** SciencePG**
Science Publishing Group

Review Article

Comparing Resource Plays in the Texas and New Mexico Permian Basin – Implications for Exploration Research

Mary Naadanswa Adu-Gyamfi[1, *], Peter Golding[2], Luis Perez[3], Anand Raj[1]

[1]Environmental Science and Engineering, University of Texas at El Paso, El Paso, Texas, USA

[2]Department of Engineering Education and Leadership, University of Texas at El Paso, El Paso, Texas, USA

[3]Department of Civil Engineering, University of Texas at El Paso, El Paso, Texas, USA

Email address:
madugyamfi@miners.utep.edu (M. N. Adu-Gyamfi), pgolding@utep.edu (P. Golding), lgperez@utep.edu (L. Perez),
araj@miners.utep.edu (A. Raj)
[*]Corresponding author

Abstract: The Permian Basin in Western Texas and North Eastern New Mexico is an energy powerhouse. With three sub-basins i.e., Delaware, Central Basin Platform and Midland Basin producing hydrocarbons from both conventional and unconventional plays, the Texan Permian has been a focus of more interest from energy companies than the North-Western Shelf of the basin in New Mexico. However, the less explored North Western shelf of the basin in New Mexico furnishes equal opportunity for oil and gas exploration companies for further exploration research and subsequent discoveries. This research is an attempt to showcase the exploration significance and highlight the gaps for in exploration research in the New Mexico Permian Basin. We compare the oil plays in both Texas and New Mexico Permian based on reservoir geology and basin architecture. Overall, The Permian Basin is dominated by carbonate reservoirs. They account for 75% of all oil production followed by clastics, which contribute 14%; then come the mixed clastics and carbonates accounting for 8%; and lastly cherts make up around 3%. The leading growing production zone is the San Andres platform (Northwest shelf) carbonate play (4.0 billion bbl) followed by the Leonard restricted platform carbonate play (3.3 billion bbl). The Lower Permian Horseshoe and Pennsylvanian plays are next (2.7 billion bbl) and lastly by the San Andres platform carbonate play contributes to the overall production (2.2 billion bbl). With known potential of shelf plays we determine that North Western Shelf has similar stratigraphy and extensive hydrocarbon potential yet to be researched and explored.

Keywords: Permian Basin, Reservoirs, Delaware Basin, Central Basin Platform and Midland Basin

1. Introduction

The ~115,000 sq mi Permian Basin in west Texas and southeast New Mexico is one of the major hydrocarbon basins of USA contributing to ~ 19% of the country's total production. The Permian Basin in New Mexico and West Texas appears to be actively originating Proterozoic (late) time as an abyssal mark at the edge (southwest) of the craton. During this time, a part of the area would have been influenced by rifting emerging from a triple junction spreading center situated far south of the present location of the basin. The rifting further extended towards north to Lea County, New Mexico associated with right-lateral strike slip faulting trending north-northwest. At this time, since this part was developing into an aulacogen, some vertical movements may also have taken place [8].

Following a pause in sedimentation, deposition in the continent resumed in the Triassic (Late) at the similar location in the Permian Basin. None the less, after a hiatus during the Jurassic era, Cretaceous sedimentation started on another pattern, as shallow seas advanced from southeast and started layering marine sandstones and limestones in the area. The Cretaceous deposition which has outlived the erosion is

mainly Comanchean time [22].

At the western margin where Permian carbonates at the shelf-edge and adjoining basinal rocks were elevated is strongly affected by the Laramide range. The graben (salt basin) was developed through the cotemporaneous and later downfaulting. These events tilted the developing Delaware Basin further towards the east and originated the Delaware and Guadalupe mountains. A vital side effect of this inclination was that the joints at the zones of weak planes started opening across the eastern part of Delaware Basin. This phenomenon greatly helped the solution of large quantities of Permian salt at the onset of Pliocene and Pleistocene. The sediments from Late Cenozoic found in the basin are more or less thin except for those quilting the graben (salt basin), the eastern part of the Delaware Basin and at the Pecos river where the trenches are filled with salt solution. Low seismic activity continued during this period as the tectonics subsided. After a long fap of tectonic uplift and disintegration while Latest Precambrian - Early Cambrian time, a slight skin of Upper Cambrian and lower

Ordovician clastic facies got deposited in the upper part of Tobosa Basin [9]. At the onset of early – middle Paleozoic time, the basin was the site of deposition at shallow-waters, mainly shales and limestones. This deposition was frequently interrupted by intervals of extensive erosion both subaerial and emerging.

