LIFE AFTER WATERFLOODING: SACROC UNIT, SCURRY CO., TEXAS

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ABSTRACT

The 2.8 Billion Barrel (Original Oil in Place) SACROC Unit is located in Scurry County, Texas and produces from the Pennsylvanian-aged Cisco and Canyon Formations of the Kelly-Snyder and Diamond M Fields. This Unit has had a colorful history, with discovery shortly after World War II, nearly half a century of waterflooding, three decades of tertiary development, and a wide variety of operators and philosophies.

Since the time of SACROC's early CO_2 efforts, local experience and industry practices have contributed greatly to our knowledge of CO_2 flooding in general. Today, Kinder Morgan CO_2 Co., L.P. (KMCO_2) is CO_2 flooding an area in the central portion of the Unit (using new techniques and philosophies) with great success. Unit production is now at a nine-year high, with average monthly production exceeding 13,000 BOPD.

Tertiary recovery efforts are very expensive and require a great deal of reservoir understanding to reduce risk and increase efficiency. So, KMCO_2 has initiated a dual-pronged approach to the continued development of SACROC Unit, with flooding efforts currently focused on "less risky" areas, and with more intense geologic study focused on understanding the more complex, higher risk, and greater potential areas. However, even in the low risk areas this reservoir is extremely complex and data is sometimes scarce, misleading, of low quality, or ambiguous. Relatively few modern logs exist, and unique situations can cause confusion about log responses. Correlations are difficult in certain areas due to complex geometries associated with mound buildups, erosional contacts, and local depositional geometry. Because the reservoir's internal architecture is so complex, strange fluid flow responses sometimes occur in areas that appear rather simple at first glance.

That said, the Unit can still be divided into northern, central, and south-western regions for general comparisons. A thick, north-south trending platform, with karst features that increase in intensity to the north and higher in the section, dominates the northern area. The central region is a broad, gently arching plain broken by steep-sided pinnacles, gentler mounds, intermittent sinuous lows, and localized depressions. The southwestern area is the most structurally complex region of the Unit, with a series of faults and channels that contribute to small, isolated compartments.

Success at SACROC can be credited to the geology and hydrodynamics of the reservoir, the technical feasiblity of tertiary recovery with CO_2, and the efforts of a multi-disciplinary team providing input from field, reservoir, and corporate levels.

INTRODUCTION

The productive, mostly-continuous "Scurry Reef Trend" (on the eastern side of the Horseshoe Atoll) includes the Strawn Formation and the Canyon Reef Pool, which is sometimes referred to in the literature as the Canyon (A) through Canyon (F) intervals (Stafford, 1957). This long and narrow trend extends approximately 45 miles, covering portions of Kent, Scurry, Borden, and Howard Counties, Texas. The SACROC Unit is a 78-mi^2 portion of the Canyon interval of this trend and occupies most of Kelly-Snyder Field and portions of Diamond "M" Field **(Figure 1).** SACROC Unit gross interval porosity averages around 7.6%, with 19 millidarcies (mD) of permeability. Using a net pay cut off of 3% yields a net average porosity of 10% and permeability of 30 mD. Original Oil in Place (OOIP) studies estimate 2.8 billion barrels in place (Dicharry, 1973; Wingate, 1996), with cumulative production on the order of 1.2 billion barrels. At its modem-day structural high point (see **Figure 2),** the top of the pay interval rises to –3740' subsea (ss), and the original water-free oil production contact (OWC) rests at 4500' ss. Originally, 81 separate operators developed what is now the SACROC Unit (Bayat, et al., 1996), and represent more than 2500 royalty interest owners (Chevron, 1971). The number of working interest owners is down dramatically, from more than 300 in 1971 to just over 170 as a result of buyouts and mergers.

GEOLOGY

The SACROC Unit is developed in Pennsylvanian aged carbonates of the Cisco and Canyon formations (Myers, et al., 1956; Stafford, 1955; Stafford, 1957; Vest 1970, Waite 1993, Wingate, 1996), but the term "Canyon Reef" seems to have caught on as a general description of the interval. The majority of the productive interval is composed of limestone, but minor amounts of anhydrite, sand, chert, and shale are present locally. Wolfcamp shales provide a seal above the carbonate and around the flanks. Towards the East and West boundaries of SACROC Unit, the Cisco / Canyon productive carbonate interval thins and drops below the regional oil / water contact. Carbonate buildups in this region of the Atoll display extremely complex geometries and steep sides, but seem to frequently initiate on or near antecedent highs in one or more underlying zones.

