## Final Report

# Demonstration of a Novel, Integrated, Multi-Scale Procedure for High-Resolution 3D Reservoir Characterization and Improved $CO_2$-EOR/Sequestration Management, SACROC Unit


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***Prepared for:***
U.S. Department of Energy
DE-FC26-04NT15514


**March, 2008**

Advanced Resources International, Inc.

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# Executive Summary

The primary goal of this project was to demonstrate a new and novel approach for high resolution, 3D reservoir characterization that can enable better management of $CO_2$ enhanced oil recovery (EOR) projects and, looking to the future, carbon sequestration projects. The approach adopted has been the subject of previous research by the DOE and others, and relies primarily upon data-mining and advanced pattern recognition approaches. This approach honors all reservoir characterization data collected, but accepts that our understanding of how these measurements relate to the information of most interest, such as how porosity and permeability vary over a reservoir volume, is imperfect. Ideally the data needed for such an approach includes surface seismic to provide the greatest amount of data over the entire reservoir volume of interest, crosswell seismic to fill the resolution gap between surface seismic and wellbore-scale measurements, geophysical well logs to provide the vertical resolution sought, and core data to provide the tie to the information of most interest. These data are combined via a series of one or more relational models to enable, in its most successful application, the prediction of porosity and permeability on a vertical resolution similar to logs at each surface seismic trace location.

In this project, the procedure was applied to the giant (and highly complex) SACROC unit of the Permian basin in West Texas, one of the world's largest $CO_2$-EOR projects and a potentially world-class geologic sequestration site. Due to operational scheduling considerations on the part of the operator of the field, the crosswell data was not obtained during the period of project performance (it is currently being collected however as part of another DOE project). This compromised the utility of the surface seismic data for the project due to the resolution gap between it and the geophysical well logs. An alternative approach was adopted that utilized a relational model to predict porosity and permeability profiles from well logs at each well location, and a 3D geostatistical variogram to generate the reservoir characterization over the reservoir volume of interest. A reservoir simulation model was built based upon this characterization and history-matched without making significant changes to it, thus validating the procedure. While not the same procedure as originally planned, the procedure ultimately employed proved successful and demonstrated that the general concepts proposed (i.e., data mining and advanced pattern recognition methods) have the flexibility to achieve the reservoir characterization objectives sought even with imperfect or incomplete data.

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# 1.0 Introduction

Enhanced oil recovery (EOR) via $CO_2$ injection is a growing component of domestic oil supply (Figure 1), and is one of the few bright spots in an otherwise precipitous decline in national oil production. $CO_2$-EOR is also a near-term, value-adding means to reduce carbon emissions via geologic sequestration. For both of these reasons, more widespread application of $CO_2$-EOR is in the national interests of the U.S.

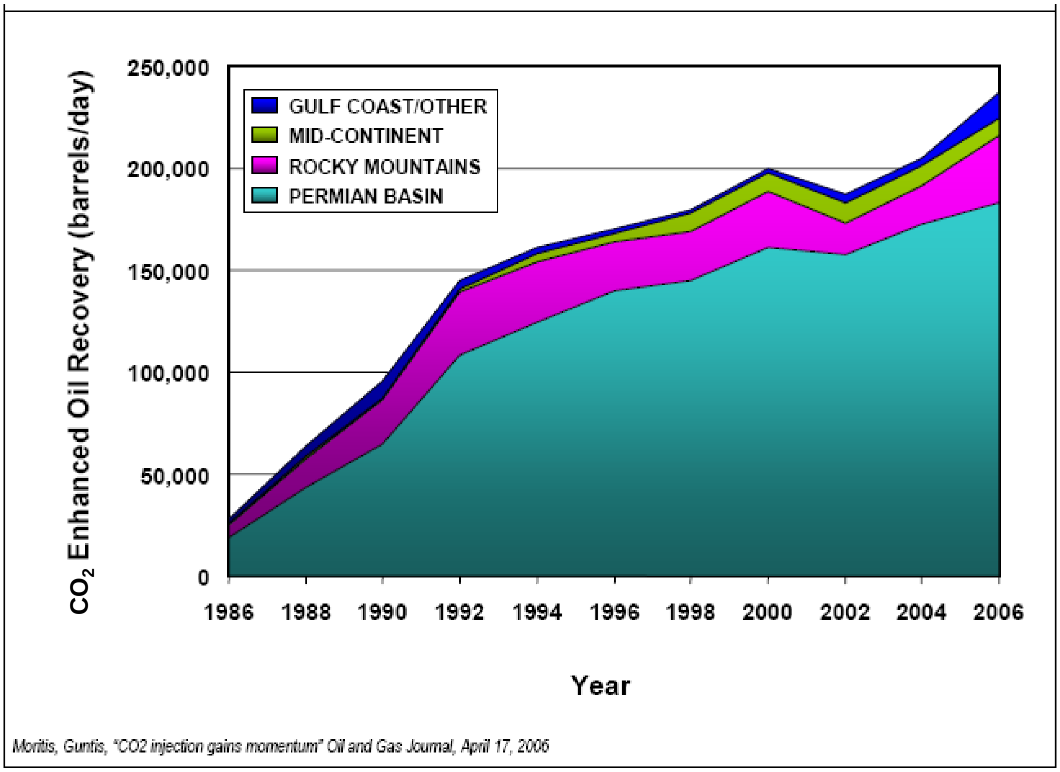


**Figure 1: U.S. $CO_2$-EOR Production**

However, despite considerable experience with the technology (mostly in the Permian Basin of West Texas and Southeast New Mexico), the efficiency of the process, on average, is still low. Recovery factors on the order of 10-20% of the original oil in place (OOIP) are typical, compared to 90%+ displacement efficiency under miscible, laboratory conditions – i.e., slim-tube experiments. This is largely because the mobility difference between low-viscosity $CO_2$ and (relatively) high-viscosity reservoir oil, as well as reservoir heterogeneity, result in poor volumetric sweep efficiency. One of the major challenges for improving oil recovery with $CO_2$-EOR, and thus facilitating its more widespread application, therefore is to reduce the amount of oil bypassed due to the poor volumetric sweep efficiency of $CO_2$ (or, for that matter, other injectants such as $N_2$ or flue gas). It is this important industry challenge that this project addressed, by demonstrating a novel, integrated, multi-scale procedure for 3D high-resolution reservoir characterization. This leads to a better understanding of small-scale (vertical) heterogeneity in oil reservoirs (on the order of +/- 2 foot resolution), enabling optimized $CO_2$ injection strategies for improved sweep efficiency and oil recovery. This procedure was demonstrated at the Scurry Area Canyon Reef Operators Committee (SACROC) Unit $CO_2$-EOR project in the giant Kelly-Snyder field located on the eastern edge of the Horshoe Atoll of the Midland Basin (Figure 2), operated by Kinder Morgan $CO_2$ Company LP ($KMCO_2$).

