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“Development Practices for Optimized MEOR in Shallow Heavy Oil Reservoirs”

Six Month, Technical Progress Report

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Abstract

The objective of this research project is to demonstrate an economically viable and sustainable method of producing shallow heavy oil reserves in western Missouri and southeastern Kansas, using an integrated approach including surface geochemical surveys, conventional MEOR treatments, horizontal fracturing in vertical wells, electrical resistivity tomography (ERT), and reservoir simulation to optimize the recovery process. The objective also includes transferring the knowledge gained from the project to other local landowners, to demonstrate how they may identify and develop their own heavy oil resources with minimal capital investment.

Tasks completed in the first six-month period include soil sampling, geochemical analysis, construction of ERT arrays, collection of background ERT surveys, and analysis of core samples to develop a geomechanical model for designing the hydraulic fracturing treatment. Five wells were to be drilled in phase I. However, weather and funding delays resulted in drilling shifting to the second phase of the project.

Work performed to date demonstrates that surface geochemical methods can be used to differentiate between productive and non-productive areas of the Warner Sand and that ERT can be used to successfully image through the Warner Sand.

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1.0 Executive Summary

The objectives of phase I work included in the original proposal, were to initiate surface geochemical analysis and collect soil samples over the leasehold according to defined grid(s); to construct electrodes to allow ERT methods to be used in tracking microbial movement within the reservoir; to drill five vertical wells; to incorporate geochemical results in selecting well locations if data are available; to complete/equip the wells for subsequent MEOR treatments; and to prepare a detailed fracturing design. Due to funding and weather delays, drilling and hydraulic fracturing design were delayed until the second project period. All other objectives of Phase I were met.

Preliminary meetings were conducted with project participants, and all participants were sub-contracted. Participants include Direct Geochemical (surface geochemistry), Nolte Smith, Inc. (hydraulic fracturing design), J-Environmental (MEOR treatments), Mr. Jim Long (consultant), Garland Oil and Gas (operator), and Dr. Lee Slater (ERT support). It should be noted that, at the time of the initial project award, Dr. Slater was located at the University of Missouri, but has subsequently moved to Rutgers University in New Jersey.

Soil samples were collected over several areas of the leasehold, to evaluate the use of geochemical analysis in identifying productive and non-productive areas of the Warner Sand, and also for differentiating the quality of the productive area throughout the leasehold. Soil samples and corresponding GPS data were collected over several areas and provided to Direct Geochemical for analysis. Results from this work demonstrate that the surface geochemistry across the leasehold, and over two known dry holes, is quite different and can be successfully differentiated.

Background electrical resistivity tomography (ERT) readings were taken over two areas of the leasehold. Two initial, 2-D resistivity lines were shot in lines running North-South and adjacent to the original corehole #1 (Figure 1). Data obtained indicated that the depth of the ERT survey did not extend through the Warner Sand. This work indicated that the electrode spacing for future surveys would need to be altered. The electrode spacing was modified to achieve a greater depth of investigation.

ERT probes for the wellbores were also constructed. Three strings of plastic tubing were equipped with electrodes and wired for connections to surface. The initial plan provided for two

ERT monitoring wells. After discussing the imaging methods, it was determined that three wells should be equipped with ERT probes to create a 3-D image with ERT. Three ERT probes were constructed, shipped to location and placed in storage.

Five wells were to be drilled in the project. Well logs, core data and results from the geochemical survey were reviewed to determine the optimum location, and general well configuration, for the five wells. ERT background work indicated wells equipped with ERT probes would need to be no more than 70 ft apart and could not be cased (initially). It was determined that the ERT wells would be configured in a triangle, and the two wells to be fractured would be located 200-300 ft outside this triangle. The fractured wells would be cased and cemented.

Continuous cores from wells (coreholes) drilled prior to this project (Figure 1) were selectively sampled to develop a geomechanical dataset for designing the hydraulic fracturing treatment. The process of developing a geomechanical dataset includes the development of a profile with depth versus Young's Modulus, in-situ stress and fracture fluid leak-off. Fifteen samples were taken from the Cushard #1 core, ranging from the shale immediately above the Bluejacket Sandstone, through the Bluejacket and Warner Sandstones, and into the Graydon Shale immediately below the Warner Sandstone. These samples were sent to NSI and analyzed in their laboratory.