During the Mississippian time, a meek tectonic activity started, escorted by vertical motion along the inherited weak zones of late Precambrian strike-slip faulting. By Middle Pennsylvanian time, the tectonic forces had intensified and deformed the middle area of Tobosa Basin by a folded and faulted uplifted tract. This geomorphology divides the province into two sub-basins i.e., the Delaware sub-basin towards west and the Midland to the east (figure 1). As these basins were developing, limestone shelves (in breadth) grew along their margins. These basins were intersected by stream channels through which fine-sized sands and shales got carried into the deposition system of these basins [8].
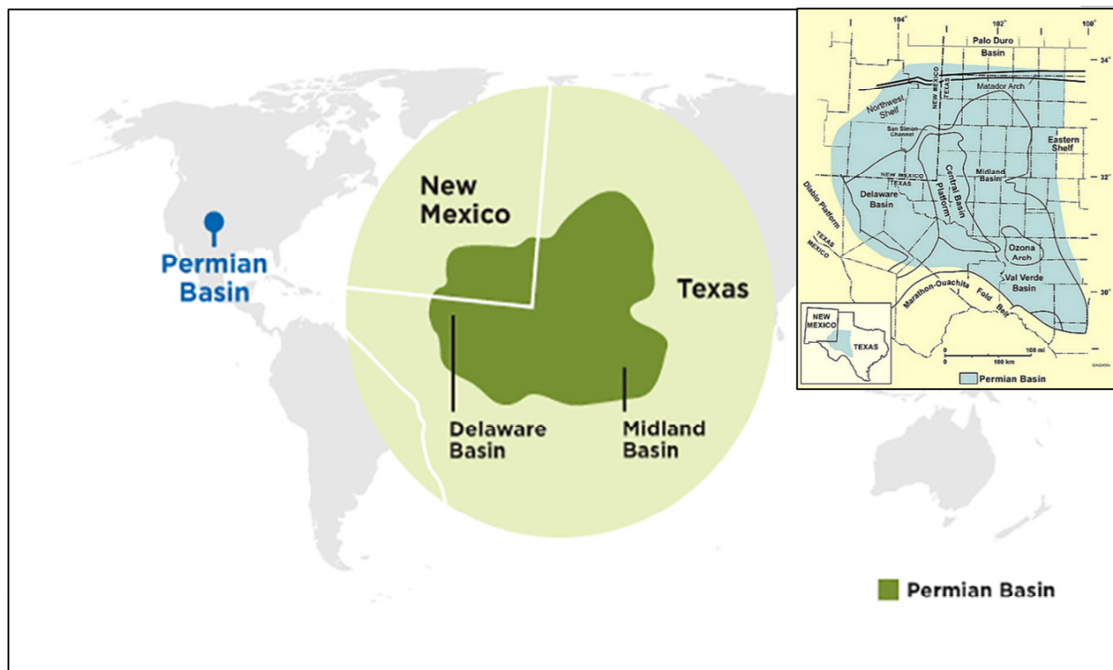

Figure 1. *Location map of Permian Basin.*

During the Late Permian period, deposition of carbonates was restricted to a narrow ring surrounding the Delaware Basin developed by an elevated barrier from Capitan reefal complex. The middle part of the basin was receiving small amounts of fine clastics deposited within a reducing stage. By the end Late Permian, cyclic retreat of the seas ensued evaporites sedimentation and formed continental red-beds throughout the basin. As we progress to Middle - Late Permian time, tectonic activity was at a premium, only influencing the gradual deepening of the Delaware Basin with slight inclination towards east.

Considering structural controls, the Permian Basin has the Marathon-Ouachita Fold Belt on the south, on the west it is bounded by the Diablo Platform and Pedernal range, Matador

Arch marks its northern boundary while it is bound on the east by the Eastern Shelf of Midland sub-basin / western margin of Bend Arch. Two hundred and sixty by three hundred miles in area, the basin and is differentiated into eastern and western compartments by the north-south plunging Central Basin Platform [20]. When viewed in cross-section, the basin has an asymmetrical shape; the western segment contains a denser distribution and much intensely deformed sequence of sedimentary deposition. The Permian Basin is distinguished as a large structurally negative region generated in consequence to the down-warping in the Precambrian basement surface situated at the southern flank of North American craton. The basin gradually got packed by Paleozoic and to a slightly lesser extent, sediments of younger age. It gradually formed

its present structural state by Early Permian time. Overall, the basin can be constrained into several discrete tectonic and structural features [10]. Ozona Arch and Central Basin Platform, which distinguish the Delaware and Val Verde Basins on the southern flank and west from the Midland Basin on the east and north, the Northwestern Shelf on the southmost periphery of the Matador Arch and Pedernal Range, and the Eastern Shelf on the western proximity Bend Arch. Sedimentary assemblages of all systems of Paleozoic era are observable as well as they reach a maximum thickness which exceeds 25,000 ft; however, throughout vertical sedimentary assemblages of Paleozoic era are rare. The biggest (production wise) and one with the most potential, the Texas Permian is in a mature and development stage, however, the New Mexico part of Permian (northern Delaware basin) is still underexplored, particularly under researched [6].