During Pennsylvanian time, relative sea level rise and fall occurred quickly, putting carbonate organisms in a "keep up" mode, resulting in high vertical carbonate accretion rates and providing a wide variety of depositional environments and facies (Mazzullo, 1997; Walker et al., 1995; Walker et al., 1991; Schatzinger, 1988). In SACROC, as in other portions of the Atoll, this setting lead to thick, steep-sided rock intervals with plenty of opportunities for erosion and diagenesis. These processes express themselves locally as detrital wedges, exposure surfaces, and karst features. The combination of depositional complexity and later modification has resulted in a region where changes within a zone can be very abrupt, even in relatively flat areas, and where the relationship between flow units can become very nebulous. Evidence for the level of complexity can be seen in areas where recent wells were drilled in close proximity to older wells. In some cases, wells spaced less than 300' apart exhibit extreme differences in vertical porosity distribution **(Figure 3).**

The carbonate complex that makes up the productive portion of SACROC can be divided into three broad geographic regions **(Figure 2).** The northern third of the unit contains the thickest interval (in excess of 750' in some places) and has several thick, laterally continuous zones, especially toward the OWC and the base of the Canyon interval. The northern portions of this area exhibit a more complex geometry (possible compartmentalization by faulting and / or karsting) and display strong evidence from production data of vertical migration pathways that cut across low permeability barriers. Carbonate debrie flows lend further complexity on the western and far eastern margins of this portion of the Unit. This high risk, high reward area is not currently under active CO_2 development. Instead, it is the primary focus area for current geologic research.

The center half of the Unit is characterized by a tri-modal morphology. The primary feature is a broad, gently arching plain. The plain is broken by growth and erosional overprints. The positive features are steep-sided pinnacles and gentler mounds. Negative features are composed of channel-like intermittent sinuous lows, and localized depressions. Perhaps the most visually impressive single feature of the central area is a 100-Acre (– 2400' diameter) pinnacle that towers 420' above a thin channel.

The southwestern portion (remainder) of the Unit is a complex series of compartments separated from the rest of the Unit by a broad, low channel that is approximately two miles wide and one hundred feet deep. This area, too, is very complex, exhibiting strange production and injection responses and odd pressure distributions. It will also need additional work if it is to be properly understood. The most striking feature of this portion of the Unit is a series of northeast trending structural features (both highs and lows) which are cross-cut (at 45" to 65" angles) by northwest trending structural lows.

HISTORY

Primary Production

The late 1940's and early 1950's defined the greatest time of development for the future SACROC area. Though it was not the first well to penetrate the Cisco / Canyon Limes in the area, Standard Oil of Texas discovered the pay interval with their Mrs. Jessie W. Brown Lease 2 Well # 1, which is now known as the SACROC Unit # 17A-1 (Vest, 1966). In late 1948, this well penetrated one of the thickest portions of the limestone complex, with more than 700 feet of limestone above the OWC. By the end of 1948, the total Canyon well count was four. The "Reef" sections of fields now called Cogdell, Diamond "M," and Kelly-Snyder began to be developed in earnest soon thereafter. Local lore holds that, at one point, 200 rigs were drilling at the same time, and that all of them were within visual range of Snyder, Texas. It is said that residents could read their newspapers on the back porch at midnight by the light of the flares. By the end of 1949, 311 wells were producing from the Canyon interval. In the next few years, total well count jumped to 1616, 1910, and 2010. Therefore, in the single year of 1950, there were 1305 wells drilled. At that time, the average time to drill and complete a Canyon well was on the order of six weeks. That calculates out to an average of 151 rigs. Add to that the 54 shallower wells (in multiple zones) and 18 deeper wells completed throughout the field that same year, and the scale of the boom in local development becomes clear. This was also the year that the area caught the industry's eye through publications in trade and scientific journals (Stafford, 1957).

The development philosophy employed by most of the early operators consisted primarily of "protect your reserves," otherwise known as the "right of capture" in legal terms. Therefore, many leases had wells snuggled up to the comers, which left large open areas in the middle of the lease. Due to the diverse ownership present in some areas, certain operators were able to drill on individual leases as small as 2.5 Acres, resulting in local well spacing as small as 280 feet.

However, all was not well in "Boomtown." Even while new drilling continued, it became obvious that primary depletion could not economically sustain operations. Over the three-field area, annual production dropped by two million barrels by the end of 1952, just two years after the initiation of widespread development, even though well count increased by 100 (Stafford, 1957). Pressures in the future SACROC area dropped from 3122 pounds per square inch (psi) at discovery to 1650 psi, 150 psi below bubblepoint, by 1952, indicating that only 18% to 24% of the Original Oil In Place (OOIP) would be recovered (Massey and Cramer, 1972; Dicharry, et al, 1973, Byat, et al., 1996).

