

DOE/BC/14869-4

University of Oklahoma Center for Reservoir Characterization

GYPSY FIELD PROJECT IN RESERVOIR CHARACTERIZATION

Contract Number: DE-FG22-95BC14869

Contractor: University of Oklahoma
Center for Reservoir Characterization
Norman, Oklahoma 73019

Contract Date: April 6, 1995

Anticipated Completion Date: April 5, 1997

Government Award: \$350,000 (Current Year)

Principal Investigator: Daniel J. O'Meara Jr.

Project Manager: Robert E. Lemmon
Bartlesville Project Office

Reporting Period: January 1 - March 31, 1996

Submitted to: Pittsburgh Energy Technology Center
U.S. Department of Energy
Wallace Road, Building 921 (Overnight Mail)
P.O. Box 10940, MS 921-118
Pittsburgh, Pennsylvania 15236
(412) 892-4862 (Telephone)
Document Control AD-20

RECEIVED
USDOE/PETC
95 JUN 13 AM 9:31
ACQUISITION & ASSISTANCE DIV.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

100 East Boyd, Room 510, Norman, Oklahoma 73019
Telephone: (405) 325-3821 Fax: (405) 325-3180

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

GYPSY FIELD PROJECT IN RESERVOIR CHARACTERIZATION

Objectives

The overall objective of this project is to use the extensive Gypsy Field laboratory and data set as a focus for developing and testing reservoir characterization methods that are targeted at improved recovery of conventional oil.

The Gypsy Field laboratory, as described by Doyle, O'Meara, and Witterholt (1992), consists of coupled outcrop and subsurface sites which have been characterized to a degree of detail not possible in a production operation. Data from these sites entail geological descriptions, core measurements, well logs, vertical seismic surveys, a 3D seismic survey, crosswell seismic surveys, and pressure transient well tests.

The overall project consists of four interdisciplinary sub-projects which are closely interlinked:

1. Modeling depositional environments.
2. Upscaling.
3. Sweep efficiency.
4. Tracer testing.

The first of these aims at improving our ability to model complex depositional environments which trap movable oil. The second entails testing the usefulness of current methods for upscaling from complex geological models to models which are more tractable for standard reservoir simulators. The third investigates the usefulness of numerical techniques for identifying unswept oil through rapid calculation of sweep efficiency in large reservoir models. The fourth explores what can be learned from tracer tests in complex depositional environments, particularly those which are fluvial dominated.

Summary of Technical Progress

During this quarter, the main activities involved the "Modeling depositional environments" and "Upscaling" sub-projects. The main accomplishments were as follows:

1. Constructed a "deterministic" model of the Gypsy Outcrop to serve as a "ground truth" model for evaluating both existing and future geological modeling tools.

2. Ran relaxed physics simulation on high resolution deterministic model of the Gypsy Outcrop with several well configurations and with several possibilities for the nature of transmissibility barriers across channel boundaries.
3. Prepared SPE Paper 35477 entitled "The Gypsy Outcrop Model for Testing Geostatistical Methods".

The first two items are described in the paper, excerpts from which are provided below. This paper suggests that the Gypsy Outcrop Model and the simulations run on it can serve as a basis for an SPE "Comparative Solutions Project" in geostatistics.

Introduction and Approach

Over the past decade, a number of geostatistical methods have emerged for modelling depositional environments. Although these methods enjoy wide acceptance, they have rarely been tested with realistic reservoir models. One reason for this is lack of quantitative data. Another is the lack of consensus on what constitutes a valid test. The present study addresses both of these problems.

Fluvial environments offer a particular challenge for geostatistical modelling. The key to unlocking recovery in such reservoirs lies in a better understanding of how reservoir architecture and connectivity affect sweep efficiency. The present study entails constructing a "deterministic" model of one such reservoir. This model describes six channels within a twenty meter interval of the well-characterized Gypsy sandstone of Northeastern Oklahoma. Detailed spatial distributions of reservoir properties (permeability, porosity, and lithology) have been obtained from extensive sampling and mapping of the geological units of this formation as it is exposed by strike and dip oriented roadcuts. In addition, three-dimensional data has been obtained from a grid of twenty-two boreholes, with oriented core, drilled within three hundred meters behind the primary strike oriented outcrop. This model is as complete and as densely sampled as any model of a producing reservoir is ever likely to be.