Statistically, forty percent of oil and gas is in the Permian basin is being produced by limestones at the basin shelf, thirty percent by dolostones at shelf and the remaining 30% from basinal shelf clastics. The trap distribution within the Permian basin is pertinent to mention here. A third of the total production is from structural traps, in more central locations, one third from stratigraphic traps mostly on the flanks / distal margins and the remaining traps are a combination of structural and stratigraphic elements [15].

Several studies, reports, and peer reviews conducted have focused mainly on the geology of the Permian Basin in west Texas. Very little research has focused on the Permian Basin in Northeastern New Mexico. As a result, this research intends to highlight the equal opportunity of oil and gas exploration in New Mexico's Permian basin by comparing the two oil plays, their geology and architecture.

2. Background History

All the big oil producing countries in the world see the oil and gas in the subsurface and the land as national heritage and property of general public which is to be developed further under licenses / concessions permits acquired by private or international developers.

In the beginning the last century, when the boom of exploration was just starting out in Texas, the Permian Basin by and large was not explored in detail primarily since it was thought to be lacking oil and gas. In 1920's, there was not a single well produced oil in a radius of 100 mile in the Delaware Basin. However, Frank Pickrell started Texon Oil and Land Company. Pickrell obtained concession in the Permian with a strict timeline. Consequently, a geologist had marked a drill point a few miles away from the rail road where the drilling equipment lay. However, since his lease was about to expire, Pickrell drilled a wildcat as close as 124 ft from the rail station. They named the well Santa Rita-1. May 27th, 1923 was when they struck oil luckily producing 100 – 150 BOPD (barrels of oil a day). Since there were no pipelines, the oil from the wildcat had to be transported rudimentarily by rail. However, unknowingly, they had ignited a spark which galvanized an influx of exploration investment [10].

Historically, as with the Santa Rita #1 well, companies used to drill vertical wells into probable reservoir rocks without much G&G investigations. It was a common practice to go for multiple dry holes to understand the subsurface, even developed fields to glean geological information. The reservoir had to include a trap, generally a fault and / or stratigraphic seal so that the hydrocarbons stay in place. The last ten years have witnessed a profound evolution in drilling and fracking technology and geological / geophysical expertise to an extent now we can make the wells produce from source rocks directly. The source rock which was previously non-considered non economical for commercial production since lacked requisite permeability and more often than not consisted of shale making it challenging to drill. Owing to the technology, using proppant and pressurized fluids the shales can be hydraulically fractured. Optimum layering of Permian Basin enables the operators to penetrate multiple shale formations from a singular surface pad, enhancing efficiency while limiting water disposal and transportation expenditures [7].

Technology has always played a leading role in exploration and recovering viable earth resources. This is particularly true in case of the finding oil, developing the resource, and further redevelopment as technology advanced in the Permian Basin generally. Following years of rich exploration and production since the initial 1923 oil find, the cooperative endeavors of many industry liaisons has significantly amplified the Permian Basin's resource value. This has proven to be true since the last decade as the property value of oil and gas acreages in this prolific patch have escalated significantly as a consequence of formidable advances in drilling and fracking technologies particularly in the US [14].

Fast forward to our days, as drilling technology reaches new heights and becomes the norm, chasing non-conventional shale plays has become viable and hydrocarbon output in the Permian Basin has swelled to two million barrels per day. Delaware basin became the most famous oil patch in the USA during the third and fourth quarters of 2016. Since boreholes in the Delaware region of south Texas average $6 - $8 million / well, oil companies started obtaining plentiful concessions since they got to know that they would get good tax incentives in Texas which were lacking in New Mexico at that time.

Currently, almost three hundred reservoirs from different parts of the Permian Basin are producing in excess of one million bbls oil (MMBO). These three hundred reservoirs gave an output of four and a half billion bbls oil two decades ago. Based on geologic framework including reservoir architecture, type of rock, environment of deposition, structural context, mechanism of trapping, these reservoirs were classified into seventeen distinct plays. Out of the seventeen, ten Permian plays that have an accumulative production of three thousand five hundred MMBO, two Pennsylvanian plays are producing four hundred and twenty-four MMBO, three Late Siluro-Devonian plays are giving an output of four hundred and forty MMBO, and the two Ordovician time plays have an accumulative output of eighty-six MMBO. During the last half of 2010, forty MMBO were pumped-out from the plays of