Secondary Efforts

Producers in the central portion of the Scurry Reef Trend, in what is now northern Diamond "M" Field and all of Kelly-Snyder Field, decided to pool resources in order to optimize field management. They formed the Scurry Area Canyon Reef Operator's Committee (SACROC), which made recom-mendations on Unit boundaries, working and royalty interest participation calculations, and drafted Unit agreements. The Unit was divided into three segments with separate operators, each of which reported to an Advisory Committee and the Unit Manager. Originally, the regions were labeled from North to South, as SACROC Unit (Segment) #1, #2, and #3, and were to be operated by Standard Oil of Texas, Magnolia Petroleum, and Pan American Production, respectively (U.O.A., 1952). However, Sun Oil Company replaced Pan American as SACROC #3 operator prior to Texas Railroad Commission (RRC) approval of Unitization (RRC, 1953). This unique naming convention later caused confusion resulting in data management problems when a single operator controlled the entire unit and pooled all well records into a single facility. The first whole-unit operator was Standard Oil of Texas (later known as Chevron) in 1962. Pennzoil (later known as PennzEnergy) took over operations in 1990. Devon Energy became operator for a brief period in 1999 before selling the property to KMCO, in 2000).

The SACROC Unit Royalty Unitization and Unit Operation Agreements became effective March 1, 1953, and secondary recovery efforts began soon after, with water injection on-line by September, 1954. The plan was to increase the reservoir pressure back above the bubble-point and push oil from the center of the Unit toward the eastern and western boundaries. Eventually, it was thought, entire areas near the center would start watering out, and the next row of wells to the east and/or west of Centerline could be converted to injection, pushing oil further and further outward, towards the next row of producers. The initial scheme called for a 53-well line of water injectors down the spine or "center-line'' of the Unit. More wells were soon added to protect the extreme northeast and extreme southwest Unit boundaries, bringing the total to 72 active injectors **(Figure 4).** This pattern was maintained throughout the entire life of the waterflood proper (Smith, 1971; Massey and Cramer, 1972; Dicharry, et al., 1973; Bayat, et al., 1996).

The results of the initial waterflood philosophy were mixed. As might be expected from the geometry, the actual results of the pressure modification efforts resulted in high reservoir pressures (above bubblepoint by 1970) in the center of the Unit and low pressures (below bubblepoint) towards the eastern and western margins (Dicharry et al., 1973). Successful recompletions of old dry holes and new drilling development around the edges of the SACROC Unit in the late 1950's implies that the waterflooding efforts of the mid-1950's were able to push oil towards the edges of the Unit (and likely beyond) in spite of the fact that pressure toward the edges could not be brought up above bubblepoint. It also implies that the centerline injectors were moving fluid faster than producers could remove it, at least under the legislated allowable constraints in place at the time, and with the physical flowing / pumping capacity available.

Modifications to the centerline pattern began in 1970, when "watered out" wells adjacent to the injection line (some of which had been shut-in for some time) were also converted to injection, partially in an effort to prepare the Unit for what we now know as tertiary recovery efforts. In preparation for some sort of tertiary effort, the SACROC Engineering Committee investigated various enhanced oil recovery technologies in a 1968 report and found that the most viable option would be the use of CO, under specified reservoir conditions (Dicharry et al., 1973). The conversions and Allowable increases associated with tertiary efforts lead to a tremendous waterflood response. Recent infill drilling efforts, however, have found some areas that appear to have been essentially by-passed by all previous secondary operations.

CO_2 Processes

There are two basic approaches to using CO_2 as an enhanced oil recovery fluid: miscible and immiscible. A miscible fluid is one that will mix with another fluid under given temperature and pressure conditions. So, in a hydrodynamic setting, two miscible fluids will flow together as a single fluid. In an oil reservoir, pressure becomes the key variable. Reservoir temperature is dominated by local heat flow conditions and physical rock properties, so induced changes by man take considerable amounts of time. Pressure, however, is at least influenced (and sometimes actually controlled) by the production and injection history and current operations in the field. Miscible CO_2 flood operations, then, attempt to balance reservoir pressure, given an existing temperature, so that liquid-phase CO_2 will readily mix with oil in the reservoir. Temperature and pressure, however, are not the only controls on miscibility. The specific composition of reservoir oil is slightly different for various fields, and the minimum pressure at which CO_2 and oil will mix, called Minimum Miscibility Pressure (MMP), changes for oils of different composition, even for similar temperature and pressure conditions. Therefore, MMP must be experimentally derived for every new field. The key advantage to CO_2 flooding above MMP is that CO_2 is very efficient at mobilizing oil. An immiscible CO_2 flood, on the other hand, is one in which the CO_2 does not mix with the oil in the reservoir, and will typically reside in the reservoir as a gas. Though much less effective than a miscible flood, CO_2 gas flooding possesses some economic advantages over other gas floods because light-end hydrocarbons are vaporized from the residual waterflood oil, resulting in a "sweeter" phase. Slider (1983) gives a more detailed description of the miscible process and White (1971) discusses both processes.

Early Tertiary Efforts

In 1969, the SACROC Unit went before the RRC to request an Order allowing for the injection of CO_2 into the reservoir and CO_2 injection commenced early in 1972. The target areas were composed of those patterns that had not seen water breakthrough. A slug of water was to be injected in each planned CO_2 injector, prior to tertiary efforts. This, it was thought, would bring the local pressures up above MMP. Ultimate total CO_2 volumes equal to 20% of the Hydrocarbon Pore Volume (HCPV) of each pattern were scheduled. Chosen well patterns were designed to be injection-centered nine-spots of approximately 160 acres each (Smith, 1971; Massey and Cramer, 1972; Dicharry, 1973).

