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Episodic Growth History of the West Columbia Salt Dome, Brazoria County, Texas, and its Potential Impact on Hydrocarbon Accumulation

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ABSTRACT

Onshore Gulf Coast salt domes offer redevelopment opportunities if new ideas/leads can be developed through a better understanding of the impact of salt dome growth history on hydrocarbon accumulation. The exploration discipline concept (Baie and Gallagher, 2008) provides a rigorous framework for generating the ideas/leads needed to redevelop some piercement-type salt domes. West Columbia Salt Dome was chosen because: (1) it has a 120 year history of exploration and production with hundreds of wells drilled and more than 100 million barrels of oil produced, (2) it is one of ten Texas Gulf Coast salt domes with identified *Heterostegina* reef material (*Het* Lime) present, and (3) the historical distribution of production seems anomalous. Prolific production was from the north, northwest, and southeast segments of the dome, while lesser production came from the east side and no commercial production from the southwest quadrant. By using several of the concepts found in the exploration discipline paper, an initial review of available data revealed that the distribution of the *Het* Lime indicates that early salt tectonism formed a broad northeast-southwest oriented swell during the Oligocene, which led to the erosion of thick, previously deposited Frio and older sandstones and underlying shales. This left a bathymetric high and a significant unconformity at the seafloor, upon which hundreds of feet of *Het* Lime accumulated over an area many times larger than the current expression of the later piercement phase. Thus at West Columbia, and probably at nine other salt domes with *Het* Lime present, salt had at least two distinct and very different periods of movement: salt swell development accompanied by erosion

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and redeposition of sedimentary sections, and later piercement of salt within the initial area of broad uplift as defined by the *Het* Lime distribution. These events each occurred during the likely time of initial generation and migration of hydrocarbons from the middle Wilcox, impacting their resulting distribution.

INTRODUCTION

West Columbia Salt Dome was discovered in 1901 and the first oil production was established in 1904. To date, the field has produced nearly 100 MMBO from lower Miocene sands, while *Marginulina* and Frio production is approaching 80 MMBO. The current structure is classified as a shallow piercement dome with cap rock occurring at 650 feet below the surface and salt penetrated at 768 feet. It is located approximately 50 miles southwest of Houston and about 25 miles from the Gulf of Mexico (Fig. 1). Significantly, the approximate total area of uplift above regional is 75 square miles while the total productive area is only 2.7 square miles. It is one of the most productive domes in Texas (Halbouty, 1979). West Columbia historically lacks commercial production over the top of salt, and but there has been a minor amount of oil production from the cap rock. Most of the production has come from sands adjacent to the dome and buttressed against salt, sands that are trapped under a major unconformity associated with early salt movement, or from simple updip sand pinch outs. The recognition of an "anomaly" in the distribution of hydrocarbon production at West Columbia (Fig. 1) initiated this search for the

