TITLE: ADVANCED RESERVOIR CHARACTERIZATION IN THE ANTELOPE SHALE TO ESTABLISH THE VIABILITY OF CO2 ENHANCED OIL RECOVERY IN CALIFORNIA'S MONTEREY FORMATION SILICEOUS SHALES

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Contractor Name and Address: Chevron U.S.A. Production Company (CPDN), 5001 California Avenue, Bakersfield, California 93309

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## Objective

The primary objective of this research is to conduct advanced reservoir characterization and modeling studies in the Antelope Shale reservoir. Characterization studies will be used to determine the technical feasibility of implementing a $CO_2$ enhanced oil recovery project in the Antelope Shale in Buena Vista Hills field. The Buena Vista Hills pilot $CO_2$ project will demonstrate the economic viability and widespread applicability of $CO_2$ flooding in fractured siliceous shales reservoirs of the San Joaquin Valley. The research consists of four primary work processes: Reservoir Matrix and Fluid Characterization; Fracture Characterization; Reservoir Modeling and Simulation; and, $CO_2$ Pilot Flood and Evaluation. Work done in these areas is subdivided into two phases or budget periods. The first phase of the project will focus on the application of a variety of advanced reservoir characterization techniques to determine the production characteristics of the Antelope Shale reservoir. Reservoir models based on the results of the characterization work will be used to evaluate how the reservoir will respond to secondary recovery and EOR processes. The second phase of the project will include the implementation and evaluation of an advanced enhanced oil recovery (EOR) pilot in the West Dome of the Buena Vista Hills field.

## Summary of Technical Progress

The Buena Vista Hills field is located about 25 miles southwest of Bakersfield, in Kern County, California, about two miles north of the city of Taft, and five miles south of

the Elk Hills field (Naval Petroleum Reserve No. 1). The Antelope Shale zone was discovered at the Buena Vista Hills field in 1952, and has since been under primary production. Little research was done to improve the completion techniques during the development phase in the 1950s, so most of the wells are completed with about 1000 ft of slotted liner. The proposed pilot consists of four existing producers on 20 acre spacing with a new 10 acre infill well drilled as the pilot $CO_2$ injector. Most of the reservoir characterization of the first phase of the project will be performed using data collected in the pilot pattern wells.

Chevron held a meeting of the "Technical Team Partners" for the project on December 10 and 11, 1996. Meeting attendees included personnel actively involved in the project from Chevron U.S.A. Production Co., Chevron Petroleum Technology Co., Core Laboratories, TerraTek, Stanford University, Schlumberger Well Services and Advanced Resources International Inc. The purpose of the meeting was to bring together all of the various groups doing work on the project to 1) define roles and responsibilities, 2) review project progress, 3) coordinate timing of tasks in order to meet deadlines, 4) discuss additional work that may be required to meet Chevron's project objectives, 5) discuss reporting requirements, and 6) discuss technical transfer requirements. The meeting included time set aside for viewing the core acquired in the pilot injector well and a site visit.

## *Reservoir Matrix and Fluid Characterization*

### Coring Program

Measurements of core properties from the Chevron Murvale 653Z-26B well continued during the 4th quarter.

Conventional core material was slabbed parallel to the axis of the core exposing maximum dip angle whenever possible. The slab was a 1/3 - 2/3 cut with the 1/3 section being used for photography and Imagelog$^{tm}$ analysis (Task A.3.O) and the 2/3 section being used to drill sample plugs for Dean Stark porosity, permeability and saturation (PK&S) analysis (Task A.3.F) and other advanced rock properties measurements. The 1/3 slab material was cleaned and mounted in Styrofoam inserts for incorporation into slab boxes for viewing and description (Task A.3.E). The 2/3 section was returned to the conventional core boxes. One-inch diameter plugs were drilled from the 2/3 slab section of the conventional core parallel to bedding strike for PK&S. The samples' fluids were extracted using a Dean Stark process for removal and measurement of water volumes and a soxhlet extraction technique for removal of residual salt and oil components. The samples were then humidity dried until weight stabilization. Porosity and permeability values (Klinkenberg and air values) were measured at three confining stress values (2100 psi, 2700 psi and 3500 psi) using Core Laboratories' CMS-300$^{tm}$ equipment.