Permian age, the Pennsylvanian yielded six and a half MMBO, the Late Silurian-Devonian plays produced one and half MMBO, and lastly, the plays of Ordovician age produced around one MMBO [2].
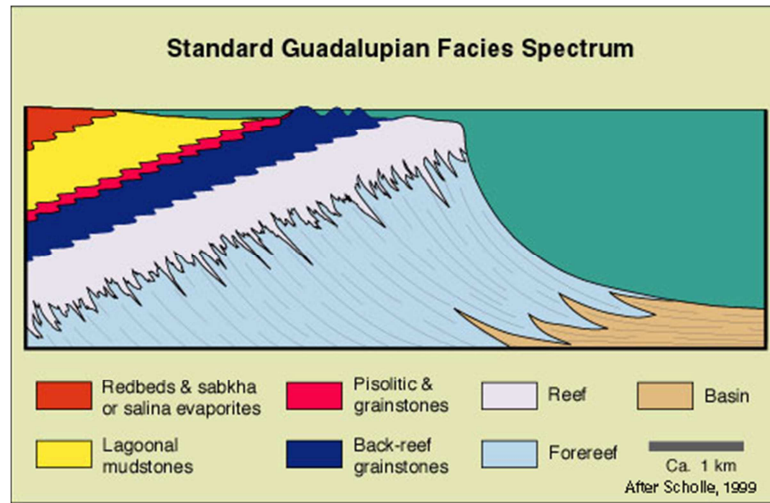

Figure 2. *Facies spectrum in the New Mexican part of Delaware Basin.*

3. Literature Review

Though the Permian basin has been producing significantly for over a century and explored and exploited rigorously, there still are gaps in the literature. Loopholes in already published research about many facets i.e., local geomorphological events, stacking patterns, regional stratigraphic framework, models concerning deposition, petrophysics based models, and exploration research for reservoirs, particularly in the New Mexico segment of Delaware Basin, leaving plenty of further research opportunity. Since consensus about stratigraphic framework or sub-divisions in Bone Spring and Wolfcamp Formations is lacking, publications from recent articles are usually cryptic and troublesome to compare with each other. Rather than contemplating previous work, this section focuses on a dearth of exploration research in New Mexico part of Permian Basin compared to the South Texan region.

If we examine previous studies, the authors have used an amalgamation / modification of historic deep-water depositional models [3, 12, 17] to explain the interposition of facies along with their observed association [5, 16, 21]. Kvale and Rahman [16] show in their study two cores nearly 50 miles apart in Delaware (New Mexico region) which resulted in the identification of two significant associated facies: (1) calcareous siltstones / fine-grained carbonates with interbedded mudstones (siliceous) and (2) mudstone and dolomitic siltstone facies. Here we can observe that first facies association has provenance from the Central Basin Platform and has adequately comparative porosity but lesser permeability with respect to the second assemblage of facies, which is suggested as only sourced from a Northwest sediment. This research suggested framework for the sake of regional sequence stratigraphy based on an alteration of Haughton's hybrid event bed deep water model. Although the research identified significant prospects w.r.t reservoir properties, trends and modeling, however, its utility is very limited; the authors did not come up with heterogeneity spread across multiple scales; and since the data was limited to two cores in the study, the results cannot be considered too reliable.

In another article, Driskill et al. [5] have proposed another complex model to represent all realizable facies successions noted in the Wolfcamp and Bone Spring formations widespread in the New Mexico and Texan part of Delaware Basin within a limited region near the thrust of this research. Even though this model subsumes, Lowe, Bouma and Haughton characteristics, it is worth mentioning that facies successions are not complete, thus individual sedimentary features and textures cannot be used to identify facies. However, this study captures heterogeneities at the core scale, the description of cores is not provided and specifications regarding core-based facies frameworks are incomplete. Resultantly, the application of this research beyond the specified scope is restricted. Similarly, attributes in methodology / analysis were left out or unclear in Thompson et al. [21], which focused to integrate various scales in data to suggest framework for sequence stratigraphy in the Delaware Basin. Though the research suggested quantifiable implications for quality of reservoirs in the four associated facies identified from two unspecified sources of proprietary core, details of specifics analyzed were not published, and characteristics of facies were unclear, thus limiting use of their work to the research.

The above-mentioned technical articles agree to the fact that frequent small-scale changes noted in size of grain distribution and sedimentary structures that characterize deposition in the Delaware Basin cannot be completely represented by any single model. This implies that all of the studies have gaps in descriptions of the identified facies and multi-scale framework of facies. Therefore, effort must be put in characterizing the individual facies along with structural elements in totality at a regional scale, hence the New Mexico part of Delaware Basin is prime focus of our research.