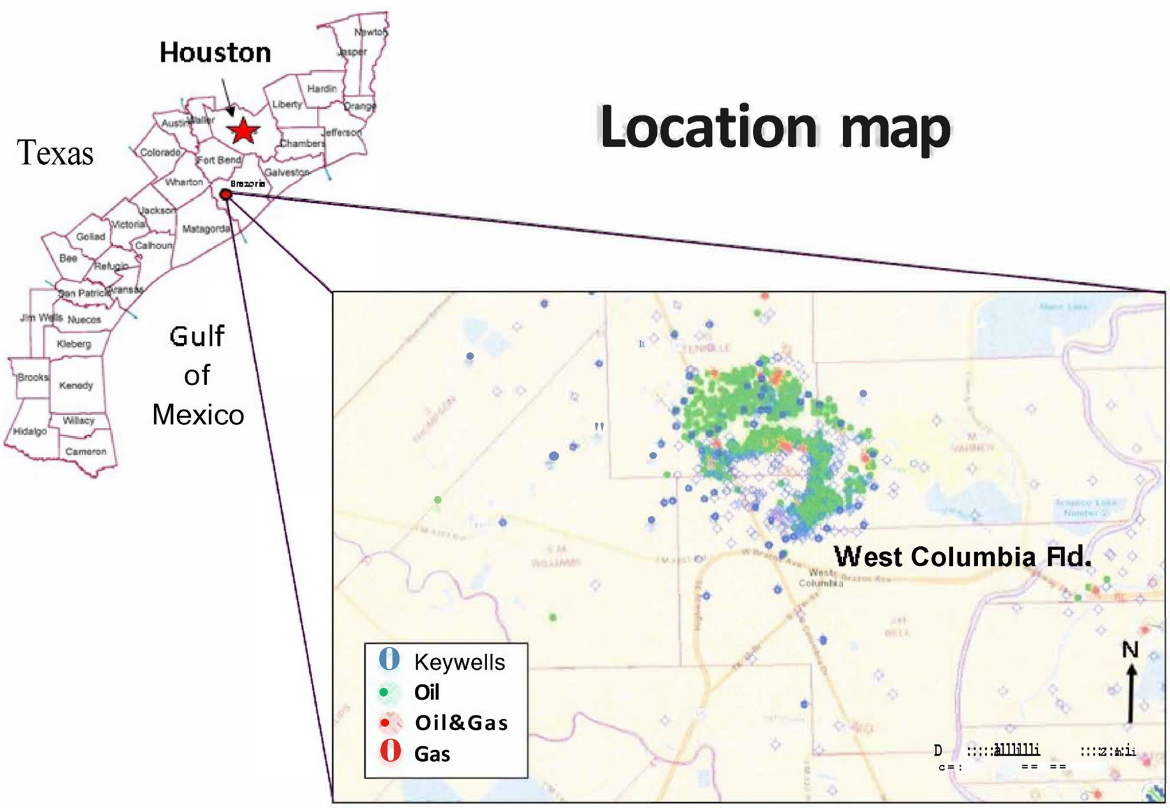

Figure 1. Location of West Columbia Field with key wells (blue circles) and the distribution of Miocene and Frio production (green = oil, solid red = gas and oil, open red = gas).

possible causes. The discipline matrix (Baie and Gallagher, 2008) was used to organize the investigation (Fig. 2) to determine if the southwest quadrant of the field truly has no possibility of commercial production and if other redevelopment opportunities exist. The purpose of this study, then, is to demonstrate how the exploration discipline matrix (Baie, 2008) can also be used in exploitation by geoscientists and engineers initially unfamiliar with an area.

METHODS

Because of West Columbia's 120 year, multiphase history of successful exploration and production, spanning many generations of geoscience thinking, economic and regulatory conditions, and technological advances, large volumes of data are available including much found in pre-1943 literature (Barton, 1921; Carlton, 1929; Deussen, 1924; Ellisor, 1926, and Miller, 1942). Additional data includes more than 200 well logs for which the depths to the base of the basal Miocene, top and base of the *Heterostegina* Lime (*Het* Lime), top of the *Marginulina* sands, and the first and last occurrence of the Frio sands are recorded (Fig. 3). Additionally, hundreds of completion cards for drilled wells in and around West Columbia field were examined at the Texas Bureau of Economic Geology, to confirm individual well locations and to gather other important information; e.g., paleo markers, tests, etc. Although all available publications from 1903 to 1942 were reviewed, no more recent, in-depth studies of West Columbia were found.

Very important (and often overlooked) material for understanding the circumstances and challenges surrounding the early history of exploration and production at West Columbia were found in the Fuel Oil Journal, later renamed the Oil Trade Journal (a monthly scouting report for wells all over the United States). One of our co-authors provided summary information on recent 3D seismic surveys recorded over the field, extending for some distance around West Co-

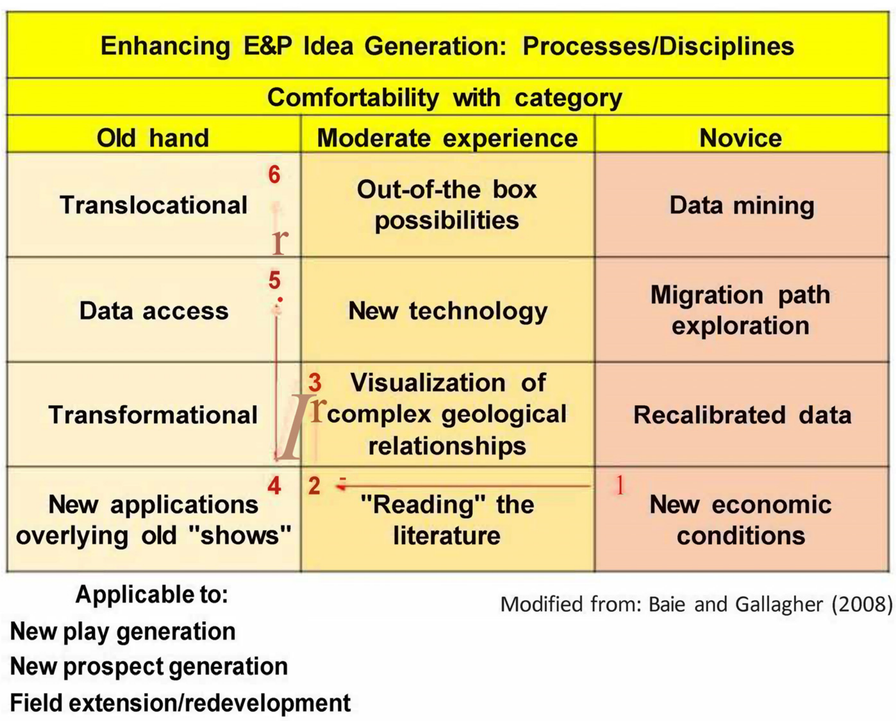

Figure 2. Discipline matrix (Baie and Gallagher, 2008) with each discipline used in this study, numbered in sequence.