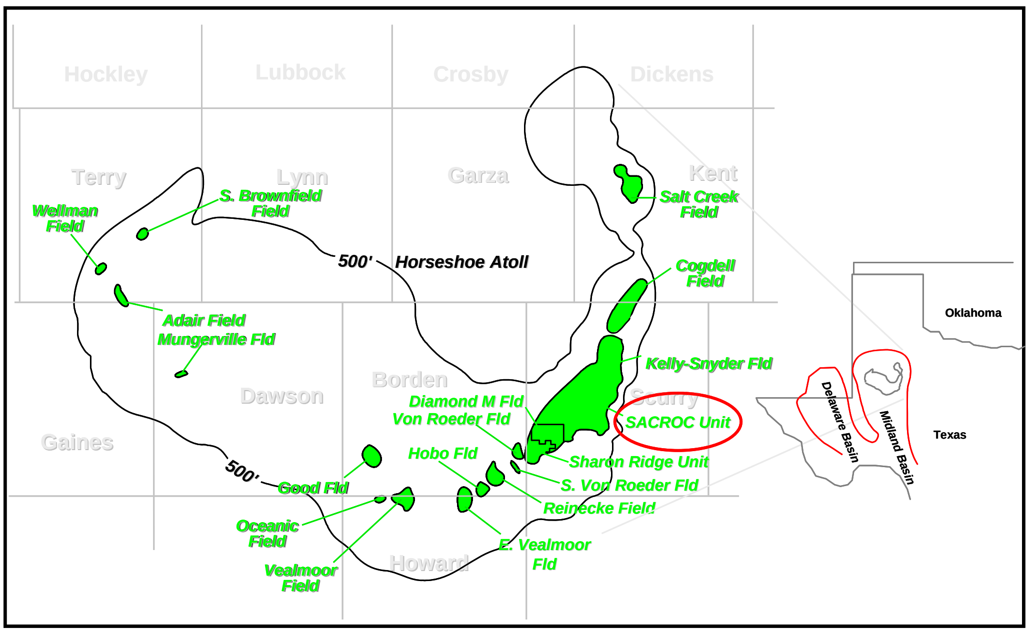


**Figure 2: Location of the SACROC Unit, Permian Basin**

The Kelly-Snyder field is located in Scurry County, Texas, and is the largest of many prolific oilfields within the Horseshoe Atoll, which is in the eastern half of the greater Permian Basin. Discovered in 1948, the field covers an area of approximately 50,000 acres with an estimated original oil in place (OOIP) of 2.8 billion barrels. It produces oil from the Pennsylvanian-aged Canyon and Cisco formations (Figure 3). The reservoir is a north-south trending carbonate buildup with a slight dog-leg to the west (Figure 4). The carbonate complex that makes up the productive portion of SACROC can be divided into three broad geographic regions, which are here referred to as the Northern Platform, Central Plain, and the Southwestern Region. The Platform area contains the thickest overall interval (Figure 5). Across the three mile width of this area, the gross thickness of section above the water-free oil production contact (OWC) ranges from 80 feet at the periphery of the field, to more than 750 feet at the center of the Platform. Additionally, a portion of this area exhibits complex geometry, with compartmentalization caused by changes in depositional environments, erosion, and possible faulting and karsting. Production data from this area displays strong evidence of vertical migration pathways that bypass low permeability barriers. Carbonate debris flows and Cisco-aged, in-place flank bioherm mounds lend further complexity on the western and eastern margins of the Platform.

The primary feature of the Central Plain is a broad, gently arching plain, which is broken by steep-sided pinnacles, gentler mounds, intermittent sinuous lows, and localized depressions. This region is the focus of current $CO_2$ flooding efforts. The Southwestern Region of SACROC contains the most structurally complex portion of the Unit and has the lowest net pay. It is not currently under consideration for tertiary flooding efforts. Overlying the Canyon is a thick sequence of dark black, organic-rich shale. This thick sequence of shale forms both an effective seal and may have served as the source for the hydrocarbons trapped in the reservoir.