The 1/3 slab section of the conventional core material was analyzed at a rate of 20 measurements per foot using Core Laboratories' Pressure Decay Profile Permeameter (PDPK$^{tm}$) as part of Task A.3.N . The PDPK measurements will be compared to the specific gas and liquid permeability values (Task A.3.F).

Core photography in white light and ultraviolet light has been completed using a format of 18' per print (Task A.3.O). The photo CD will be further used to analyze the ultraviolet images to quantify lithology and pay intervals on a small scale for integration in a core-log transform (Task A.6.B). Using Core Laboratories' Imagelog$^{tm}$ software, the ultraviolet images will be converted into binary images with the pay intervals being integrated to determine net pay in the cored interval.

The spectral core gamma scan was performed on all core material to determine potassium, uranium and thorium concentrations in the core material. In addition, bulk density index, total gamma values and uranium-free gamma values were measured. This completes Task A.3.C.

Ten samples were selected by CPDN personnel for wettability testing at Core Laboratories (Task A.3.A). All ten samples needed for the test are still in the cleaning process.

### Wireline Logging Program

Activity for the quarter was centered around the amassing of the well log data by Schlumberger into montage format (Task A.5.A). This was completed with the wireline data available to date. Once the core analysis is received they will proceed to calibrate log and core data in order to fine tune the wellbore formation parameters.

### Preliminary Findings

Table 1 is a preliminary analysis of the core measurements which shows the difference in properties between the Brown Shale and the Upper and Lower Antelope Shale. Figure 1 shows the core measurements plotted against log measurements.

## *Fracture Characterization*

### Shear-Wave Birefringence VSP

The Buena Vista Hills multicomponent VSP survey (Task A.4.A) was recorded in Well 653Z-26B on Nov. 14-16, 1996, primarily for the purpose of evaluating stress and fracture effects as a function of depth. Stress and fracture evaluation is possible from an analysis of shear waves as they propagate through the various formations. The data also have potential use for imaging both P-wave and S-wave reflections from interfaces near the wellbore. The essential VSP hardware consisted of a multicomponent seismic source

at the surface and a clampable three-component geophone on a wireline that traversed the full well depth and furnished data to a recording system also at the surface. A monitor geophone had been planted earlier at a depth of 300 ft near the source location to provide an accurate zero time. VSP recording began the morning of the 14th, but a severe noise problem identified as tube-wave contamination soon became apparent. We stopped recording at that point to bail more liquid out of the well to eliminate the tube wave. Recording resumed by the afternoon of the 15th with no sign of tube wave contamination. By the morning of the 16$^{th}$, 48 VSP levels had been recorded at intervals of 100 ft from 4830 ft to 130 ft. Data on field records appeared to be of outstanding quality. Initial processing revealed unexpected and so far unexplained source-generated noise at some levels, but the prospects seem good at this stage that it will subtract out of the S-wave data and allow high-quality analysis.

**Cross-well Seismic Acquisition and Processing**

John Fairborn of Paulsson Geophysical Services completed a modeling and planning study for the upcoming crosswell work (Task A.4.B). The purpose was to reassess the original DOE proposal now that we have well-log and core data from the 653Z well. His reassessment also assumed that we would use Paulsson's downhole vibrator as the energy source. Based on this study, CPTC and CPDN agreed to focus on obtaining data along one diagonal profile that extends from one corner of the pilot area through the central injector (653Z) to the other corner in order to stay within the existing budget. Unfortunately, the model does not help address two major unanswered questions: (1) Will we see reflected energy which can be used to help characterize the reservoir, and (2) What is the frequency content of the crosswell energy? We need to know these two things in order to put in place an acquisition strategy that is within budget. Therefore, during the first quarter of '97, we plan to collect data in Buena Vista Hills for about one day, shut down for 24-48 hours to evaluate our results, and then proceed with the acquisition strategy dictated by the answers to the questions, above.

Plans still call for using Paulsson Geophysical Services' downhole vibrator as the energy source in the cross-well survey. The tool was undergoing final modifications in Salt Lake City at year's end. Field testing of the tool in La Habra, CA was planned for January '97 with Buena Vista Hills data acquisition to follow shortly thereafter.

**High Resolution Structural Mapping**

Work was begun on building an Openworks database containing all Buena Vista Hills wells that penetrate the Brown Shale and Antelope Formations (Task A.4.D). By year's end, approximately 160 wells had been loaded to the database with at least 60 more to be loaded in early 1997. Data for the 160 wells included surface locations, directional surveys, and digital open-hole logs. Arrangements were made to have the logs for the remaining 60 wells digitized in early 1997.