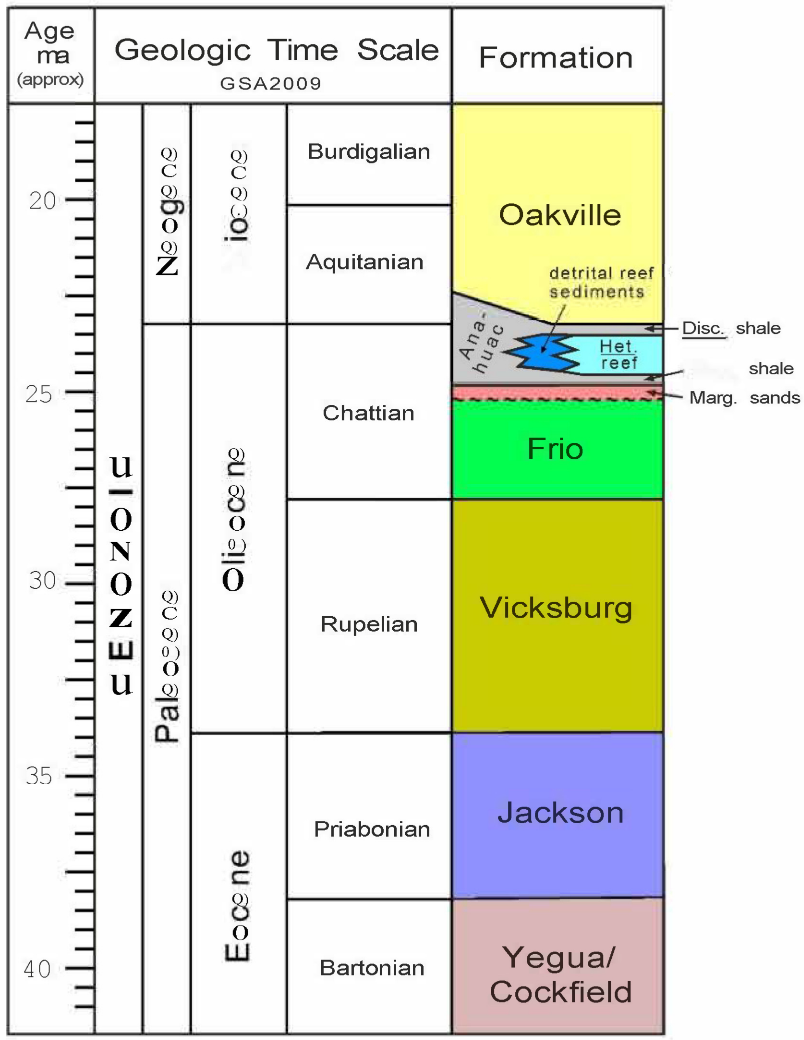

Figure 3. Stratigraphic section of the West Columbia Field area.

lumbia Oil Field, helping us confirm the full, areal extent of the *Het* Lime complex (Fig. 4), but no proprietary seismic data was used herein. Galloway et al. (1982) provided a basis for our understanding the regional sand thicknesses of the Frio, which were impacted later by the episodic growth phases of the West Columbia's salt structure. While several geochemical studies (summarized in Zhou, 2015) have been published for the oils of the Brazoria County area, we have not seen any oil source rock correlation information which could confirm the actual source of the oils trapped in Miocene and Oligocene reservoirs at West Columbia Field. Our new understanding that many paleo "markers" only carry depositional environment information and not always time correlations (L. Tuttle, 2021, personal communication) was key to building the history of salt movement.