All of the technical work performed during Phase I of the project was successful, despite delays due to an extremely cold winter and very wet spring. The geochemical analysis of soil samples was completed and provided useful results. Adjustments to the ERT array were made and those adjustments subsequently proved the ability to image through the Warner Sand. Three ERT arrays were constructed and shipped to site. Available Cushard cores were sampled selectively for supporting the final hydraulic fracture design.

In addition to the technical work completed in Phase I, it should be noted that the project received publicity through the University's website, local radio, and through a special report on KY-3 television on Springfield, Missouri. A project website was also created for general information and technology transfer.

2.0 Phase I Objectives and Results

The following sections of this report provide additional detail for proposed tasks that were completed during Phase I of the project.

Task 1 – Develop Surface Geochemical Sampling Plan and Grid

In November 2002, Direct Geochemical met with the faculty at UMR and Mr. Jim Long to devise a soil-sampling scheme. The initial concept for the field sampling plan involved two aspects, modeling and grid sampling.

Modeling

It was proposed to take sufficient number of samples to develop both local and regional models. Each model was expected to consist of one or more wells with known characteristics, i.e. a good well and a very bad well. The following sampling was proposed (referencing corehole locations shown in Figure 1):

- * Well (corehole) 1 and Well (corehole) 4: 10 samples near each well
- * Well (corehole) 12: 15 samples near the well
- * Offsite Good well: 15 samples near the well
- * Offsite Bad well: 15 samples near the well

"Near the well" samples were to be taken all the way around the location, in a rough circle. All of the samples were to be obtained close enough to be representative of the subsurface geologic characteristics but far enough away to be in natural or at least non-oil disturbed ground.

Grid

Three connected grids were initially proposed. Grid number 1 was to cover the main target area, in the E1/2 of the NE 1/4 of Section 32. The proposed grid for the target comprised 66 samples, approximately 265 ft on center. The grid proposed 11 rows of 6 samples.

Grid number 2 consisted of 160 acres in the SW1/4 of the SE1/4 and the SE1/4 of the SW1/4 of Section 29 plus the NW1/4 of the NE1/4 and NE1/4 of the NW1/4 of Section 32. Sampling was proposed to be on 530 ft spacing, and consisted of 33 samples arranged generally as 6 rows of 5 samples, plus 3 on the east line. This grid connected the main grid across to Well 4 (Corehole #4 in Figure 1).

Grid number 3 was proposed to connect Well 1 and the main grid across to Well 7, which was the medium quality well. It consisted of 3 rows of 5 samples in the S1/2 of the NW1/4 of Section 33.

The grids included 114 soil samples and the models proposed a further 65 soil samples.

The non-productive wells (offsite bad, offsite good) selected were the Ellis #1 dry hole located approximately one mile SE of the leasehold and the Harpel well, located several miles to the north-northeast of the leasehold area. These wells were selected because they were recent wells (2001), and the operator had leasehold rights for access to the wells.

Task 2 – Collect Soil Samples for Surface Geochemistry

Direct Geochemical provided soil sample instructions, sample field note sheets and sample jars for collecting the soil samples. GPS units were provided by the University, for noting the location of soil samples taken.

During January, 2003, model soil samples were collected, but weather conditions limited the number of samples taken and prevented grid samples from being collected. Extremely cold winter conditions hampered soil sampling efforts considerably.

During February, 2003, UMR students and faculty returned to the leasehold and collected approximately 100 soil samples over the three proposed grid areas. Figure 2 is a photograph from the soil collection effort.

The samples collected consisted of three sections, and approximated the proposed grids. The center section incorporated 53 samples, acquired on approximately 200-foot centers. The western section used 31 samples on 400-500 foot centers. The eastern section used 15 samples on 300-400 foot centers. These sample locations are shown as a base map in Figure 3.

Soil samples and GPS data were transmitted to Direct Geochemical for analysis. Figures 4-10 show hydrocarbon analysis and other results for the soil samples collected. The complete report from Direct Geochemical will be provided as an appendix to the first annual project

report.

Preliminary findings indicated that the area around corehole #4 might be slightly better than corehole #1. Based on these findings (and pending ERT results), it was decided to drill to the east of corehole #4.