Work was also begun on correlating formation marker tops in the Brown Shale and Antelope sections using Stratworks. A total of 7 Brown Shale and 15 Antelope marker tops were being correlated. By year's end, most of the 160 wells had been correlated and a list of observed fault cuts had been tabulated. Completion of the correlations, fault interpretations, and structure maps is expected in early 1997 upon completion of the log digitizing and subsequent addition of the remaining wells to the database.

**Regional Tectonic Synthesis**

Under Task A.4.H, Advanced Resources International (ARI) made a geological literature search and review of all information to be used for the Regional Tectonic Synthesis (part I), and the data acquisition for the Natural Fracture Detection and Structural Analysis (part II), which will be accomplished by using geological remote sensing methods. These tasks are being conducted in parallel. The comprehensive literature review and synthesis of the structure and tectonics of the southern San Joaquin Basin is providing the foundation for the analysis and interpretation of the recently acquired regional data sets. The analysis and interpretation of the data sets will be included in the Regional Tectonic Synthesis.

To date, for Part I, ARI has completed the geological literature search; obtained review copies of the most important literature identified by their search; compiled a list of topics, essential maps, and illustrations which will be incorporated in the synthesis and subsequent reports; and have planned to complete a first draft report by the end of January 1997.

For Part II, they have identified all the remote imagery data sets available over the San Joaquin/Buena Vista region. ARI has been using the Internet's browsing capabilities in order to determine data quality and coverage prior to acquisition. Those data sets that meet their criteria are being, or have been, acquired. ARI has also received an offer of assistance from the Geology Program at NASA Headquarters to acquire AVIRIS data for the San Joaquin/Buena Vista area (previously unavailable) within the next two to three months. ARI is now in the initial stages of image cleanup and enhancement of the acquired data.

## *Reservoir Modeling and Simulation*

A reservoir engineering database continues to be constructed using a Chevron proprietary database.

## *Technology Transfer*

### San Joaquin Well Logging Society Meeting

Bruce Bilodeau, coordinator for the reservoir matrix and fluids characterization process for the project, presented an overview of the program to the local section of the Society of Professional Well Log Analysts. Approximately 50 people attended from various oil companies in the San Joaquin Valley. He highlighted the various technologies to be used in characterizing the reservoir.