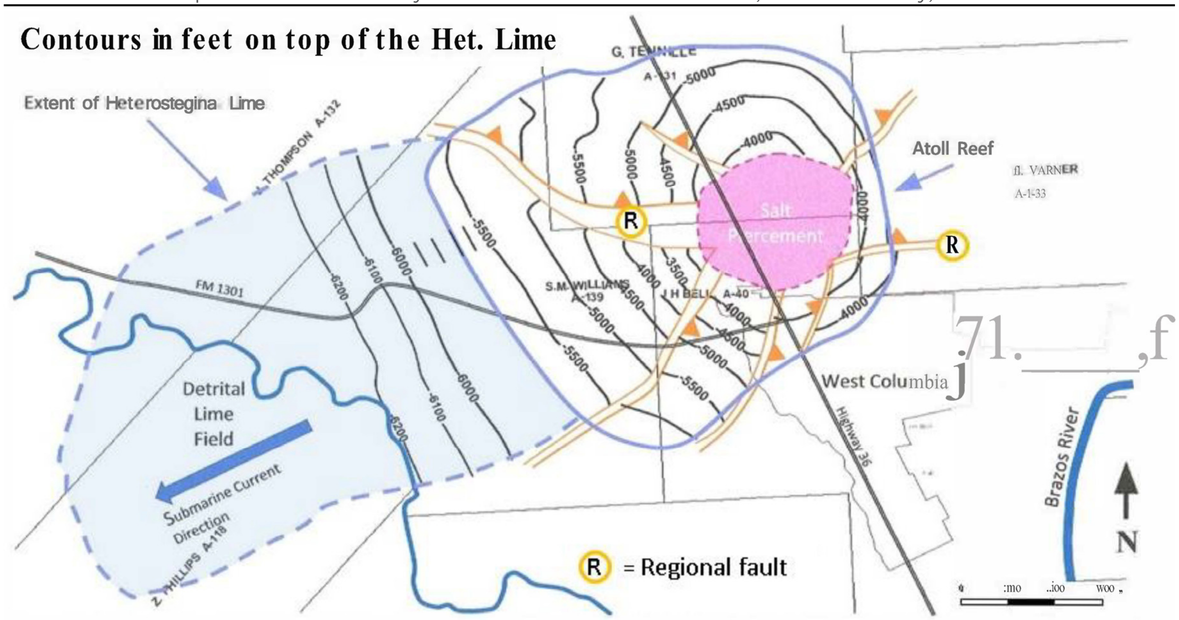

Figure 4. Map of the *Het* Lime in the West Columbia Field area, showing both regional (R) and radial faults and the separation of *Het* Reef and detrital material, based primarily on well control.

RESULTS

The importance of using the discipline matrix (Fig. 2) cannot be overstated. Once the "anomaly" (Fig. 1) was recognized, the process began by "reading the literature" on West Columbia's exploration and production history (1903-1942). This set the stage for understanding the conditions under which the early drilling activities occurred. For example, what production level made an economic well at different times, what did the early explorers have most difficulty with, what was the impact on future activities of the June 22, 1921, hurricane, which destroyed 185 derricks in the field. This history of the early exploration and production activities was then examined under the disciplines titled "visualization of complex relationships" and "new applications over old shows," which includes our modern understanding of the paleontological (L. Tuttle, 2021, personal communication), geochemical (S. Brown, 2021, personal communication; J. Zumberge, 2021, personal communication), and other data. One result of the above processes is that the episodic history of the salt movement at West Columbia is now interpreted to include at least four phases:

(1) The possible presence of a salt swell as indicated by the thinning of the Basal Frio sand isolith (Fig. 5) compared to thicker areas to the east and west (Galloway et al., 1982).
(2) The major sub-basal *Marginulina* unconformity (Fig. 6) which removed thousands of feet of the Frio, Vicksburg, and Jackson formations, and over which the Anahuac Formation was deposited, in a water depth shallow enough for the *Het* Reef to grow to a thickness greater than 400 feet in places near the current salt piercement.
(3) A pre–Basal Miocene A sand unconformity on a horst-like uplift in the southeast quadrant of the current piercement (Miller, 1942), and
(4) The middle Miocene-Pliocene-Pleistocene piercement phase.

A second result is that we now have a more accurate map of the *Het* Lime (Fig. 4) including the distributions of the actual reef material and its related detrital carbonate material, which are recognizable on spontaneous potential and resistivity logs. This separation of two carbonate