Hindsight and modern knowledge of CO_2 operations reveal several things about the initial design and or operational implementation that could have been improved. Due to historical development practices (see above), many of the planned injection wells were not in regularly spaced grids, so some patterns were larger than the planned 160 Acres. In practice, only lower performance wells were actually converted to CO_2 injection, leaving a haphazard array of injectors and producers. It was not uncommon for wells to inject (primarily water) over parting pressures in an effort to locally raise reservoir pressures above bubblepoint and the empirically-derived SACROC Oil MMP of - 1800 psi. Furthermore, CO_2 patterns were typically not adequately contained. In many cases, sufficient pressure support was not maintained after injection start-up or was never achieved locally prior to first injection (Bayat, 1996). Due to operational considerations, supply, and I or economic considerations, CO_2 volumes were often curtailed soon after initiation, or in some cases injection was intermittent as volumes became available. Finally, in some cases, injectors and producers were not completed in equivalent zones. These situations allowed the CO_2 bank at various times or in certain flood patterns to: 1) migrate out of the intended pattern, 2) communicate with only one or two wells in the pattern, 3) convert into an immiscible (gas) phase, 4) bypass large portions of the reservoir (vertically and lor laterally) by following induced or natural high relative permeability pathways (breakthrough), 5) fail to build up a miscible bank (or have the miscible bank disperse before reaching offset producers), and lor 6) fail to contact some portion of the oil column. In general, no clear cut CO_2 response was seen in the Unit until the mid-1990s, when Pennzoil changed many of the flooding parameters.

CURRENT OPERATIONS

A basic philosophy difference between the early SACROC CO_2 flood and current concepts exists. While earlier efforts were looking for areas of unswept waterflood oil, the new concentration is upon areas with good waterflood results. Current development efforts are focused on the central portion of the Unit, where waterflood response was excellent. The target is now residual-to-waterflood oil. This concept can be summarized as: "Oil is where oil was" or "a good waterflood will make a good CO_2 flood." There are times, of course, where pure philosophy must give way to the realities of the physical and fiscal world. Again, the primary restriction is pressure. It must be high enough to exceed MMP, but not so high that it takes excessive (expensive) volumes at surface conditions to equal reservoir volumes at bottom hole conditions.

In practice, there are three issues (aside from oil price) that control the economic success of a CO_2 flood: a) hydrocarbon target size, b) quick throughput, and c) sweep efficiency. Two of these (throughput and efficiency), are non-compatible. In other words, due to the up-front expense of facility work, CO_2 purchases, equipment upgrades, and the time value of money, the faster the oil comes back, the better. But, quick response often means that only the flow unit with the highest relative permeability has responded. Once this zone experiences breakthrough to a single offset producer, a sort of hysteresis effect is seen. The permeability relative to CO_2 becomes much higher in this one zone and in this one direction. The other flow units no longer receive pressure support, resulting in stranded CO_2 / oil banks that soon begin to dissipate. As the single responding zone cycles CO_2, there comes a point when very little new hydrocarbons are being mobilized because the rock along the preferential pathway has been swept clean, leaving very little residual oil. Also, the offset producer may have to be shut in due to problems such as wellhead freezing when the CO_2 converts into a gas phase and expands in the well-bore. So, fast response often means that large volumes of oil are left behind. On the other extreme, since CO_2 is so efficient at mobilizing the oil it contacts, it would be ideal to induce cylindrical flood-fronts that progress equally in all zones and in all directions. Obviously, this is not likely to happen, given current technology. It would require high resolution (vertical and lateral) monitoring of the flood front, knowledge of the spatial locations and magnitudes of permeability changes between injectors and producers (within individual flow units), the ability to control pressures (on the injection and production sides) on a flow-unit scale, and the ability to control injection volumes on a flow-unit scale. Even if it were possible to control the flood in such detail, an economic disadvantage would still exist. The lowest permeability flow-unit would control the timing of oil production response. There would also still be the problem of overall pattern geometry, and how to fit cylindrical flood fronts and cylindrical pressure sinks into a rectangular-shaped well grid.