**Table 1. Preliminary Summary of PK&S Measurements.**

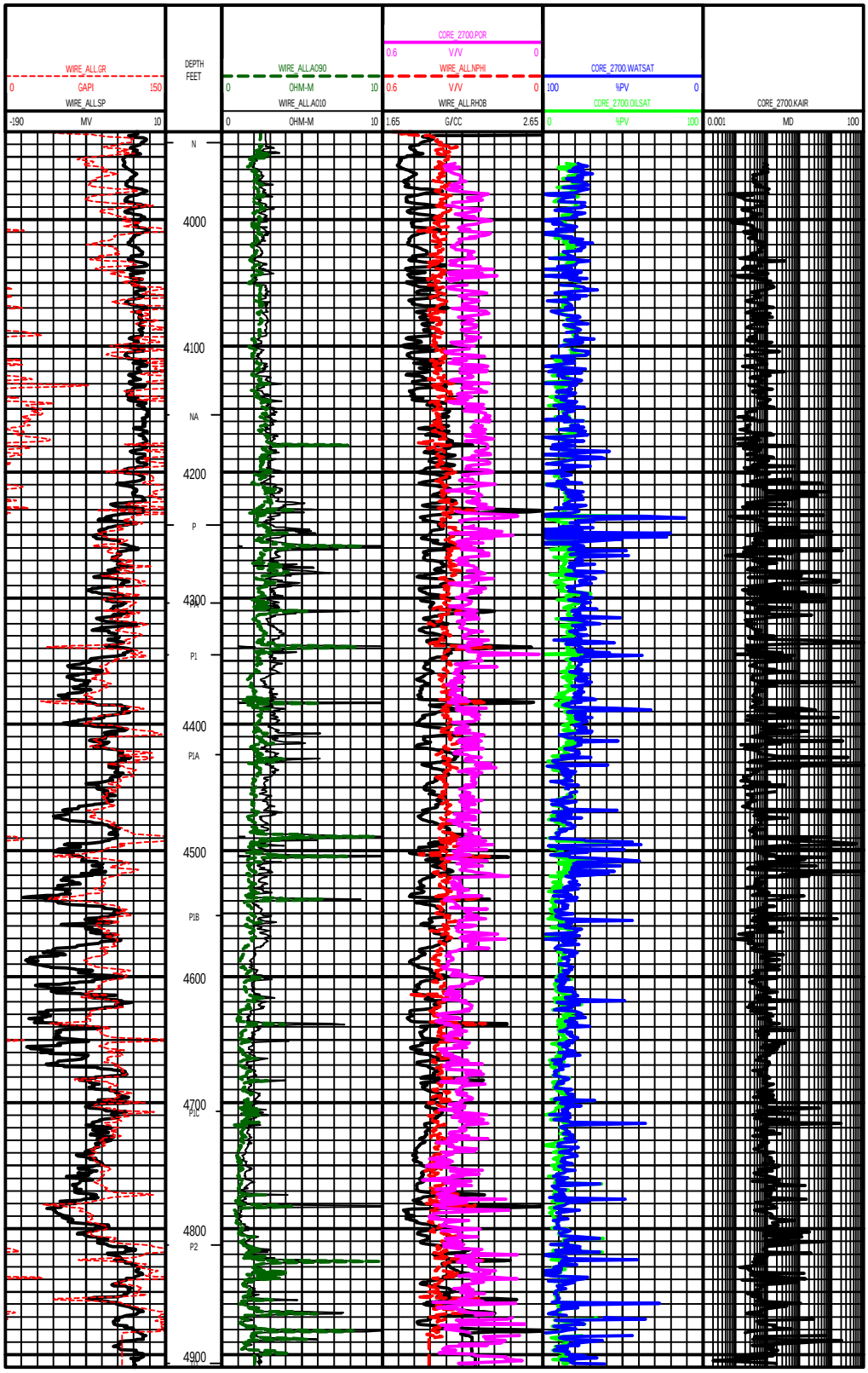
| **Summary of Averages, 2100 psi** | | **Porosity** | **K liq** | **K air** | **So** | **Sw** | **Gr Den** | **Samples** |
|---|---|---|---|---|---|---|---|---|
| *Brown Shale* | *3939-4242* | 27.4 | 0.050 | 0.077 | 14.5 | 78.4 | 2.31 | 277 |
| *Upper U. Antelope* | *4242-4552* | 28.2 | 0.098 | 0.152 | 14.4 | 77.3 | 2.36 | 305 |
| *Lower L. Antelope* | *4552-4907* | 30.4 | 0.091 | 0.146 | 11.5 | 83.9 | 2.39 | 354 |
| Total | | 28.8 | 0.078 | 0.122 | 13.3 | 80.1 | 2.36 | 936 |

| **Summary of Averages, 2700 psi** | | **Porosity** | **K liq** | **K air** | **So** | **Sw** | **Gr Den** | **Samples** |
|---|---|---|---|---|---|---|---|---|
| *Brown Shale* | *3939-4242* | 27.1 | 0.031 | 0.054 | 15.1 | 81.7 | 2.31 | 277 |
| *Upper U. Antelope* | *4242-4552* | 27.9 | 0.067 | 0.116 | 14.7 | 78.7 | 2.36 | 305 |
| *Lower L. Antelope* | *4552-4907* | 30.3 | 0.052 | 0.098 | 11.6 | 84.9 | 2.39 | 352 |
| Total | | 28.6 | 0.049 | 0.087 | 13.6 | 82.0 | 2.36 | 935 |

| **Summary of Averages, 3500 psi** | | **Porosity** | **K liq** | **K air** | **So** | **Sw** | **Gr Den** | **Samples** |
|---|---|---|---|---|---|---|---|---|
| *Brown Shale* | *3939-4242* | 27.0 | 0.020 | 0.038 | 15.3 | 82.7 | 2.31 | 275 |
| *Upper U. Antelope* | *4242-4552* | 27.8 | 0.052 | 0.094 | 14.8 | 79.3 | 2.36 | 304 |
| *Lower L. Antelope* | *4552-4907* | 30.2 | 0.037 | 0.078 | 11.7 | 85.6 | 2.39 | 350 |
| Total | | 28.5 | 0.034 | 0.067 | 13.7 | 82.8 | 2.36 | 929 |

**Figure 2. Log and PK&S Core data for 653Z-26B.**

*(Figure is on next page)*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