Simulations on the Gypsy Outcrop Model show that waterflood recovery efficiencies can be highly variable, depending on the choice of well placement and transmissibility multipliers. Recovery efficiencies are presented for the case of unit mobility ratio displacements. An important focus for comparing various geostatistical methods should be to determine whether they can mimic the variability in recovery efficiencies that is displayed by models such as the present one. The criteria for evaluating the relative merits of competing approaches should emphasize recovery efficiency, rather than mere visualizations of heterogeneities in porosity and permeability.

Just as with reservoir simulation, there needs to be an SPE "Comparative Solution Project" in geostatistics. The Gypsy Outcrop model presented herein can serve as one of several "ground truth" models for evaluating both existing and future geostatistical methods. Comparison of

flow modeling results using stochastic realizations constructed from such deterministic models will permit evaluations of the sensitivity of geostatistical methods to the type and amount of data available.

Reservoir Modelling

We have constructed a single “deterministic” reservoir model of the Gypsy Outcrop. This model honors all existing data as closely as possible. As such, the model represents our best understanding of the Outcrop. We adopt this model as our “ground truth” description. Granted, it cannot be an exact description for what actually exists. However, the model contains real data and represents a realistic geological interpretation. This model is as complete and as densely sampled as any model of a producing reservoir is ever likely to be.

There are six channels and one crevasse–splay facies within the Gypsy interval. The overbank or floodplain deposits are largely impermeable siltstone and mudstone; they may serve as partial flow barriers between channel sandbodies. Within channel sandbodies, lithofacies comprise the major heterogeneities. Four reservoir lithofacies have been defined within a typical channel sequence of Gypsy sandstone. From bottom to top, the lithofacies units are mudclast sandstone, cross–bed and plane–bed sandstone, ripple sandstone, and overbank deposit. These lithofacies have been defined based upon rock textures, geological constituents, and sedimentary structures.

Cross–bed and plane–bed facies exhibit best reservoir quality, with mean permeability of 864 md and mean porosity of 24.2%. The overbank facies is likely to act as a major flow barrier, although it does have a non–zero, measured mean permeability of 0.635 md and mean porosity of 11.5%. Mudclast and ripple facies are very heterogeneous, containing both reservoir quality rock and flow barriers. The mudclast facies has a mean permeability of 73.1 md and a mean porosity of 15.0%. The ripple facies has a mean permeability of 165 md and a mean porosity of 20.0%.

The channels and the crevasse–splay were distributed into the three–dimensional model (**Figure 1**) in the following way, using a standard software mapping package. For the first channel, the bottom surface and the isopach were mapped. The top of the first channel, also the bottom of the second channel, was determined by adding the isopach of the first channel to its bottom surface. For each subsequent sandbody, the isopachs were mapped and the top was determined by adding its isopach to the top of the underlying sandbody. For every isopach map, it was necessary to add control points to ensure that a geologically sensible result was obtained. Thus, geological interpretation was imbedded into the model.

Once the channels were determined, the various facies were distributed in the following way. For purposes of the present discussion, we have defined a “sequence” to consist of a unique combination of facies and channel or facies and crevasse–splay. For example, the mudclast facies in channel 2 defines a unique sequence. Using this terminology, our model consists of 24

sequences: 5 of the channels have the entire four facies defined above, channel 6 displays only 3 of these facies, the crevasse-splay consists entirely of the ripple facies. These sequences were mapped in the same way as the channels, except that additional control points to guide the mapping were limited by the position of the associated channel. The resulting lithofacies distribution is shown in **Figure 2**.