4. Discussion

With an understanding of the structural / tectonic and stratigraphic controls over the Delaware basin, we categorize how the various reservoir facies are distributed in the Delaware basin to analyze why exploration research has lagged in the northern region i.e., New Mexico compared to the south Texan region where handsome investments from oil players have gone into basin research for oil exploration (figure 3). We will review a conventional and an un-conventional reservoir, their distribution across the Delaware basin we will gain useful insights on why effective exploration research in New Mexico region of Delaware basin is required and can be vital for companies in de-risking their projects and to get foothold in a competitive oil price environment in the short and long terms [18].
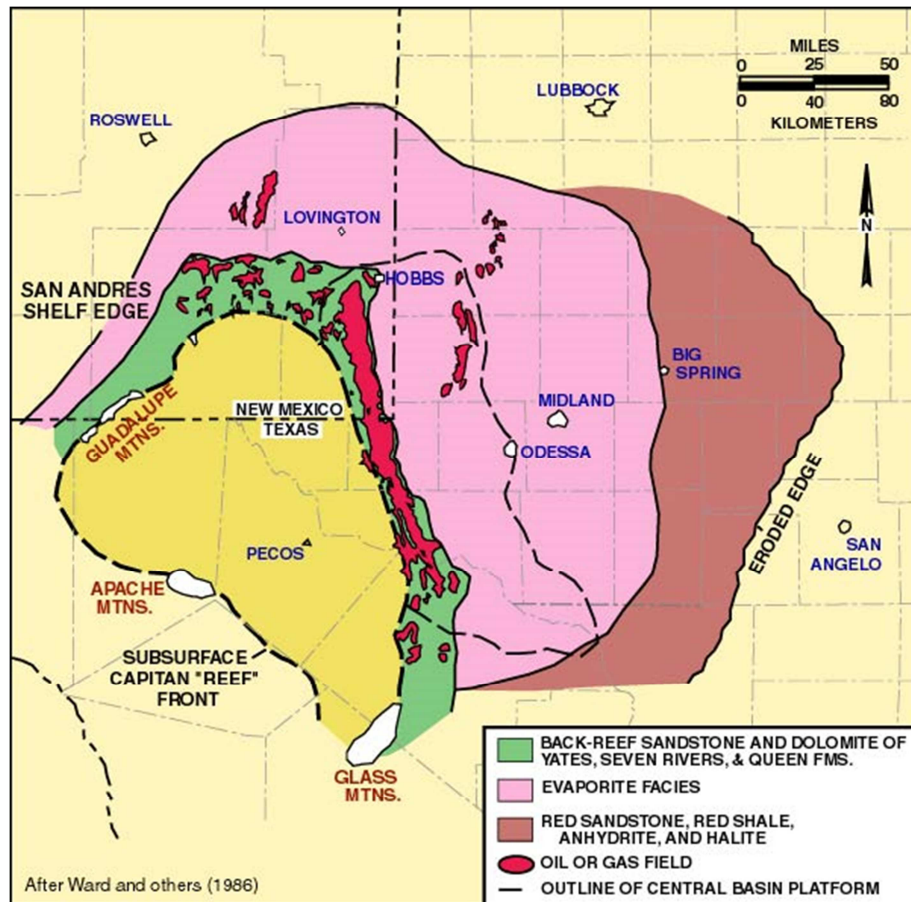

Figure 3. Oil and gas fields distribution in the Permian basin.

Conventional - *The Lower Pennsylvanian Sandstone Play*

A stimulating feature of this play is the favorable outcome in the exploration and exploitation of Morrow Sandstone reservoirs (primarily gas) in the northern Delaware Basin and adjoining shelfal area of New Mexico. However, one of the principal factors restricting exploration conceivable for the play is the common criticism about the Permian oil province i.e., the substantial exploration and drilling history.

The resource play includes minor oil and gas pools in both structural and stratigraphic traps corresponding to mainly Early Pennsylvanian conglomerate and quartz sandstone reservoirs. These units have provenance in the highlands which got uplifted in the late Paleozoic collision of the ancient North America plate with Africa and South America. The collision event consequently gave rise to the present geomorphology of the Permian Basin and Ouachita structural fore-end. The play is bound towards the north by Palo Duro Basin in New Mexico. The provincial periphery marks the eastern boundary of the play. The pinch-out of reservoir facies on the Pedernal Uplift limits the play on the west. The southern boundary of the play is bound by the fore-front of the Ouachita Range. The thickness of the clastic wedge exceeds 5,000 ft at the maximum limit.