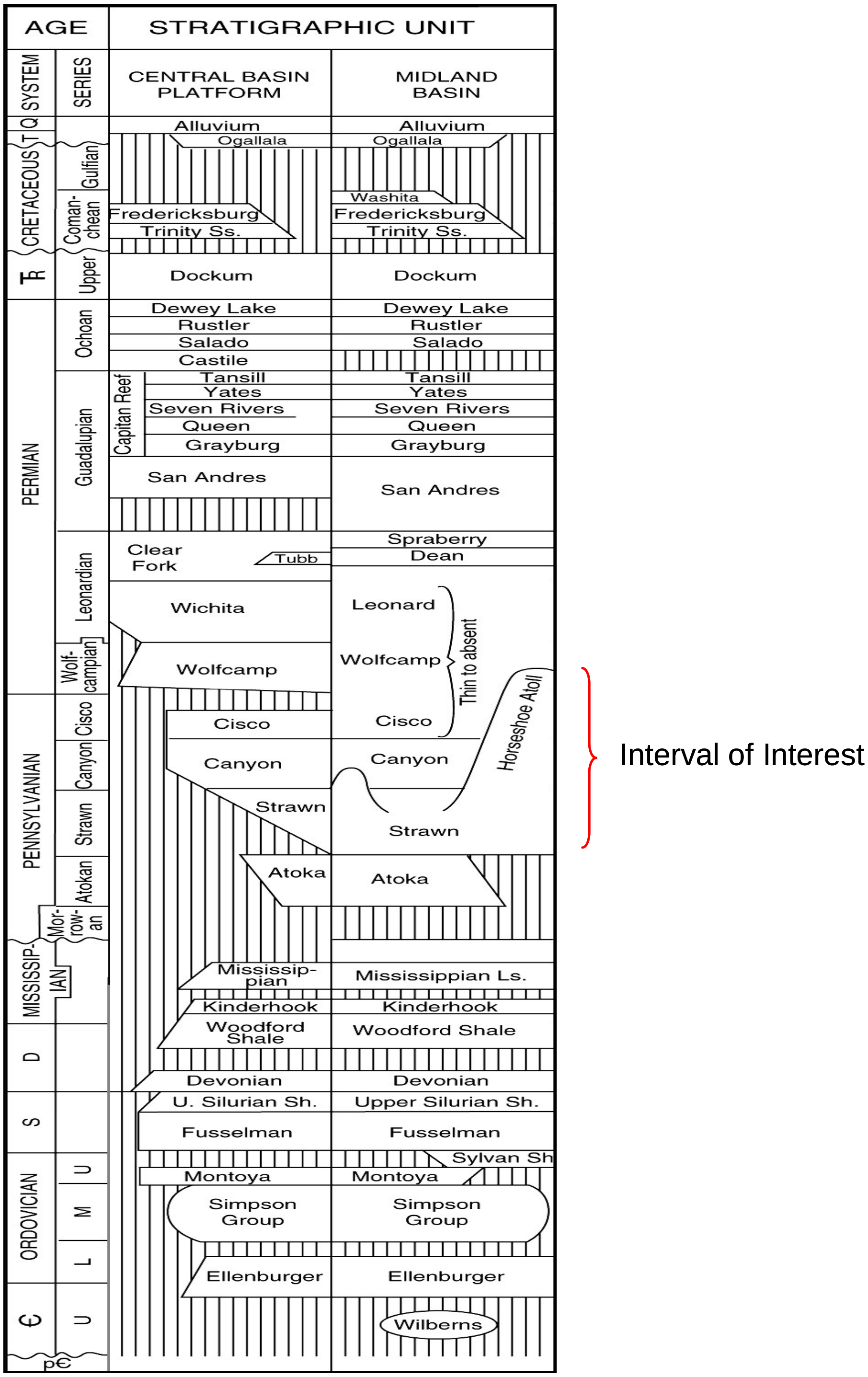


**Figure 3: Stratigraphic Column of the Permian Basin, Canyon/Cisco Formations Noted**

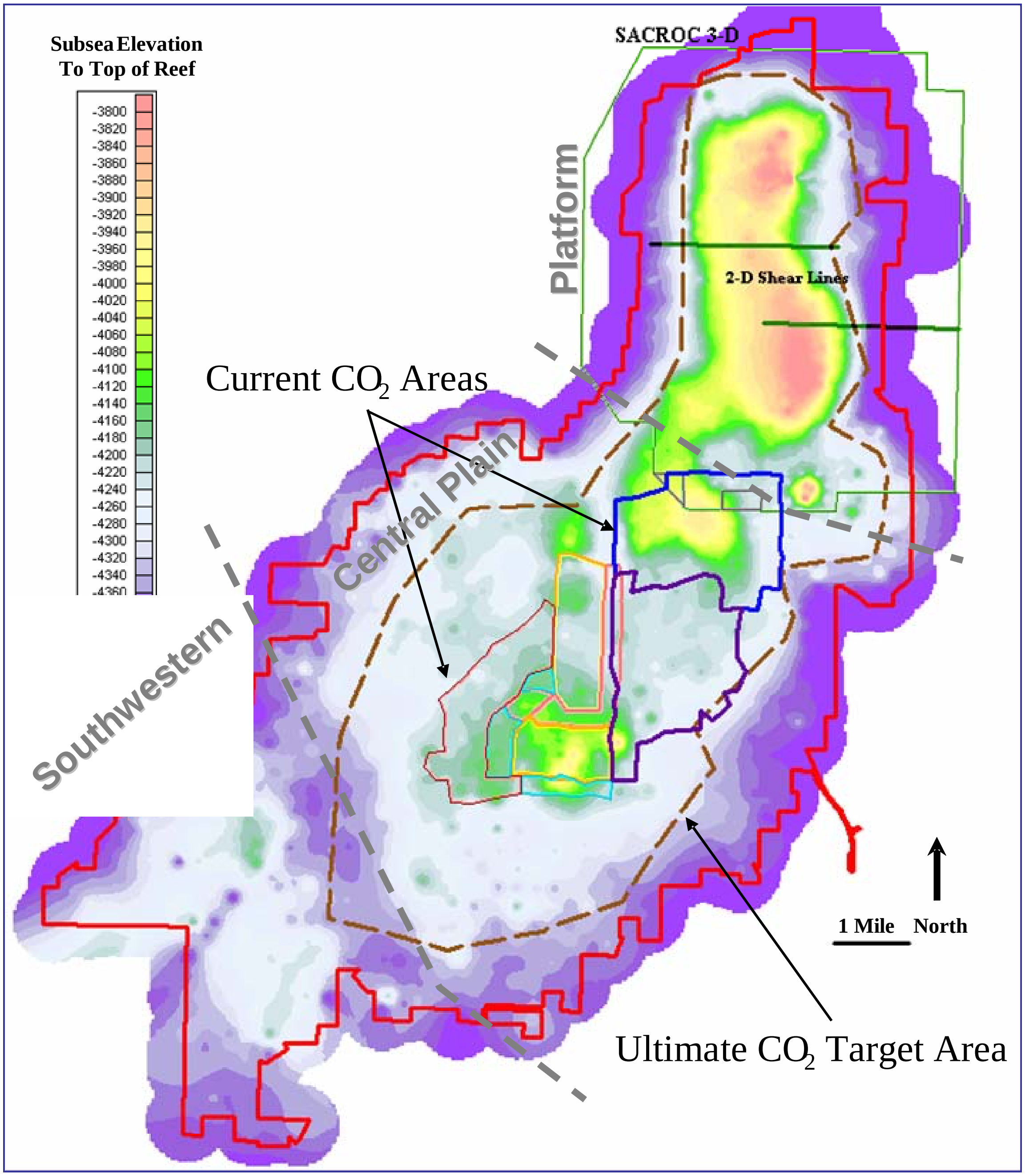


**Figure 4: Top of Canyon Structure Map, SACROC Unit**

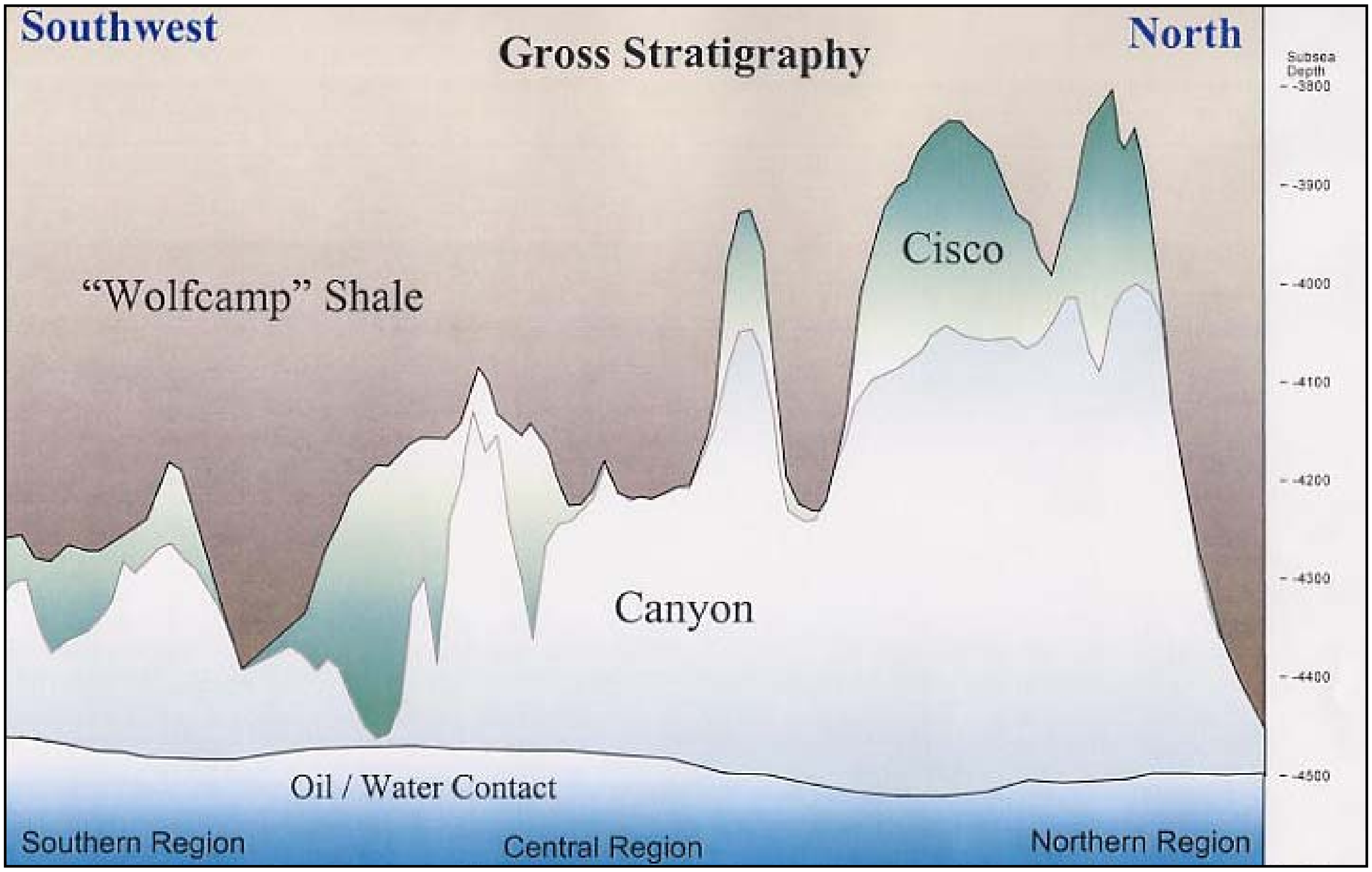

**Figure 5: General Lithologic Setting of SACROC Unit**

The SACROC Unit was formed in 1952 to facilitate coordinated waterflooding operations in the field, which began in 1954. $CO_2$-EOR began in 1972 originally using anthropogenic $CO_2$, and in recent years has primarily been focused in the Central Plain where reservoir architecture is more representative of horizontal deposition and amenable to pattern flooding. The decade of the 1990's found operations at a critical milestone; production had been dropping more than 20% per year from a peak of 210,000 barrels of oil per day (BOPD) in the mid-70's to only 9,000 BOPD in 1995. It was considered to be very mature by the mid-90s, and the Unit owners were faced with a significant abandonment effort as the estimated economic limit was rapidly approaching. Rather than face the prospect of negative cash flow and abandonment liability, the owners decided to implement a long-term plan to arrest the production decline, reduce expenditures, and ultimately restore the economic viability of the Unit. Since 2000, in addition to reducing costs, $KMCO_2$ has almost tripled production via more focused and aggressive $CO_2$ injection as well as better pattern management (Figure 6).