The geochemical analysis revealed a difference between areas known to be productive and dry holes. The Ellis dry hole and Cushard (corehole) 12 both appeared quite dry.

The Harpel well, which did have oil present, appeared different than the Cushard coreholes. It exhibited a lower overall concentration of hydrocarbons almost always. It predicted as a weaker version of the Cushard coreholes #1 and #4.

On a limited data set, it also appeared that the oil wells as a group showed higher arsenic, calcium, and magnesium than the dry holes. The application of metals is difficult to understand at this point.

A simple analysis of the geochemical data strongly supports the notion that the surface geochemistry can be used to differentiate where oil occurs in the Warner Sand.

Task 3. Construct Plastic Tubing with Perforations and Electrodes for ERT Work

Three ERT arrays were constructed for deployment in the wells. Array design was based on a modification of instrumentation used by Dr. Lee Slater in previous DOE funded projects and is summarized in Figure 11.

Lead electrodes were used as previous field experience has indicated that they are electrically quieter than electrodes constructed from Type 304 stainless steel mesh. We intend to obtain reliable cross-borehole induced polarization data in addition to electrical resistivity data during ERT data acquisition. For each array twenty-four electrodes were placed on 3-inch diameter PVC pipe at 1.5 m intervals. This provides a vertical dimension of 38 m for the image zone (Figure 11). The ERT image aspect ratio is 1.52 (35 m/22.9 m), which is appropriate for cross-borehole ERT imaging. Note that the zone of interest is designed to occupy about 33 % of the image plane (Figure 11).

Each electrode is connected to two 18 gauge copper wires that provide electrical contact with the electrical imaging system placed on the surface and at the center of the boreholes.

The arrays were constructed in 3.1 m sections for transportation and final construction during well installation. They are also designed for rapid removal and re-installation on an as-required basis by two-three persons. A heavy-grade rope is attached for lowering and retrieving the array to/from the approximately 50 m installation depth.

All three arrays are currently stored on-site and available for installation as required.

Task 4. Record A Baseline ERT Survey

Geophysical students acquired 2 dimensional background resistivity data around corehole #1 in the late fall 2002 using a dipole-dipole array (DD). The results indicated that electrode spacing of 8 m did not provide enough depth to image the entire reservoir (Warner). As a result new array geometry was recommended.

Weather conditions delayed the acquisition of the background resistivity data. Frozen ground during the winter and heavy rains in the spring hampered field data acquisition. Students returned to the field in early May, but could not complete the survey because the fields were excessively muddy. However, some data were acquired using a new array geometry (pole-dipole array) which allowed for greater depth penetration. We were able to image to depths exceeding the depth of the reservoir. Figure 13 depicts the sample ERT image obtained.

The resistivity profile in Figure 13 shows that the shallow subsurface is very conductive with resistivities less than 11 Ohm.m. We interpret this to be due to shallow clays. Below this is a more resistive layer approximately 50 m thick. The reservoir layer is imaged beneath this more resistive layer at a depth of approximately 55-60 m with apparent resistivity values between 26-30 Ohm.m (dark tan color image). This layer appears to thicken towards the east (towards corehole #5).

Task 5. Preliminary Fracturing Review and Design

During February, 2003 samples were selected from the Cushard #1 core, for geo-mechanical analysis. A summary of core samples selected for analysis is presented in Figure 12. These samples were taken to NSI Laboratories in Tulsa, Oklahoma for analysis.

The complete geomechanical analysis and associated laboratory testing for fluid compatibility, fines migration and embedment will be completed in Phase II as needed. The

design of the hydraulic fracturing treatment will also be finalized in Phase II, and it is expected that the actual treatment will be pumped in September, 2003.

Although not initially part of the project, it should be noted that Pinnacle Technologies has offered to lend the use of 15 latest-generation tiltmeters and associated equipment, to ensure adequate tiltmeter characterization of the shallow hydraulic fracture. This has been a tremendous support for the fracturing work.

Task 6. Technology Transfer/Publicity

A preliminary website has been developed for this project. The website contains text for each technical aspect of the project. The website will have additional text and pictures added after all field is completed. The website URL is www.umn.edu/~doe.

Publicity for the project was generated through press releases and through KY3 television in Springfield Missouri. KY3 ran a television spot in February on the research project. Copies of press releases will be provided in the final report.