The current design of the SACROC CO_2 flood has attempted to incorporate as many of the historical, philosophical, and operational considerations as possible, as well as lessons learned from other CO_2 floods around the Permian Basin. Perhaps the most unnerving feature of CO_2 flooding at SACROC is the relationship between water saturation and completion intervals. It seems that calculated formation water saturations are not critical for the CO_2 flood area at SACROC. In fact, due to the extensive waterflood history in our current operational area, some production wells must move thousands of barrels of water daily before an oil bank can be produced. The reason that local water saturations are not critical can be traced to two factors. One is the ability of CO_2 to mobilize oil in zones that contain high water saturations (where oil saturations are at residual-to-waterflood levels). The second reason is that the SACROC unit has a thick calculated transition zone and a thin net porosity interval below the original free OWC. In other words, there is very little flow capacity below the free OWC, and zones above the free OWC remain viable targets when past operational practices are considered. So, all potential pay zones (zones with porosity greater than 6%) are opened in all wells. The exception to the rule is a zone that exhibits evidence of high gas saturations. The Scurry Reef Trend and all other productive horizons in the Kelly-Snyder field have no natural gas caps or gas-rich zones (Stafford, 1957). So, unless the specific pattern had operated below the current bubblepoint of the system, any gas zones in a SACROC well must have come from injection operations. Since such zones have probably already been swept clean, they are not typically completed.

Historically, regular patterns were not universally implemented at SACROC. In fact, much of the area presently being CO_2 flooded **(Figure 2)** has had no pattern development at all, due to its proximity to the original centerline injection wells. Well conversion and new drilling efforts are allowing for closer well spacing and smaller patterns. These new injector-centered 5-spots, however, are still frequently a little larger than 40-acres and many are somewhat irregular in geometry, due to limitations imposed by the original well positions. In addition to the pattern geometry itself, it is now recognized that the entire project area must be contained. Volumetric (mass balance) analysis indicates that most of the historically injected CO_2 was lost out of the intended patterns (which were actually under immiscible conditions at the time), and the CO_2 was therefore not available for enhanced oil recovery. Even in fairly recent operations, estimates indicate that about half the injected CO_2 was lost outside the intended target acreage. Therefore, additional conversions and new drills are being implemented in an effort to contain the CO_2 within the project area. Production wells are now activated outside of the most external CO_2 injectors, and those producers, in turn, are surrounded by a row of "water curtain wells" that define the external borders of the entire project area. The water curtain discourages fluid migration outside of the project area and provides perimeter pressure support for the targeted acreage.

In fact, pressure maintenance is another key feature to current operations. The SACROC Unit now tries to ensure that pressure inside a new area is above the MMP prior to the startup of CO_2 injection. If pressures are not high enough, water injection operations (below the fracture gradient) are initiated in advance.

CO_2 injection volume schedules have changed dramatically since the 1968 study. The current injection scheme calls for an ultimate CO_2 volume of as much as 70% HCPV to be injected for each pattern. Also, the volume is no longer injected as one or two continuous slugs (Thompson, et al., 1971; Massey and Cramer, 1972; Dicharry et al., 1973). Instead, a true multi-phase Water Alternating with Gas (WAG) scheme is used. In a modem WAG scenario, the injection fluid alternates between CO_2 and water. Specific volumes and timing are determined on a pattern-by-pattern basis, and depend on production / injection behavior. The primary function of a WAG scheme is multifold. It has the advantage of slowing down the CO_2 flood front to delay breakthrough, more easily maintaining reservoir pressure, reducing the up-front costs associated with injectant purchases, providing some control to operations associated with surface gas handling processes, and improving recovery efficiency.

Attempts at controlling breakthrough through continuing fluid analysis at the wellhead and down hole are utilized whenever possible. Gas breakthrough is used as a proxy for vertical efficiency on a per-zone basis. Gas production is monitored with the frequent use of production log profiles, which are flagged by changes in GOR or gas composition in the produced stream. Profile modifications are sometimes necessary when gas production becomes too high in a zone(s). Currently, the most successful options available are squeeze jobs (cement or other materials) and permanent mechanical isolation of the offending zone in the offending production well, and / or "wetting" the WAG (lengthening the water cycle and reducing the CO_2 cycle) in the offending injection well.

Another approach that helps KMCO, as a new operator is the use of the waterflood analogy. Successful waterflood operations generally reside in areas of high OOIP and good throughput. Since both are important to CO_2 development, these are the areas where CO_2 operations should be successful, too. In fact, the most successful CO_2 flooding to date has taken place along portions of the old waterflood centerline, where water has been continuously injected for almost 50 years. Current operations, concentrated in the middle portion of the old centerline water injection area **(Figure 4),** now produce about 8000 Barrels of Oil per Day (BOPD). Total unit-wide well count is now above 1700, with ~ 378 wells presently active as either producers or injectors. Plans are in place to expand the CO_2 flood area as more CO_2 becomes available. At SACROC, it typically takes about nine months to see oil response from offset CO_2 injection. Therefore, it is important (from a time-value of money aspect) to see production response (and cash flow streams) as soon as possible. Use of the waterflood analogy allows for an early cash flow stream without excessive risk. The internal structure and flow unit pathways in these areas may not be completely understood, but by investigating the area's waterflood response, a tertiary response can be calculated and the economics evaluated. Furthermore, by placing low risk (well behaved) areas on injection early, more time becomes available to focus geologic efforts and flow unit pathway identification on riskier, more complex areas, which may take longer than nine months to see response, and which may take considerable amounts of time to properly prepare for CO_2.