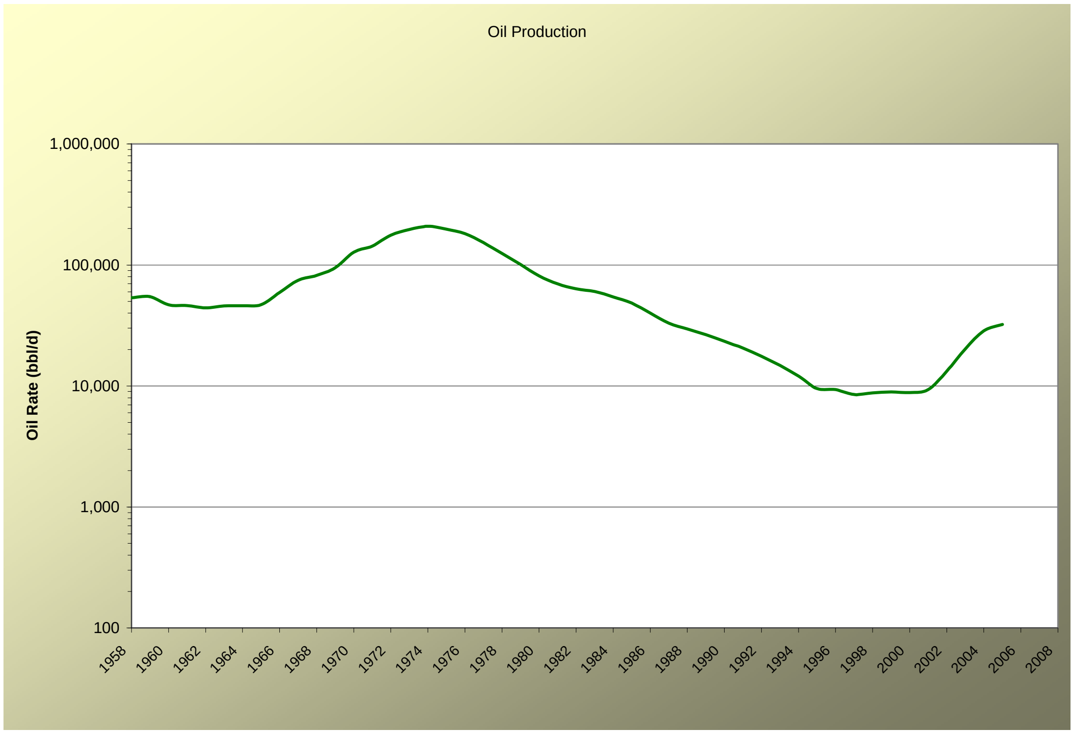


**Figure 6: SACROC Unit Production Since Discovery**

$KMCO_2$ is now considering its options regarding $CO_2$-EOR for the Northern Platform. It appears to have the necessary characteristics to host a $CO_2$-EOR flood of some form. However, this area may be at a pressure below the MMP since operations here had mostly ceased by the 1990's. Therefore, aggressive $CO_2$ injection and pressure control efforts will be needed. At the same time, it is paramount to avoid the detrimental effects associated with poor mobility ratio, specifically gravity override, which could be an issue with pattern flooding in the thick net pays that exist in this area. As such, $KMCO_2$ has established an important corporate objective to evaluate the feasibility of $CO_2$-EOR flooding in selected zones of the SACROC Unit Platform area. This project represented one important component of that overall effort.

# 2.0 Description of Reservoir Characterization Procedure

The reservoir characterization procedure is one that has been a topic of research for several years by Advanced Resources International (ARI), under DOE sponsorship, and with increasingly encouraging results.[1,2]. Essentially it utilizes advanced pattern recognition technology to establish relationships between data of different scales and types, ultimately leading to a core-type reservoir description (i.e., porosity (Ø) and permeability (k)), at a high vertical resolution, and in 3D space. A fundamental requirement of the proposed technique is the acquisition/availability of data at various scales of measurement to bridge the (vertical) resolution gap between the extremes represented by surface seismic and core-scale data. In it's ideal application, the technique requires the following data:

1) surface seismic, which provides the full 3D data cube for the reservoir (at the lowest cost per unit of reservoir volume surveyed),
2) crosswell seismic, which provides an important bridge in terms of both data type and resolution between surface seismic and well logs,
3) wireline well logs and,
4) standard whole core analysis which provides the link to the reservoir engineering parameters of permeability and porosity.

Each of these four data types are explored and conditioned, individually and in combination, using clustering techniques, a form of self organizing maps (SOM's). These are unsupervised artificial neural networks (ANN's) that can identify patterns and commonalities in data. In this case, the analysis provides insights into lithofacies and depositional environments.

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[1] Reeves, S. R., Mohaghegh, S. D., Fairborn, J. W., and Luca, G.: "Feasibility Assessment of a New Approach for Integrating Multiscale Data for High-Resolution Reservoir Characterization", SPE 77759, presented at the SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, September 29 – October, 2, 2002.

[2] Reeves, S.R.; "Development of an Advanced Approach for Next-Generation Integrated Reservoir Characterization", Final Report prepared for the U.S. Department of Energy, Award No. DE-FC26-01BC15357, April, 2005.

The heart of the procedure is to create several ANN's that utilize the raw data, as well as the clustering information, to relate 1) surface to crosswell seismic (specifically seismic attributes to crosswell traces), 2) crosswell attributes (computed from crosswell traces) to geophysical log responses, and 3) geophysical log responses to core permeability and porosity. With these three models, any surface seismic trace can be deconvolved from a low resolution elastic waveform to a high-resolution representation of permeability and porosity (Figure 7).

As mentioned earlier, this approach can be distinguished from the conventional approaches because it:

- is based purely on pattern recognition, yet still honors the underlying geology and rock physics,
- improves resolution via direct relationships of data at different scales,
- provides estimates of permeability in addition to porosity,
- can be performed relatively quickly and with readily available and inexpensive software.

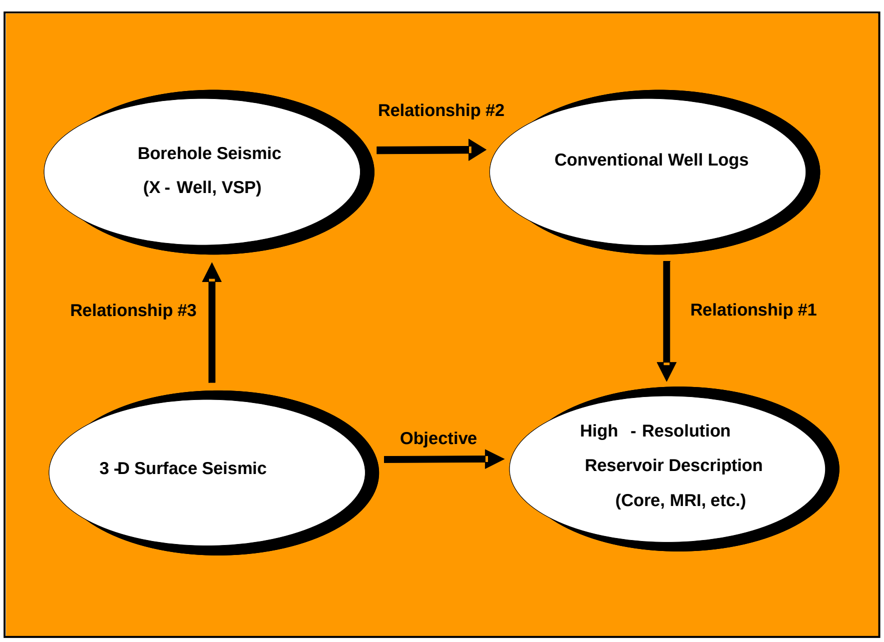


**Figure 7: Pathway to 3D High-Resolution Reservoir Characterization**

# 3.0 Proposed Work Plan

The work plan originally proposed for the project is summarized below.

