells have been met with some technical success but, it is very fair to say, a lack of economic success. A recent presentation by Shannon Stilwell

of Walsh Petroleum[3] emphasizes this point. As was the case for shales, the advance of horizontal drilling technologies has allowed the wellbore surface exposure to be dramatically improved increasing the pressure drawdown volumetrics resulting in very large quantities of water being produced but, with the accompanying drop in reservoir pressure, significant oil production volumes.

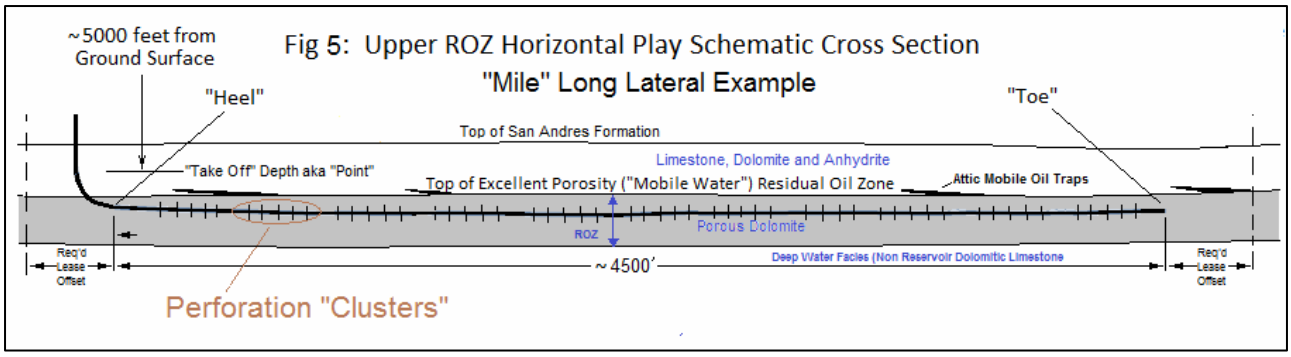
So the stage is set to combine the concepts of horizontal drilling the ROZ fairways with depressurizing the upper ROZ to examine the economics of the new wells. The play started in a higher oil price environment but is holding some momentum even in the current suppressed price environment. The development is generally concentrated in one of the four county areas that were identified in Figure 3.

Figure 4 illustrates the monthly oil from two of the original operators leading the play. Several wells date back to late 2013 and have over a year of producing life. Most leases now are complicated by two or more wells making individual well analysis less exact. Because of the average nature of the wells, 4500' length lateral, and the longevity of production, we have chosen to curve fit two of the original wells – one from each operator - with a hyperbolic function and use that as our analog well shown in its earliest months in Figure 4.



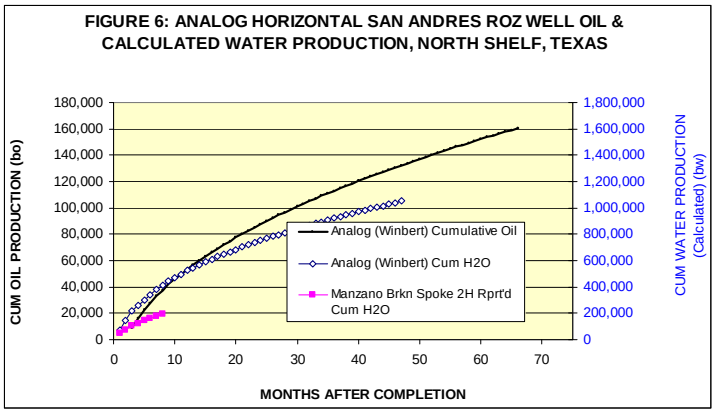
To be fair, the concept of producing residual oil by depressuring is still somewhat controversial. In the author's opinion, the well production results as displayed in Figure 4 are difficult to explain otherwise. But one of the competing explanations is that, in these upper ROZs, there is some mobile oil. The industry has known that some stratigraphic traps lie on top of the "big water" ROZs. These are explained in the recent ROZ studies as having been isolated from the natural lateral sweep. A few smaller companies have made a living going after these "attic traps" which lie above the "big water" zones. Attempts at vertical completions into the ROZ are almost always frustrated by the inevitable large volumes of water and uneconomic oil. Figure 5 is an attempt to graphically display this concept. Whatever the final explanation becomes, the production results are what they are and the oil and gas revenues resulting from the on-going play are clearly a game changing one.

[3] http://vimeopro.com/user33086088/pb15/video/120942798



Water Production

In order to begin to depressure a ROZ reservoir, it is necessary to have a pressure depletable one (no efficient water drive) and an expectation of producing very large volumes of water. Water handling is therefore critical and a well or wells capable of disposing the produced volumes of water is imperative. The case histories demonstrate that oil cuts remain nil for at least a month and even well beyond the flow back loads and tend to rise to 15 to 25% in a matter of months. From there, they seem to level out and remain there for the life of the well. The cumulative oil for the analog well and cumulative water production data is shown in Figure 6 for the wells we have been able to obtain.



Well Configurations and Reserves

What is apparent from the initial wells in the DUROZ area is that the average projected recovery from the wells will meet or exceed 250,000 barrels. Two representative case history wells both made 60,000 barrels in 14 months, even when including the initial 30 days of no oil and 100% water production.

Almost all of the original wells in the play were drilled in a north-south orientation to just less than a mile in lateral length, on a “stand-up” 160-acre pooled unit and completed with 8-12 stages with a varying hydrofracture design.

Since that time many 1.5 mile laterals have been drilled and are showing promised of being commercially preferable where lease conditions allow. It is likely that some optimization of well configurations, spacings, leg lengths and frac design are likely possible for additional upsides.

Conclusions

Most experienced oil industry professionals are probably not surprised that a well just below the oil/water contact in a field area would make some oil. Transition zone thinking would lead one to

believe that some mobile oil would be recoverable. Outside of the field areas, however, the magnitude of oil recoveries demonstrated herein is likely surprising to most especially considering the numerous dry holes in the greenfield areas and the very limited vertical well oil recoveries.

Three hundred foot thick transition zones were an enigma for the Permian Basin industry for quite some time and now are explained by a very thick paleo trap that has been laterally swept. The lateral sweep can be vertically complete so that effectively no mobile oil is left at the top of the reservoir quality rock. Much like the shales, the DUROZ play can be extended to acreage that was devoid of mobile oil, i.e. the greenfield fairway areas between fields. But the DUROZ play takes advantage of a much better reservoir with an efficient drainage efficiency from the reservoir matrix due to the horizontal well technologies.

Coupling the Type 3 laterally swept ROZ concept with the fact that the DUROZ analog wells require depressuring to produce oil, forces one to a whole new and game changing play concept. What makes the residual oil mobile is the gas expansion – analogous in a sense to gas solution drive in main payzones. But the idea of commercially producing immobile oil is new and is being met with much doubt as even some of the current companies in the play are holding on to a structural or stratigraphic concept to explain the exciting production.

Drilling and completion costs in the Permian Basin have been receding and provide an excellent opportunity to compensate for the oil price environment and enhancing the profitability of the wells when oil prices rebound. Only a percentage of the residual oil will be produced when the DUROZ play runs its course. Further upsides could come from a second stage of production from the prospect acreage using EOR technologies to recover yet additional reserves.