Reservoirs: The reservoirs, commonly interpreted as the deposited turbidites in deep water are cardinally quartz sandstones. Minor carbonate reservoirs also exist including both platform (Chapman) and much deeper detrital deposits (Rojo Caballos). The porosity range is 4-17 percent with an average of 10-12 percent for both categories of reservoirs. Good permeabilities exist i.e., ranging from single digits to a few tens of millidarcies. Average thicknesses of the reservoir are observed in the tens of feet; however, the overall Bend interval is hundreds of feet. This play has a productive depth from 5,500 to 12,000 ft [1].

Source rocks: The reservoirs are mainly charged by Late Devonian Woodford Shale and high in organic matter

Pennsylvanian shales in the Delaware Basin. Morrow gas fields in north Delaware Basin and on adjoining New Mexico shelf area offer proof of the prospect that gaseous hydrocarbons are showing an upward migration trend in the Delaware Basin.

Timing and migration: The stratigraphic and structural traps of this play existed at the Pennsylvanian time. The predominance of gas charging the play most likely formed as leakage of gas up-ward through deeper early Paleozoic reservoirs in primitive basin setting. Migration most probably continues in the same fashion to the present day [1].

Traps and Seals: Mostly trapping mechanism comprises of fault-bounded anticlines, simple anticlines, and also stratigraphic traps of both categories i.e., truncation / pinch-outs and facies controlled. Numerous shale beds in this section provide optimum seals.

Exploration status: If we take a look at the growing production from this play through 1990, it was almost 141 MMBO, 5.7 TCFG, and 85 MMBNGL. Boyd was explored in 1951, the biggest oil field, which produced 27 MMBO [6]. The next discovery was Carlsbad South, found in1 968, is the most extensive gas field, with a cumulative production of 305 BCFG. Following this, major gas finds have been going on since 1980's.

Resource potential: This play has good potential for further gas discoveries.

Unconventional – Upper Devonian Woodford play

The Upper Devonian Woodford Formation illustrates an organic-rich petroleum source rock. This source rock extends through West Texas as well as southeastern New Mexico which is presently generating oil / gas in the subsurface [2].

Table 1. *The Woodford Shale.*

Woodford Shale (Hentz Family 7-1)						
Silica	Clay	TOC (wt)	Porosity	Cal.%Ro*	So	Sw
55-75%	15-30%	5-9%	8-10%	0.91-0.94	>50%	<20%

*After Jarvie et al., 2001

The Woodford Shale is rich in organic matter, moderately dolomitic, pyritic, silty, siliceous (55-75% silica) mudstone, 10-30% clay, and the TOC ranges from 5-9%.

Thermal Maturity: Source rock evaluation was performed on seventeen even-spaced samples from the core. T_{max} averaged 448, which translates to approximately 0.91 calculated %Ro [13], showing that the Woodford is in the peak oil-prone window. The T_{max} vs hydrogen index values indicate that the Woodford kerogen is Type II oil-prone aligning with previous reports [4, 19]. Four additional core samples along with source-rock extraction evaluation also provided the same values for %Ro of 0.91. Samples of oil were studied to determine the light/mid-range maturity realized on thermally-dependent. The outcome for core-extract samples (0.93 to 0.94 VREQ) are very similar to the result for extracted oil samples (~ 0.94 VREQ). Gas maturity which is conditioned on ethane / propane carbon isotopes (VREG) (GeoMark proprietary isotope/maturity calibration scale) has an average of approximately 0.93 for samples core head-space [11]. The average saturates/aromatics ratio samples and low asphaltenes sulfur provide evidence of high-quality oil and are aligned to the API gravity of 42.0 deg. Altogether, maturity data for oil, source-rock, the maturities are very similar, indicating slight or no migration. The maturity data in addition to the other T_{max} data from the region highlight a strong depth – thermal maturity relation. It is most likely within the early oil window, but only the Delaware including the New Mexico region of the sub-basin is within the peak oil-generation aperture.
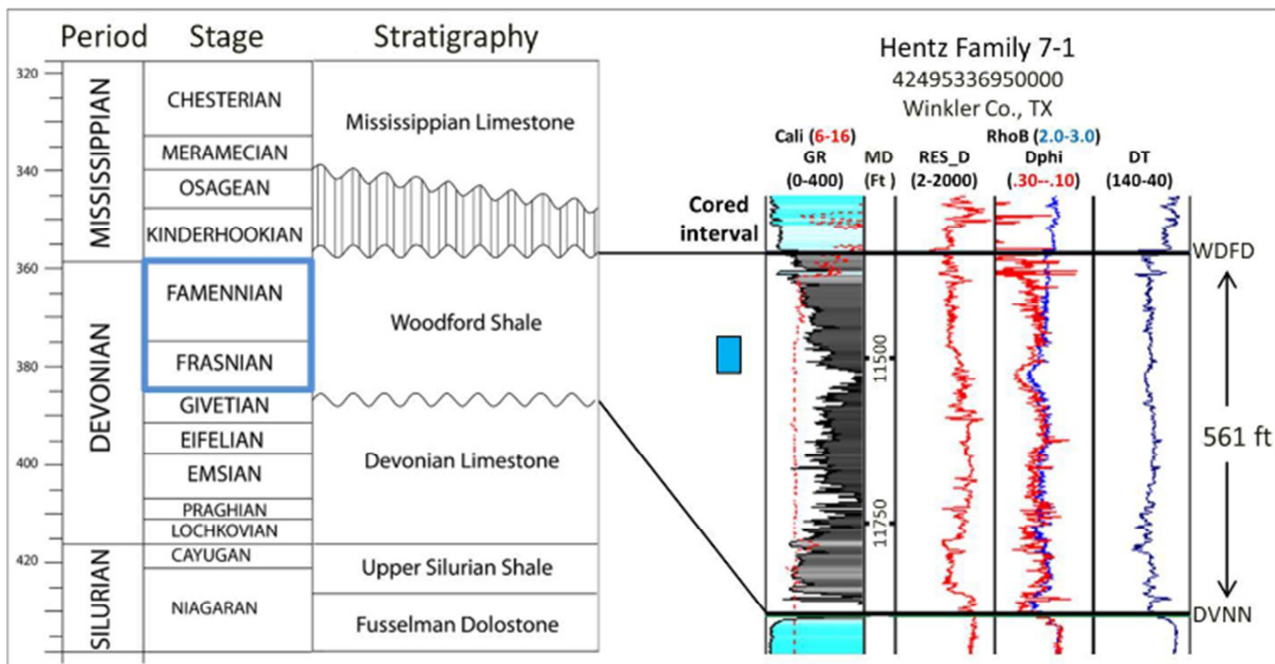