CONCLUSIONS

The SACROC Unit, a Cisco / Canyon Formation carbonate located on the eastern flank of the Horseshoe Atoll, saw primary development in the late 1940's and early 1950's. Since that time, SACROC has undergone extensive secondary operations, with good results. Early tertiary efforts, designed to utilizing a miscible CO_2 flood approach, began in 1972, and have had mixed results. By changing some of the operational and philosophical approaches to the field, KMCO₂ has revitalized a portion of this old unit. The key changes that have been initiated are: 1) focusing efforts on areas with high OOIP, 2) targeting oil that is residual to waterflood, 3) closely controlling reservoir pressures, 4) using smaller (~ 40-Acre) patterns, 5) avoiding (where possible) areas with high relative permeability to CO_2, 6) fully containing the CO_2 project area, and 7) utilizing a waterflood analogy to identify and target lower risk, quicker return on investment area's for early development. The new development to-date has resulted in approximately 8000 BOPD of incremental production.

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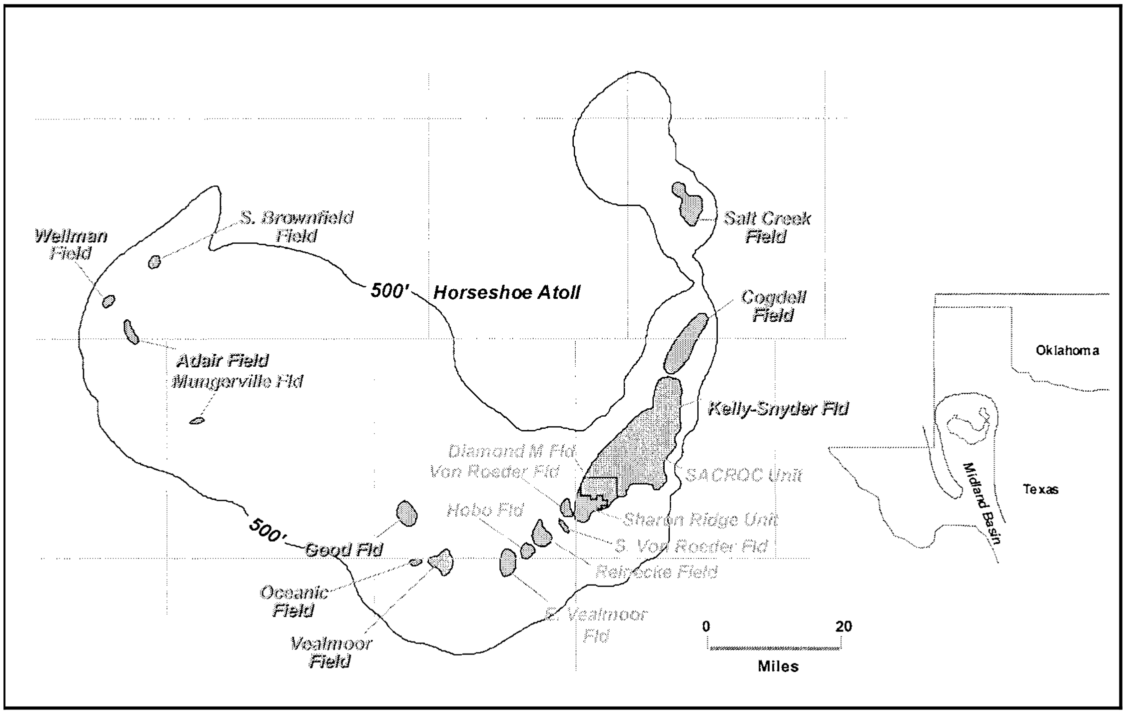

Figure 1- The Kelly-Snyder and Diamond "M" Fields are part of an extensive "Scurry Reef" productive trend on the eastern side of the Pennsylvanian Horseshoe Atoll. The Atoll, located in the northern portion of the Midland Basin, is predominantly constructed from Strawn, Canyon, and Cisco carbonates. The uppermost carbonates in the series are sealed above by shales and thin towards the flanks of the Atoll.
(Figure modified from Vest, 1970)