Each sequence has been sub-divided into layers of 0.3 m thickness which are parallel to the bottom of the sequence. These layers are truncated by the bottom of the overlying sequence. Within the 24 sequences there are 190 layers. The resolution in the areal plane is 47 x 48 gridblocks.

Waterflood Simulations

Simulations were performed in order to investigate three important effects: flow barriers, transmissibility multipliers for internal heterogeneities, and well configurations. To simplify the description of the flow, a unit mobility ratio simulator was used.

Flow Barriers. Four cases of flow barriers have been simulated for an isolated, inverted five spot configuration of wells:

1. Unimpeded flow across channel or facies boundaries.
2. No flow across channel boundaries.
3. No flow across sequence boundaries.
4. No flow across boundaries between high (cross-beds and plane-beds) and low (mudclast, ripple, and overbank) permeability lithofacies.

The first case entails allowing flow to be determined entirely by the permeability distribution, irrespective of considerations of boundaries between channels or lithofacies. The second case sets the transmissibility multiplier to zero across any gridblock interface for which there is a change in channels. The third case sets the transmissibility multiplier to zero across any gridblock interface for which there is a change in sequence. The fourth case sets the transmissibility multiplier to zero across any gridblock interface between high and low permeability lithofacies. In all cases, there is a constant rate of injection into a central well, with four production wells, at the corners, producing at the same constant bottom hole pressure.

Consider the geological reasonableness of these four models. The first and fourth cases are the most sensible. The former assumes that all of the flow boundaries have been explicitly mapped. The latter accounts for the possibility of clay or shale drapes between the high and low permeability facies. Case 3 is the least sensible insofar as it cuts off flow whenever either the channel or lithofacies change across interfaces between gridblocks. Case 2 requires some sort of barrier to have been deposited between channels, when the more likely situation entails one channel incising another, thus offering no impediment to sand upon sand contacts between

channels. Case 2, however, is not far-fetched in terms of what one might model. After all, to know that there are sand-sand contacts requires detailed modeling of lithofacies within the channels. Without such modeling it may be easy to assume the presence of barriers between channels.

Figure 3 shows the differences in oil recovery for up to 0.82 pore volumes of water injected. There are substantial differences between the various cases. As one would expect, case 1 shows the highest recovery and case 3 shows the lowest. The main reason for the relative positions of cases 2 and 4 is because the cross-bedded zones are fairly well connected across the model, irrespective of channel boundaries. In other words, cross-bed upon cross-bed, or good sand on good sand, contacts allow flow across channel boundaries in cases 1 and 4. These contacts are prevented in cases 2 and 3. **Figures 4 and 5** show oil saturation profiles along cross-sections emanating from the central well after injecting 0.82 pore volume of water. **Figure 4** depicts case 1, where there is unimpeded flow and **Figure 5** depicts case 2, where there is no flow across channel boundaries.

Internal Heterogeneity. We have explored the consequences of impeding flow in the vertical (Z) direction for the case of an inverted five spot and a line drive directed along the channels. Z direction transmissibility multipliers were chosen as a function of lithofacies (0 for overbank, 0.01 for mudclast, 0.02 for ripple, and 0.1 for cross and plane beds). The following three cases were investigated:

1. Five spot with unimpeded flow.
2. Five spot with Z direction transmissibility multiplier dependent on lithofacies.
3. Line drive along channels with Z direction transmissibility multiplier dependent on lithofacies.

Figure 6 shows the differences in oil recovery for up to 0.82 pore volumes of water injected. Oil recovery for the five spot is 0.06 pore volume less using the Z transmissibility multipliers of Table 3. The line drive recovers 0.13 pore volume more oil than the five spot, using Z transmissibility multipliers.