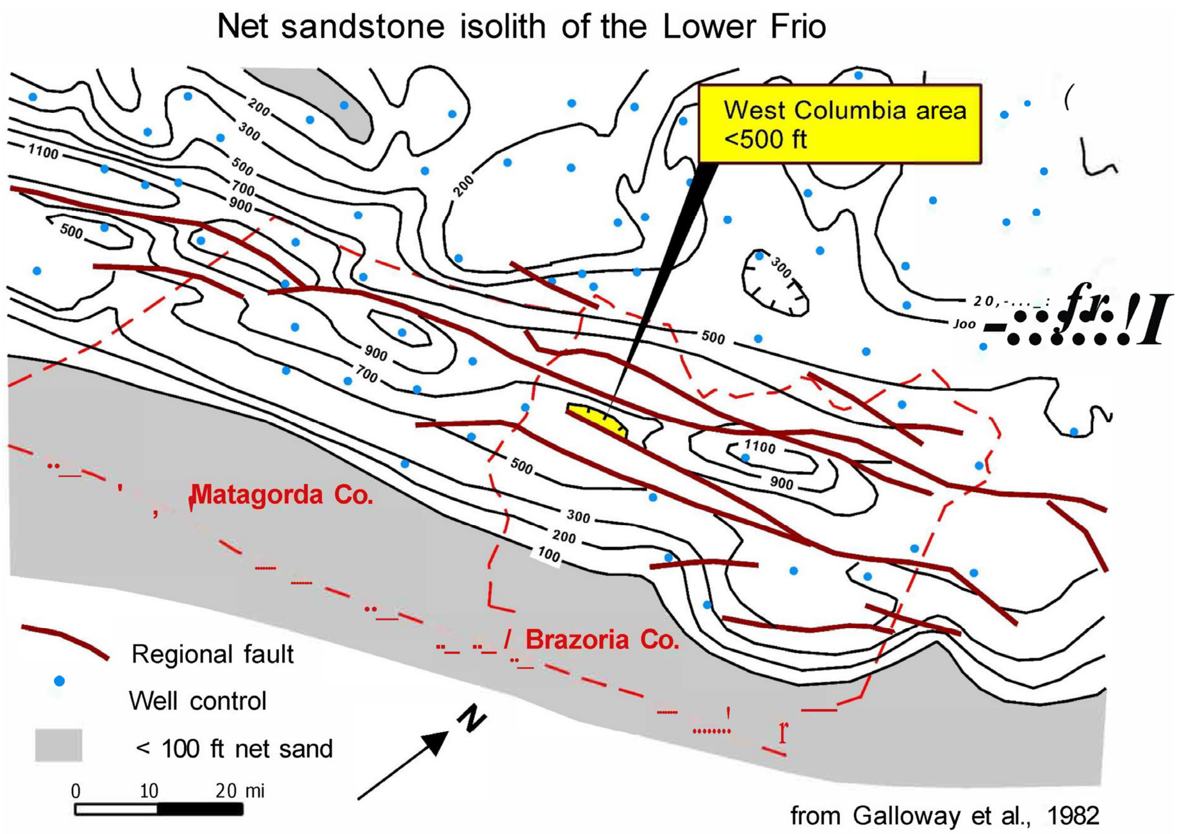

Figure 5. Basal Frio net sand isolith showing an isolith thin in the area of West Columbia Field (Galloway et al., 1982).

material types, identifies the location of the extensive, sub-basal *Marginulina* seafloor high upon which the reef itself grew (Fig. 7), over an area larger than the current, near-surface expression of the piercement salt dome.

A third result is that an understanding of the early history (Fuel Oil Journal) reveals that many wells, which appear on various vintages of maps, were lost to "heaving shale," the Hurricane of 1921, to falling oil prices stemming from both domestic successes and foreign competition, or were junked and abandoned. The same scouting reports show that ten of the early wells drilled in the southwest quadrant had actual, small oil production and/or good "shows,", suggesting that oil migration did reach this portion of the structure, but was deemed non-commercial at that time.

Fourthly, Zhou (2015) integrated several studies near West Columbia (e.g., Guo, 2004) and suggested a hydrocarbon-source age based on the environments of deposition and the maturity of the oils sampled. He concluded that the source for the sampled Frio-reservoired oils "was likely from the middle Wilcox or deeper beds, which entered the oil window 26–15 million years ago, based on modelling. Although this conclusion is not as solid as an oil-source rock correlation would have been, this time frame for the generation and expulsion of Wilcox-sourced oil fits well into West Columbia's salt deformation history.

It was during this time interval that *Het* reef distribution shows the probable extent of the early Miocene structure (Fig. 7). A further hint for a possible source for the West Columbia oil charge is found in Carlton (1929) who noted that the lower Jackson Formation clays in the Humble #1 Lovejoy well were reported to be "dark brown calcareous clay and unctious [oily] clay in