Figure 4. *Log responses of Woodford Shale in the Permian basin.*

However, shale plays in the New Mexican part of Permian basin are still underdeveloped with a lot of scope for exploration research; even the Wolfcamp play, one of the most highly producing conventional play is yet to be completely understood in terms of unconventional exploitation. The Upper Devonian Woodford shale is not thickest in the New Mexican part of the Permian basin, and here lies the research gap aligned with technology. Wells have to be drilled and the Upper Devonian Woodford has to be fracked extensively, the geomechanics has to be understood to produce economically.

Though the conventional reservoir facies are well distributed, lack of well density and advanced geophysical studies in the New Mexican part of Permian basin are gaps to be filled since the reservoir architecture is well understood and all the correlation maps are readily available from the south Texas fields. The risk is minimal and profit substantial in exploring the New Mexican Permian basin.

5. Conclusion

From our detailed literature survey and analysis, we conclude that since the petroleum systems are common in the northern Delaware Basin (New Mexico) and southern Delaware Basin (Texas), however because of better tax incentives on production in Texas, exploration companies have invested more in research in the Texan Delaware. Research is critical for technology development to de-risk and turn resources into commercial plays, hence there has been more unconventional development in the south rather than north.

However, with challenging times ahead for oil exploration, development and re-development of prolific oil patches / near field exploration is of the essence. Using a standardized sequence stratigraphic framework and following the porosity, permeability and heterogeny trends at a regional scale, more money needs to be put in exploration research in the Northern Delaware basin in New Mexico to tap the carbonate shelf and associated facies for getting first to first oil as well as minimizing exploration risk in a challenging oil price environment. This will provide a better understanding of the basin architecture and boost exploration success considerably in New Mexico. When oil revenue starts flowing, New Mexico's oil research, exploration and development tax incentives will favor the operators and create a win – win situation which will be a stepping stone for the Permian basin to produce for another century.

References

[1] Ball, M. M. (2006). Permian Basin Province (044).

[2] Barnaby, R. J., & Ward, W. B. (2007). Outcrop analog for mixed siliciclastic–carbonate ramp reservoirs—stratigraphic hierarchy, facies architecture, and geologic heterogeneity: Grayburg Formation, Permian Basin, USA. *Journal of Sedimentary Research*, *77* (1), 34-58.

[3] Bouma, A. H., 1962, Sedimentology of Some Flysch Deposits. Elsevier, Amsterdam, p. 168.

[4] Comer, J. B. (1991). Stratigraphic analysis of the upper Devonian Woodford formation, Permian basin, west Texas and southeastern New Mexico (Vol. 201). Bureau of Economic Geology, University of Texas at Austin.

[5] Driskill, B., Pickering, J., Rowe, H., 2018, Interpretation of High Resolution XRF data from the Bone Spring and Upper Wolfcamp, Delaware Basin, USA, URTeC Technical Program, 2018, URTeC: 2901968.