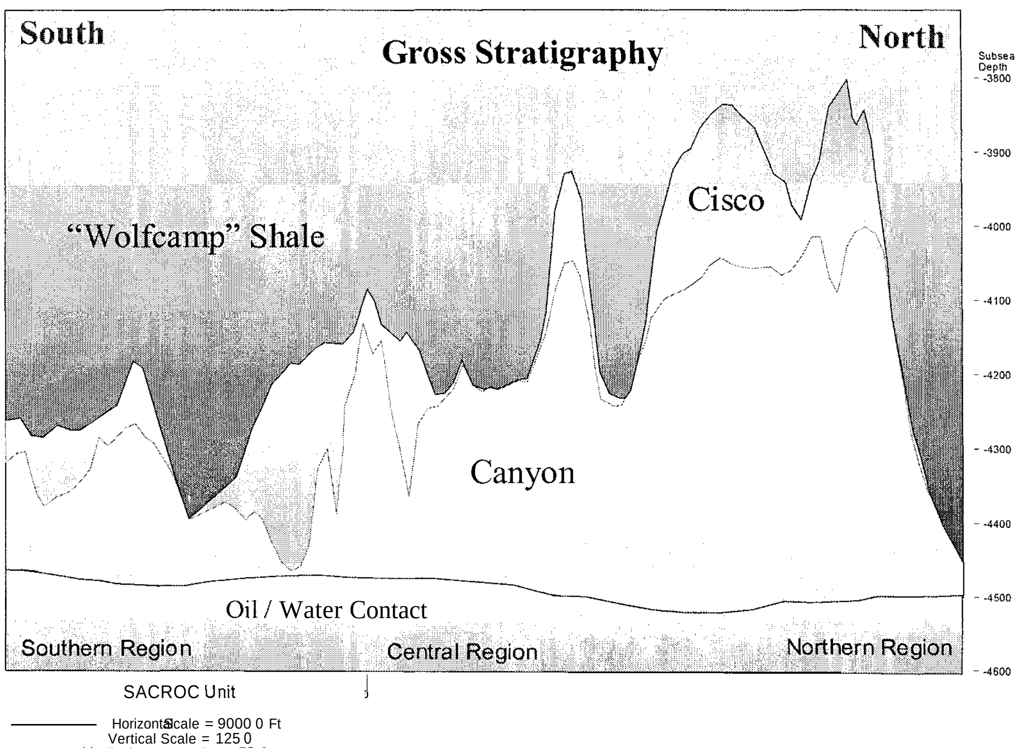

Figure 2 - General Lithologic Setting of SACROC Unit
Total Length of Cross-Section is 16.25 miles