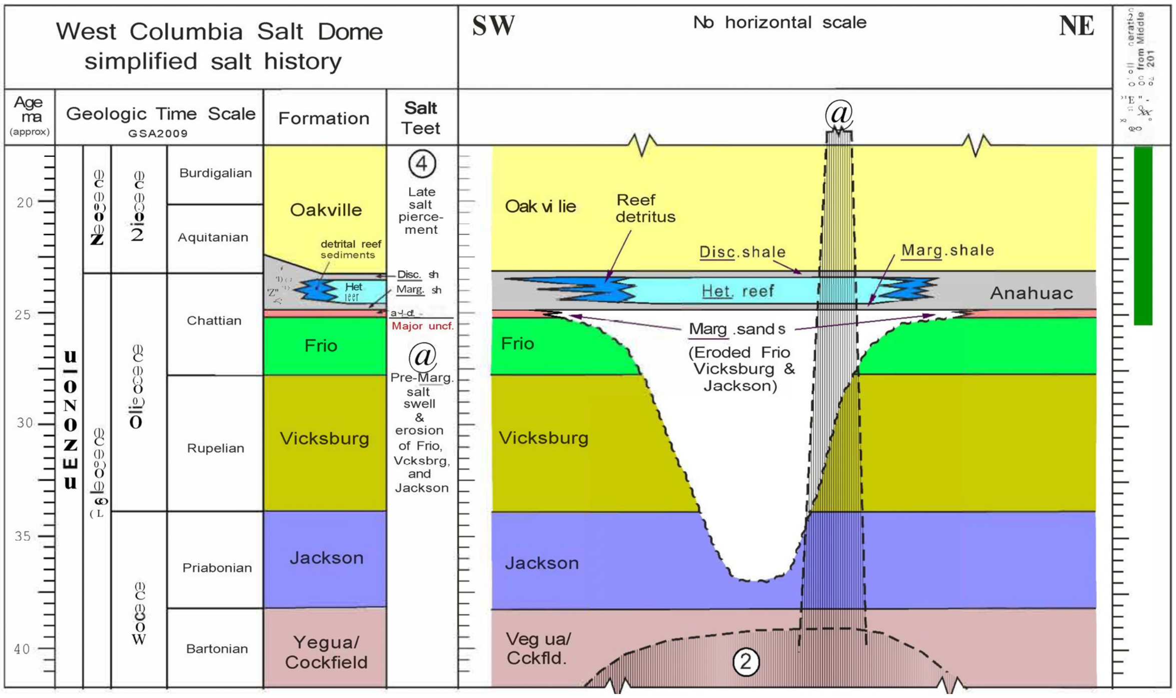

Figure 6. Chronostratigraphic chart of West Columbia Field simplified salt movement history showing early (phase 2) and late (phase 4) salt movements.

places. Unfortunately, no clay/shale samples are currently available for modern source rock or oil-source correlation analyses. We also have not studied the "plumbing" of the West Columbia area to answer this question, although thanks to Sue Ann Operating, we have obtained 6 oil samples from the field. And finally, the later salt diapiric phase was the generator of the radial faulting now observed around West Columbia Dome (Fig. 4). These fault segments play an important role in the distribution of hydrocarbons.

SUMMARY

By confirming the actual locations of the key wells in the West Columbia area, a more accurate base map reveals areas that are not fully evaluated for potential hydrocarbon exploitation, especially in the southwest quadrant of the current piercement salt dome

The four phases of episodic growth history at West Columbia have controlled the distribution of reservoirs and their oil accumulations, such as the Frio sands under the sub-basal *Marginulina* unconformity, the sands in the *Marginulina* shale, which were redeposited from the eroded, upper Frio section containing sand (Fig. 8).

By referring back to the Fuel Oil Journal publications (1911–1924), a contemporaneous understanding of the physical, economic and subsurface conditions under which the exploration and development activities occurred, many of the questions concerning why certain wells were not produced in spite of reported "oil to the surface" and shows were answered.

The source of hydrocarbons at West Columbia Field remains uncertain, but the very large volume of oil barrels per acre/foot and "anomalies" such as the Hogg-Japhet 20 acre lease, which has produced more than 12 million barrels of oil, leave some interesting questions, such as