Task 1.0 – Obtain and Analyze Whole Core, Geophysical Well Logs

The first task was to obtain fresh whole core for the entire Canyon interval. Four new wells were to be drilled in different parts of the main Northern Platform area. Oriented core was to be obtained over the entire Canyon formation, which at this location is approximately 800 feet thick. After description and cataloging, the core analysis program consisted of 1) on each foot of core, 3D permeability to air in two azimuthal horizontal and one vertical orientation, porosity, fluid saturations, and grain density, 2) core plug analysis (permeability and porosity) on 50 core plugs from selected locations, and 3) thin section analysis was to be performed on each of the 50 plug samples. In addition, a modern well log suite was to be run in each cored well, to consist of spectral gamma ray, neutron porosity, lithodensity, sonic, and laterlog.

Task 2.0 – Collect and Process Pre-Injection Data

The first subtask was to involve identifying and collecting all the reservoir descriptive and performance data available for the area in which an injection test was to be performed. This was expected to be near to one of the cored wells, and was to include geophysical well logs, preexisting core data, fluid property data (including $CO_2$-oil tests), pressure transient and reservoir pressure data, and historical well production/injection volumes.

The next subtask was to involve acquiring crosswell seismic surveys. Crosswell surveys were proposed between at least one cored well and an offset well. For the purposes of planning, it was assumed that four well-pairs will be surveyed. Processing of the seismic data was also to be performed as part of this task.

Task 3.0 – Perform Reservoir Characterization and Predictive Modeling

The next task was to be to utilize all the data collected in Task 2 to develop the reservoir characterization itself, and to forecast injection and $CO_2$ movement pathways via reservoir simulation. The first step of the reservoir characterization was to develop a virtual intelligence model to relate surface seismic attributes to the crosswell traces, at the collocated (crosswell) positions. This would likely involve the use of up to 12 surface seismic attributes as inputs, and the crosswell traces as the outputs.

The next subtask was to train, test and validate the crosswell-to-log model. The first step in developing this model was to compute the seismic attributes from the synthetic crosswell traces developed in the previous subtask. A virtual intelligence model was to then be built with up to 12 crosswell attributes as inputs, and up to 6 geophysical well logs as outputs. The dataset would include several crosswell traces in each direction from the well in which the modern log suite will be acquired.

The final virtual intelligence model was to relate the geophysical well logs to core data. Similar to the previous subtasks, a model was to be developed with up to six logs as the inputs and the two core measurements as the outputs.

Assuming satisfactory models were developed, the next step was be to apply it to generate estimates of permeability and porosity on 1 foot intervals for each synthetic log suite for the test area. At the conclusion of this subtask, permeability and porosity was to exist on 1 foot intervals at each surface seismic trace location in the injection test area, thus creating the high resolution reservoir characterization.

Based on the resulting high-resolution reservoir characterization, a reservoir model was to be constructed. The model would strictly honor the results of the reservoir characterization. The history of the test area would then be matched. Only the most uncertain parameters would be allowed to vary. If a successful match is achieved, this would provide some validation to the reservoir characterization.

Task 4.0 – Perform Injection Test

The next task was to perform an injection test. A primary purpose of the test (or series of tests) was to measure vertical connectivity throughout the entire Canyon interval, which will be critical for performing a $CO_2$-EOR flood. Specifically, sections of the wellbore were to be isolated while other sections were injected into. The observance of pressure between isolated sections was to provide some indication of vertical pressure communication and, thus, vertical permeability. The use of tracers was to be considered.

Task 5.0 – Validate Predictions

Following the injection tests, the actual reservoir responses to injection were to be compared to those predicted via simulation using the reservoir characterization developed in Task 3. An assessment was to be made as to the accuracy of the reservoir characterization based on these data. If successful, a high-resolution reservoir characterization was to be generated for each seismic trace in the entire Northern Dome. This was to provide $KMCO_2$ the reservoir characterization needed for planning and managing full-scale implementation of the $CO_2$-EOR flood.

The original project schedule is provided in Figure 8.

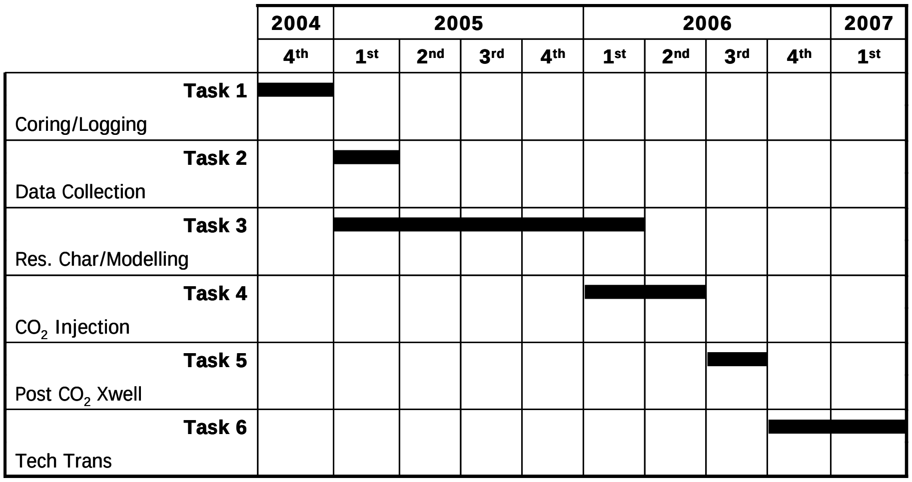


**Figure 8: Project Schedule**

# 4.0 Deviations from Proposed Work Plan

Despite considerable efforts to perform the project as originally proposed, business and operational considerations on the part of the operator created delays in implementation of the crosswell surveys and injection test, so much so that alternative approaches had to be sought to meet the project objectives. These are described below. We should note, however, that the operator is proceeding with these activities, at their own cost, in coordination with the DOE's Southwestern Partnership for Carbon Sequestration. They are simply being performed too late for inclusion in this project.