[6] Dutton, S. P., Kim, E. M., Broadhead, R. F., Breton, C. L., Raatz, W. D., Ruppel, S. C., and Kerans, C., 2005, Play analysis and digital portfolio of major oil reservoirs in the Permian Basin: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 271, 287 p., CD-ROM.

[7] Forand, D., Heesakkers, V., & Schwartz, K. (2017, September). Constraints on natural fracture and in-situ stress trends of unconventional reservoirs in the Permian Basin, USA. In *Unconventional Resources Technology Conference, Austin, Texas, 24-26 July 2017* (pp. 654-672). Society of Exploration Geophysicists, American Association of Petroleum Geologists, Society of Petroleum Engineers.

[8] Galley, J. D., 1958, Oil and gas geology in the Permian Basin in Texas and New Mexico, in Weeks, L. G., ed., Habitat of oil—a symposium, Tulsa, Oklahoma: American Association of Petroleum Geologists, p. 395–446.

[9] Galloway, W. E., Ewing, T. E., Garrett, C. M., Jr., Tyler, N., and Bebout, D. G., 1983, Atlas of major Texas oil reservoirs: The University of Texas at Austin, Bureau of Economic Geology, p. 139.

[10] Gibson, G. R., 1965, Oil and gas in southwestern region—geologic framework, in Young, A., and Galley, J. E., eds., Fluids in the subsurface environment: American Association of Petroleum Geologists Memoir 4, p. 66–100.

[11] Green, H., Šegvić, B., Zanoni, G., Omodeo-Salé, S., & Adatte, T. (2020). Evaluation of Shale Source Rocks and Clay Mineral Diagenesis in the Permian Basin, USA: Inferences on Basin Thermal Maturity and Source Rock Potential. *Geosciences*, *10* (10), 381.

[12] Haughton, P., Christopher, D., McCaffrey, W., Simon, B., 2009, Hybrid sediment gravity flow deposits – Classification, origin and significance. Marine and Petroleum Geology. v. 26. 1900-1918. 10.1016/j.marpetgeo.2009.02.012.

[13] Jarvie, D. M., B. L. Claxton, B. Henk, and J. T. Breyer, 2001, Oil and Shale Gas from the Barnett Shale, Ft. Worth Basin, Texas: AAPG National Convention, June 3-6, 2001, Denver, CO, American Association of Petroleum Geologists Bulletin, v. 85/13 (Supplement), p. A100.

[14] Jarvie, D. M., Prose, D., Jarvie, B. M., Drozd, R., & Maende, A. (2017, April). Conventional and unconventional petroleum systems of the delaware basin. In *Proceedings of the AAPG Annual Convention and Exhibition, Houston, TX, USA* (pp. 2-5).

[15] Jones, T. S., 1973, Stratigraphy of the Permian Basin of West Texas: West Texas Geological Society Publication 53-29, p. 63.

[16] Kvale, E. and Rahman, M., 2016, Depositional Facies and Organic Content of Upper Wolfcamp Fm (Permian) Delaware Basin and Implication for Sequences. Unconventional Resources Technology Conference.

[17] Lowe, D. R., 1982, Sediment Gravity Flows: II Depositional Models with Special Reference to the Deposits of High-Density Turbidity Currents. Journal of Sedimentary Research.

[18] Osleger, D. A., & Tinker, S. W. (1999). Three-dimensional architecture of Upper Permian high-frequency sequences, Yates-Capitan shelf margin, Permian Basin, USA.

[19] Parker, A., D. Entzminger, J. Leone, M. Sonnenfeld, and L. Canter, 2014, Lessons Learned from the KCC #503H Woodford Horizontal Well at Keystone South Field.

[20] Winkler County, TX: AAPG 2014 Southwest Section Annual Convention, Midland, Texas, May 11-14, 2014, Search and Discovery Article #20254 (2014).

[21] Pierre, J. P., Andrews, J. R., Young, M. H., Sun, A. Y., & Wolaver, B. D. (2020). Projected Landscape Impacts from Oil and Gas Development Scenarios in the Permian Basin, USA. *Environmental Management*, *66* (3), 348-363.

[22] Tyler, N., Bebout, D. G., Garrett, C. M., Jr., Guevara, E. H., Hocott, C. R., Holtz, M. H., Hovorka, S. D., Kerans, C., Lucia, F. J., Major, R. P., Ruppel, S. C., and Vander Stoep, G. W., 1991, Integrated characterization of Permian Basin reservoirs, University Lands, West Texas: targeting the remaining resource for advanced oil recovery: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 203, 42 p.