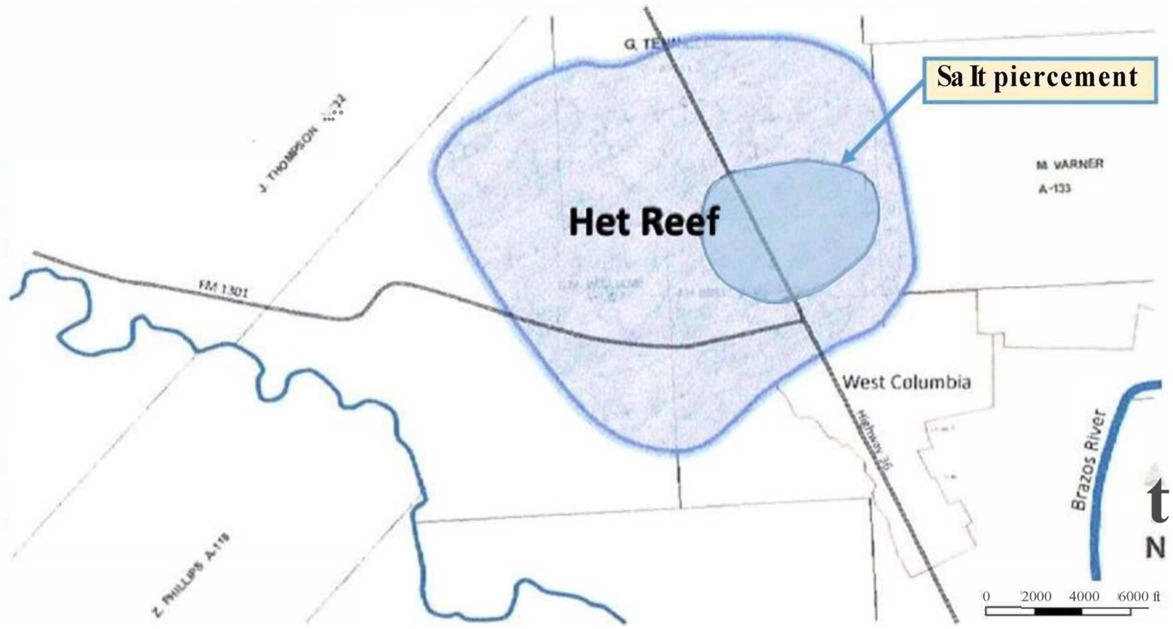

Figure 7. Map of the *Het* Reef distribution representing the Top of the Basal Miocene structure (phase 2: a possible early hydrocarbon trap) with the later piercement phase structure (phase 4) superimposed.

"could there have been more than one source, and timing of migration for the oils found?" which might be answered by applying modern geochemical techniques.

Nine other Texas Gulf Coast salt domes (Fig. 9), with the *Het* reef present (Zachos and Molineux, 2007), offer an opportunity to use the discipline matrix to study their history to determine if additional hydrocarbon potential exists around them. Each of these salt domes share a similar complex structural history with West Columbia, and also a similar set of conditions that existed during their early exploration and production phases.

The discipline matrix provides a formalized process to take an explorationist, development geoscientist, or reservoir engineer on a "journey" toward identifying new opportunities in and around old salt dome fields in the Texas Gulf Coast, and other regions of the United States and the world. This process avoids the irresistible initial focus on 3D seismic data and modern wells and well logs, which often leads to overlooking significant historical data. Our journey was certainly illuminating.

AKNOWLEDGMENTS

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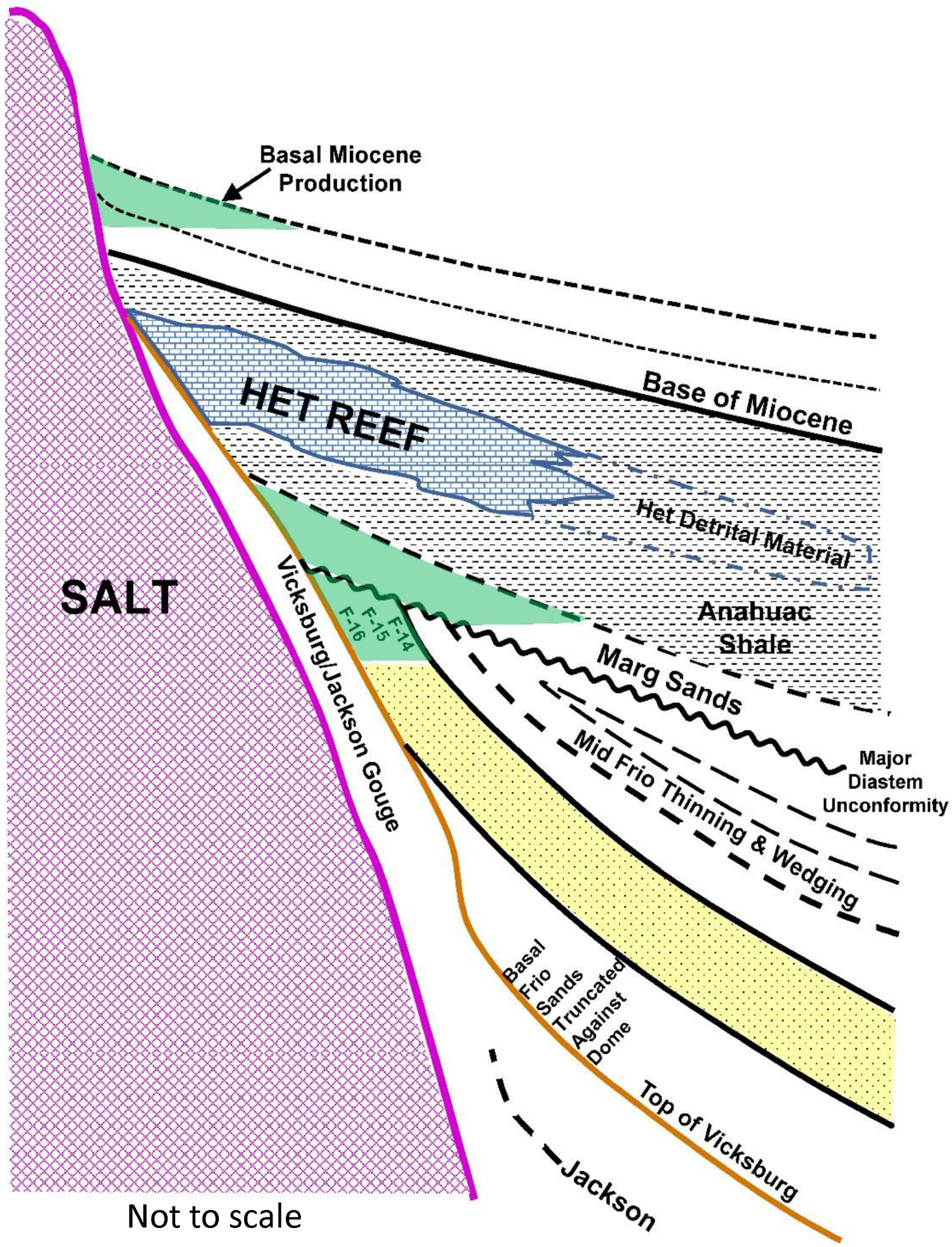