## *4.1 Core Wells*

Only three wells were ultimately cored over the entire Canyon interval, as opposed to the originally planned four. The fourth well was eliminated from the program by $KMCO_2$, but did not impact the project results. The wealth of data collected from the three wells was sufficient for the purposes of the project. The cost share associated with these three wells is shown in Table 1.

## *4.2 Crosswell Seismic Surveys and Injection Test*

As mentioned above, due to scheduling differences and shifting priorities, the operator delayed the acquisition of cross-well survey data and $CO_2$-EOR pilot testing in the platform area until after this project was over. DOE declined to extend the project to wait for these activities to be completed. As a result, our approach to the reservoir characterization procedure itself, as well as its validation, had to be modified, which was done in the following manner:

- In the absence of crosswell seismic data, core and log data could not be directly related to surface seismic data (despite appending considerable efforts to do so). The alternative approach was therefore to utilize the log-to-core model to predict permeability and porosity for all wells in a focused area of the Northern Platform, and create a three-dimensional geostatistical variogram to estimate these properties throughout the area.

- The resulting reservoir characterization was validated by building a reservoir simulation model of the study area and history-matching the historical production performance without significantly modifying the reservoir characterization.

These two steps were successfully performed, the technical details of which are described in the project deliverables. Copies of the Topical Reports are provided in the Appendices.

## *4.3 Deliverables*

The deliverables from the project included:

### 4.3.1 Conference Papers

- Gonzalez, R., Schepers, K., Reeves, S.R., Eslinger, E. and Back, T. ; "Integrated Clustering/Geostatistical/Evolutionary Strategies Approach for 3D Reservoir Characterization and Assisted History-Matching in a Complex Carbonate Reservoir, SACROC Unit, Permian Basin", SPE 113978-PP, prepared for presentation at the *2008 SPE Improved Oil Recovery Symposium* held in Tulsa, OK, April 19-23, 2008.

- González, R.J., Reeves, S.R., Eslinger, E. and García, G.: "Development and Application of an Integrated Clustering/Geostatistical Approach for 3D Reservoir Characterization, SACROC Unit, Permian Basin", Paper 111453-MS presented at the 2007 SPE/EAGE Reservoir Characterization and Simulation Conference, Abu Dhabi, 28-31 October, 2007.

### 4.3.2 Topical Reports

- Schepers, K., Gonzalez, R.J., and Reeves, S.R.; "Optimized Reservoir History Matching Simulation of Canyon Formation, SACROC Unit, Permian Basin", Topical Report, prepared for *U.S. Department of Energy, DE-FC26-04NT15514*, November, 2007.

- González, R.J., Reeves, S.R., and Eslinger, E.; "Geostatistical Reservoir Characterization of the Canyon Formation, SACROC Unit, Permain Basin", Topical Report for U. S. Department of Energy, Contract Number DE-FC26-04NT15514, September, 2007.

- González, R.J., Reeves, S.R., and Eslinger, E.; “Predicting Porosity and Permeability for the Canyon Formation, SACROC Unit (Kelly-Snyder Field), Using the Geologic Analysis via Maximum Likelihood System”, Topical Report prepared for *U. S. Department of Energy, Contract Number DE-FC26-04NT15514*, September, 2007.

### *4.4 Schedule*

The project was completed by September 30, 2007, six months later than originally proposed. The delay was primarily a result of providing (limited) additional time for $KMCO_2$ to obtain the cross-well seismic surveys.