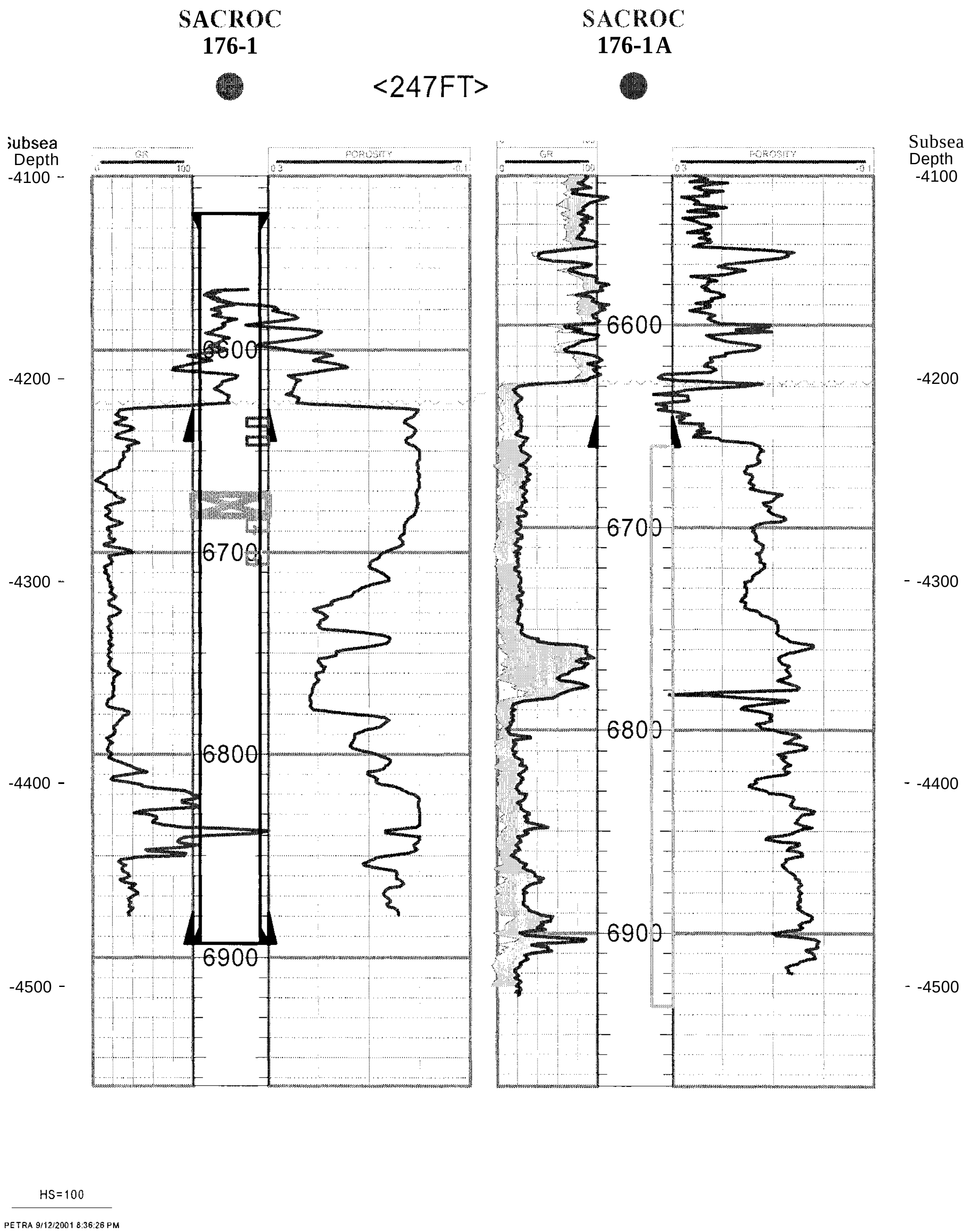

Figure 3 - Plugged well SACROC Unit # 176-1 (left) and its replacement well, # 176-1A (right) are spaced 247' apart, and yet they have very different porosity distribution profiles. Also note that in well 176-1A, the difference between the CGR (Uranium compensated GR) and total GR is shaded.

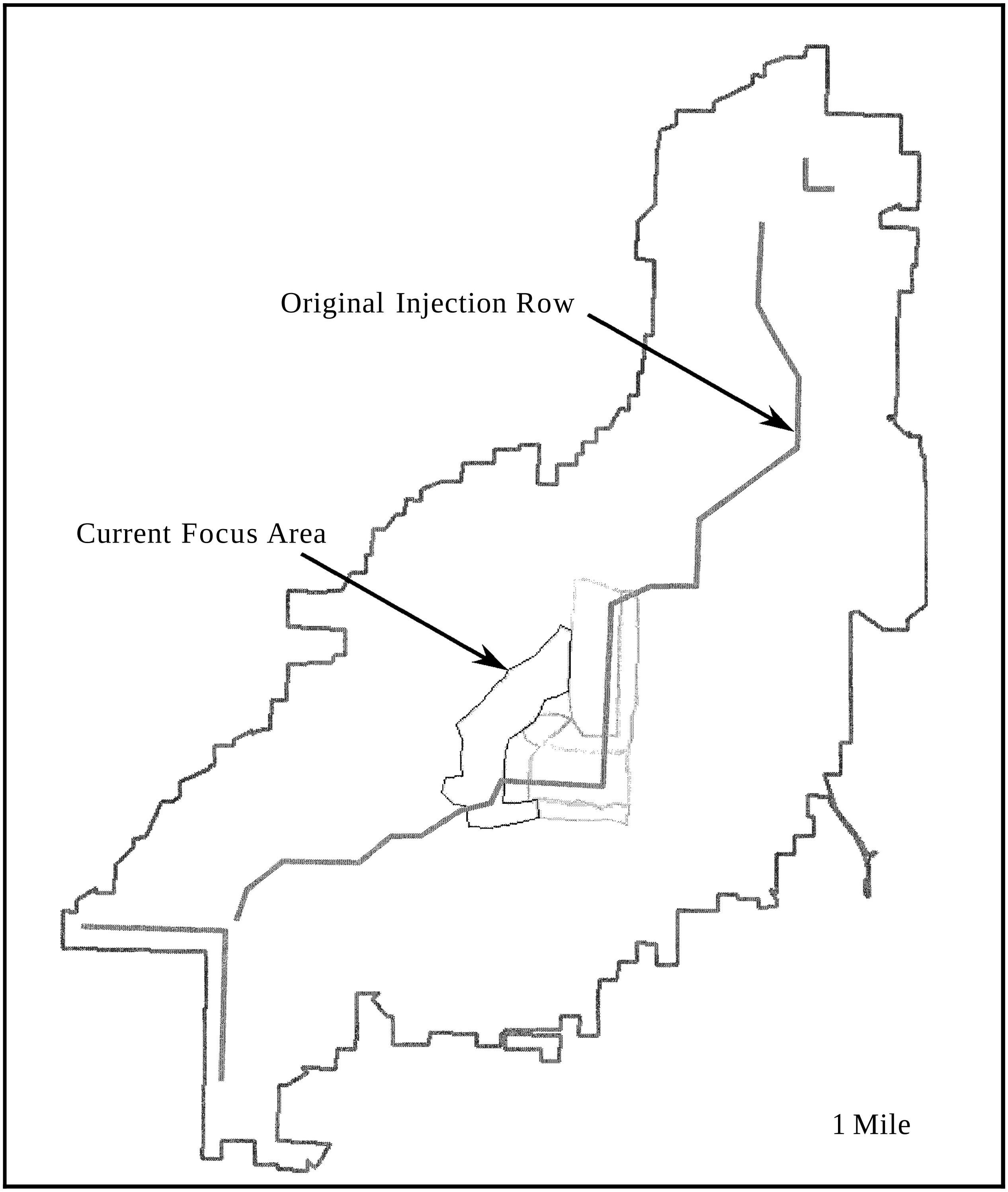

Figure 4- Original "Centerline" Injection Row and Current Focus Area