Figure 8. Generalized structural cross-section of present West Columbia piercement salt dome showing the Basal Miocene, *Marginulina* "sands" and Frio hydrocarbon flank traps.

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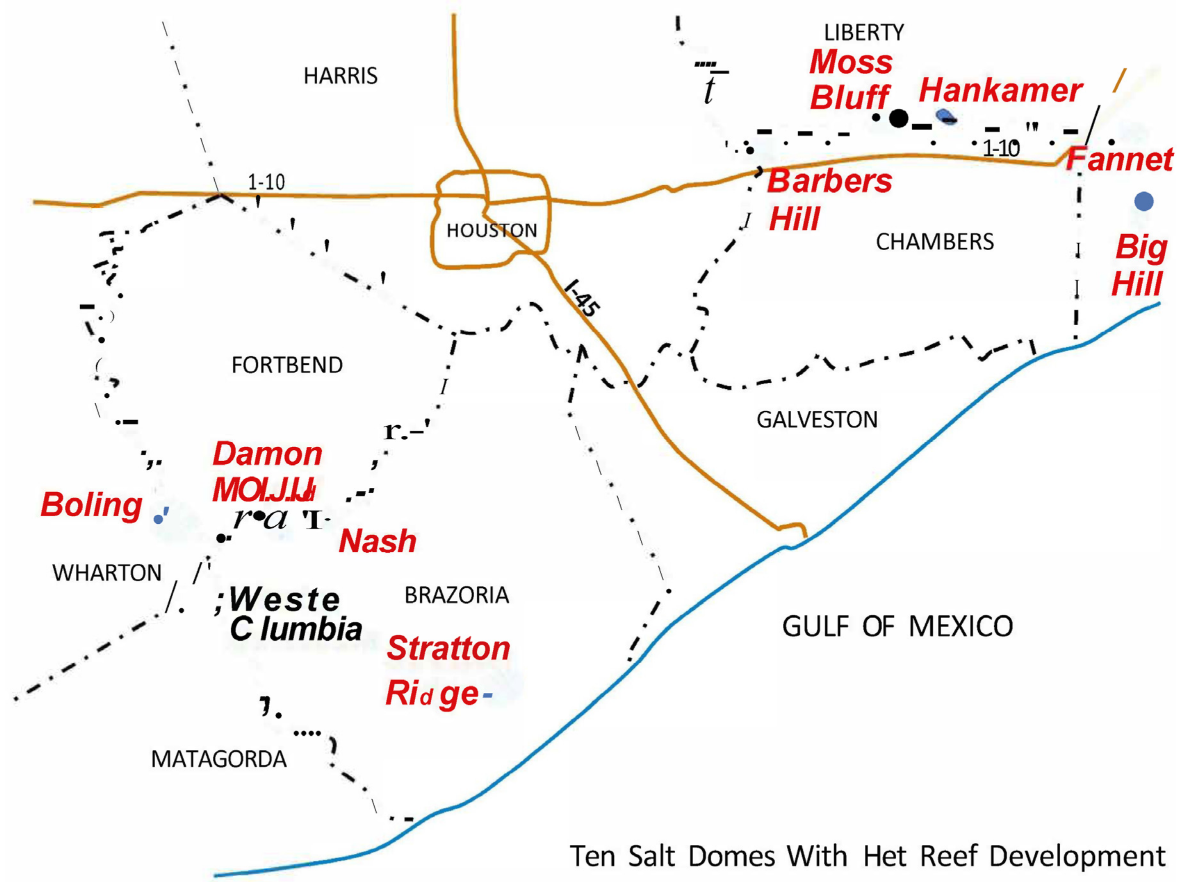

Figure 9. Map showing nine additional Texas Gulf Coast salt domes with recognized *Het* Reef development, indicating a possible West Columbia–like history of multiple phases of salt movement.

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NOTES