# Table 1: Case Share Associated With Three Cored Wells

| Sum of Tran_Amt | | Year | | | |
|---|---|---|---|---|---|
| **Property_Id** | **Desc** | **2004** | **2005** | **2006** | **Grand Total** |
| 11-15 | Bits | 7,262.20 | | | 7,262.20 |
| | Casing and Other Tangible Crews | | 8,421.00 | | 8,421.00 |
| | Cementing Services | | 42,875.40 | | 42,875.40 |
| | Conductor/Surface Casing | | 24,156.71 | | 24,156.71 |
| | Contract Labor | | 4,176.00 | | 4,176.00 |
| | Coring and Analysis | | 184,740.20 | 889.61 | 185,629.81 |
| | Damages | | 6,500.00 | | 6,500.00 |
| | Dirtwork/Roads | | 1,321.00 | | 1,321.00 |
| | Drilling - Daywork | | 338,294.68 | | 338,294.68 |
| | Electric and Other Logging | | 11,846.20 | | 11,846.20 |
| | Fuel, Power, and Water | 3,639.85 | 43,954.77 | | 47,594.62 |
| | Intermediate Casing | | 196,719.35 | | 196,719.35 |
| | Miscellaneous Supplies | | 200.00 | | 200.00 |
| | Miscellaneous Supply and Services | | 4,427.08 | | 4,427.08 |
| | Miscellaneous Tangibles | | 19,846.00 | | 19,846.00 |
| | Move In and Move Out | | 14,500.00 | | 14,500.00 |
| | Mud and Chemicals | | 56,793.62 | | 56,793.62 |
| | Mud Logging/MWD | | 12,772.00 | | 12,772.00 |
| | Other Subsurface Casing | | 18,954.25 | | 18,954.25 |
| | Professional Services and Consultants | 250.00 | 25,329.00 | | 25,579.00 |
| | Regulatory Permitting Fees | | 425.00 | | 425.00 |
| | Rental -Tools and Equipment | | 7,350.95 | | 7,350.95 |
| | Seismic Acquisition | | 2,480.94 | | 2,480.94 |
| | Site Preparation and Cleanup | 91,885.58 | 12,066.50 | | 103,952.08 |
| | Transportation | | 4,151.12 | | 4,151.12 |
| | Tubular Inspection and Testing | | 1,310.00 | | 1,310.00 |
| | Well Surveys and Testing | | 583.00 | | 583.00 |
| | Wellhead Equipment | 1,699.27 | 3,294.19 | | 4,993.46 |
| 11-15 Total | | 104,736.90 | 1,047,488.96 | 889.61 | 1,153,115.47 |
| 19-12 | Bits | | 5,675.00 | | 5,675.00 |
| | Casing and Other Tangible Crews | | 15,475.00 | | 15,475.00 |
| | Cementing Services | | 29,160.15 | | 29,160.15 |
| | Conductor/Surface Casing | | (4,328.57) | | (4,328.57) |
| | Contract Labor | | 6,490.50 | | 6,490.50 |
| | Coring and Analysis | | 152,222.90 | 35,291.11 | 187,514.01 |
| | Damages | | 6,500.00 | | 6,500.00 |
| | Drilling - Daywork | | 380,874.97 | | 380,874.97 |
| | Electric and Other Logging | | 18,750.03 | | 18,750.03 |
| | Fuel, Power, and Water | | 164,688.50 | | 164,688.50 |
| | Intermediate Casing | | 18,009.93 | 332.84 | 18,342.77 |
| | Miscellaneous Supply and Services | | 4,029.42 | | 4,029.42 |
| | Miscellaneous Tangibles | | 19,639.03 | | 19,639.03 |
| | Move In and Move Out | | 27,500.00 | | 27,500.00 |
| | Mud and Chemicals | | 4,223.75 | | 4,223.75 |
| | Mud Logging/MWD | | 11,124.00 | | 11,124.00 |
| | Other Subsurface Casing | | 112,636.48 | | 112,636.48 |
| | Professional Services and Consultants | | 26,175.00 | | 26,175.00 |
| | Regulatory Permitting Fees | | 500.00 | | 500.00 |
| | Rental -Tools and Equipment | | 63,359.32 | | 63,359.32 |
| | Site Preparation and Cleanup | 2,009.00 | 62,212.34 | | 64,221.34 |
| | Supervision | | 396.00 | | 396.00 |
| | Transportation | | 13,002.05 | | 13,002.05 |
| | Tubular Inspection and Testing | | 3,353.50 | 43.78 | 3,397.28 |
| | Various Transportation | | 884.00 | | 884.00 |
| | Welding | | 366.80 | | 366.80 |
| | Wellhead Equipment | | 6,317.71 | | 6,317.71 |
| 19-12 Total | | 2,009.00 | 1,149,237.81 | 35,667.73 | 1,186,914.54 |
| 37-11 | Bits | 12,961.70 | 66,493.15 | | 79,454.85 |
| | Casing and Other Tangible Crews | 11,377.25 | | | 11,377.25 |
| | Cementing Services | 43,132.80 | | | 43,132.80 |
| | Conductor/Surface Casing | 23,519.71 | | | 23,519.71 |
| | Contract Labor | 1,769.00 | | | 1,769.00 |
| | Coring and Analysis | 106,400.00 | 104,184.94 | | 210,584.94 |
| | Damages | 8,000.00 | 500.00 | | 8,500.00 |
| | Drilling - Daywork | 305,991.70 | | | 305,991.70 |
| | Electric and Other Logging | 20,779.47 | | | 20,779.47 |
| | Fuel, Power, and Water | 55,536.42 | | | 55,536.42 |
| | Intermediate Casing | 205,080.68 | | | 205,080.68 |
| | Miscellaneous Supply and Services | 5,313.00 | 1,890.00 | | 7,203.00 |
| | Miscellaneous Tangibles | 19,996.00 | | | 19,996.00 |
| | Move In and Move Out | 14,500.00 | | | 14,500.00 |
| | Mud and Chemicals | 5,511.25 | 65,289.56 | | 70,800.81 |
| | Mud Logging/MWD | 11,948.00 | | | 11,948.00 |
| | Other Subsurface Casing | 21,503.95 | | | 21,503.95 |
| | Professional Services and Consultants | 8,400.00 | 20,500.00 | | 28,900.00 |
| | Regulatory Permitting Fees | | 425.00 | | 425.00 |
| | Rental -Tools and Equipment | 30,847.23 | 250.00 | | 31,097.23 |
| | Site Preparation and Cleanup | 23,182.00 | 9,752.40 | | 32,934.40 |
| | Transportation | 5,664.93 | 871.16 | | 6,536.09 |
| | Tubular Inspection and Testing | 2,833.00 | | | 2,833.00 |
| | Wellhead Equipment | 10,509.94 | | | 10,509.94 |
| 37-11 Total | | 954,758.03 | 270,156.21 | | 1,224,914.24 |
| **Grand Total** | | **1,061,503.93** | **2,466,882.98** | **36,557.34** | **3,564,944.25** |

## 5.0 Conclusions

Due to operational scheduling considerations on the part of the operator of the field, the crosswell data was not obtained during the period of project performance (it is currently being collected however as part of another DOE project). This compromised the utility of the surface seismic data for the project due to the resolution gap between it and the geophysical well logs. An alternative approach was adopted that utilized a relational model to predict porosity and permeability profiles from well logs at each well location, and a 3D geostatistical variogram to generate the reservoir characterization over the reservoir volume of interest. A reservoir simulation model was built based upon this characterization and history-matched without making significant changes to it, thus validating the procedure. While not the same procedure as originally planned, the procedure ultimately employed proved successful and demonstrated that the general concepts proposed (i.e., data mining and advanced pattern recognition methods) have the flexibility to achieve the reservoir characterization objectives sought even with imperfect or incomplete data.

# Appendix A:   Topical Report –Optimized Reservoir History Matching Simulation of Canyon Formation, SACROC Unit, Permian Basin

# Appendix B:  Topical Report – Geostatistical Reservoir Characterization of the Canyon Formation, SACROC Unit, Permian Basin

**Appendix C: Topical Report – Predicting Porosity and Permeability for the Canyon Formation, SACROC Unit (Kelly-Snyder Field), Using the Geologic Analysis via Maximum Likelihood System**