The internal UMR press release can be found at:

http://www.umn.edu/index.php?id=1586&backPID=245&swords=Dunn-Norman&tt_news=88

4.0 Phase II Future Plans – Second 6 months

The objective of phase II work was specified as initiating and monitoring MEOR treatments in the wells. Due to the weather and funding delays, it is now expected that drilling, hydraulic fracturing and placement of the ERT probes will occur in Phase II of the project, and that MEOR treatments will not begin until September, near the end of Phase II. All of the work originally outlined for the drilling, fracturing and completion tasks will take place in Phase II.

5.0 Results and Discussion

Results of the geochemical analysis are perhaps the most interesting aspect of the work completed in Phase I. Examining the results for the Ellis #1 and Cushard #12 (insets to Figures 4,5,6,7 and 9) it is clear that the dry holes exhibit responses quite different than the productive wells found in the main leasehold. This strongly suggests that surface geochemistry might be

used as an inexpensive way of identifying the existence of hydrocarbons in western Missouri. The finding is important, since no regional geochemical study has been undertaken to date.

Another significant result of the work performed to date is confirmation of ERT capabilities. Through adjustment of probe spacing and background surveys, it was demonstrated that the Warner sand can be successfully imaged.

Beyond the technical success of the work performed, it should be mentioned that the project publicity has also been highly effective, and that the University and project PI have had numerous calls regarding the work. Two other groups are now either working or planning to work near the location of the current project.

6.0 Conclusions

Phase I of the project “Development Practices for Optimized MEOR in Shallow Heavy Oil Reservoirs” has been successfully completed. Soil samples were collected as planned and geochemical analysis of the surface samples providing insights into how surface geochemistry may be used as an exploration tool in Western Missouri. Background ERT surveys were conducted and the surveys provided insights into the proper electrode spacing to image through the Warner sand. Three ERT arrays were constructed and transported to location for use when needed. Core samples were taken from the Cushard #1 corehole and used to prepare the geomechanical dataset for designing the hydraulic fracturing treatment.

This DOE funded project has already been highly effective in promoting interest for other work in the area. At least two other developments north and south of the current leasehold are planned, or are underway. In addition, the Missouri Department of Natural Resources indicates a company is attempting to secure a lease over 60,000 acres. It is believed that the DOE project has helped to spur this interest in Western Missouri.

Figure 1. Leasehold in Vernon County.

Figure depicts the location of coreholes previously drilled and abandoned. Initially it was believed that area shaded in green would be proposed drilling area. Surface geochemistry indicates area around corehole #4 may be slightly better and this will be investigated in the final ERT work.

Figure 2. Student collecting soil samples over leasehold, February 2003.

Figure 3. Leasehold Base Map showing location of soil samples.

Figure 4. C₁-C₆ Composition

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Figure 5. C₁-C₆ Discrimination

Figure 6. Percent Pentane

Figure 7. Fluorescence Hydrocarbon Analysis SSF 1

Figure 8. Fluorescence Hydrocarbon Analysis SSF 410

Figure 9. SSF Intensity by Well

Figure 10. Wetness Ratio

Figure 11. Schematic of electrode arrays constructed for ERT imaging and relationship to depth in formation and location of zone of interest for MEOR

Sample ID	Depth, feet	Lithology	Static E, 10 ⁶ psi
03030401-A	110.50	Shale	1.03
03030501-A	119.00	Shale	1.44
03030502-A	121.50	L. Bluejacket SS	3.94
03031101	128.50	L. Bluejacket SS	3.12
03032401-B	130.00	L. Bluejacket SS	2.33
03032601	136.50	Rowe Coal	1.48
03032502-B	138.50	Rowe SS	2.44
03030701	144.00	Warner SS	0.92
03031102-A	167.00	Warner SS	1.30
03032402	170.00	Warner SS	1.72
03031001-A	176.00	Warner SS	0.96
03032501-B	178.00	Warner SS	1.56
03031002-B	191.00	Warner SS	1.52
03030601	200.30	Graydon Shale	3.27
00000211-B	211.00	Graydon Shale	1.43

Figure 12. Core Samples for Geomechanical Data

Figure 13. Electrical Resistivity Tomography Sample – Line from Corehole #5 to Corehole #4.
Vertical scale is depth in meters.