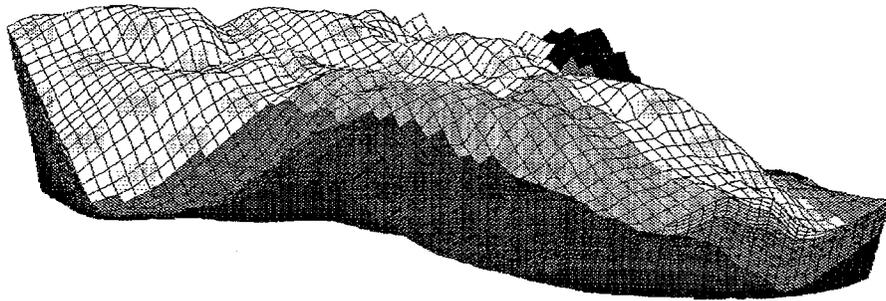


Figure 1. Distribution of six fluvial channels within Gypsy outcrop model, where shades of grey denote different channels.

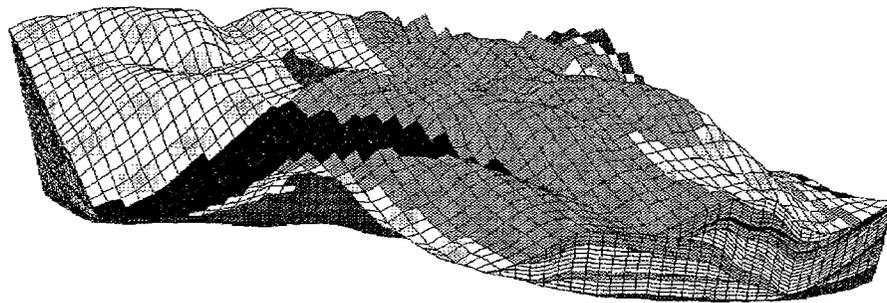


Figure 2. Distribution of lithofacies within Gypsy outcrop model. Shale is colored black. Low permeability lithofacies (such as mudstone) are dark grey. High permeability lithofacies (such as crossbeds and plane beds) are colored with lighter shades of grey.

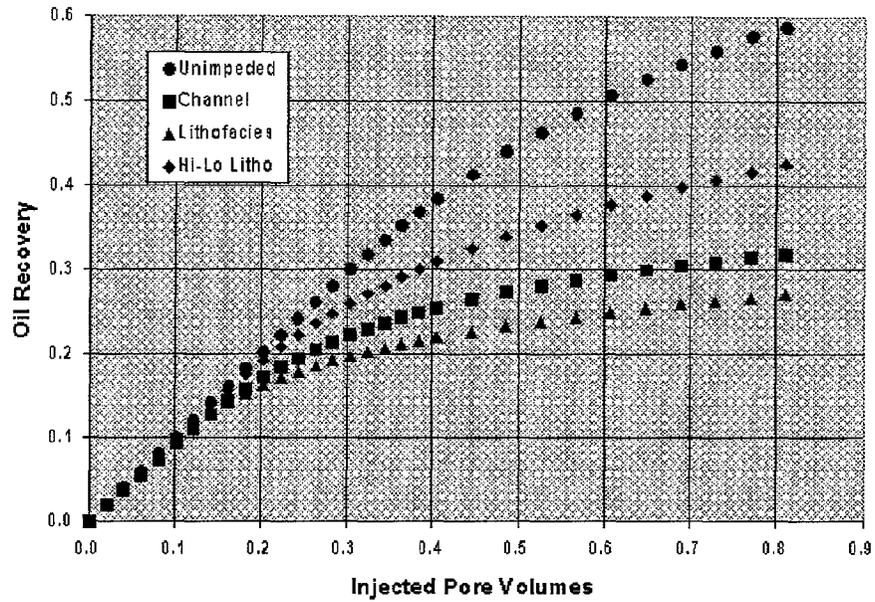


Figure 3. Oil recovery (in pore volumes) as a function of water injected (pore volumes) for four cases of flow in an inverted five spot: unimpeded flow across channel or lithofacies boundaries, no flow across channel boundaries, no flow across sequence (lithofacies/channel combination) boundaries, and no flow across boundaries between high (cross-beds and plane-beds) and low (mudclast and ripple) permeability lithofacies.

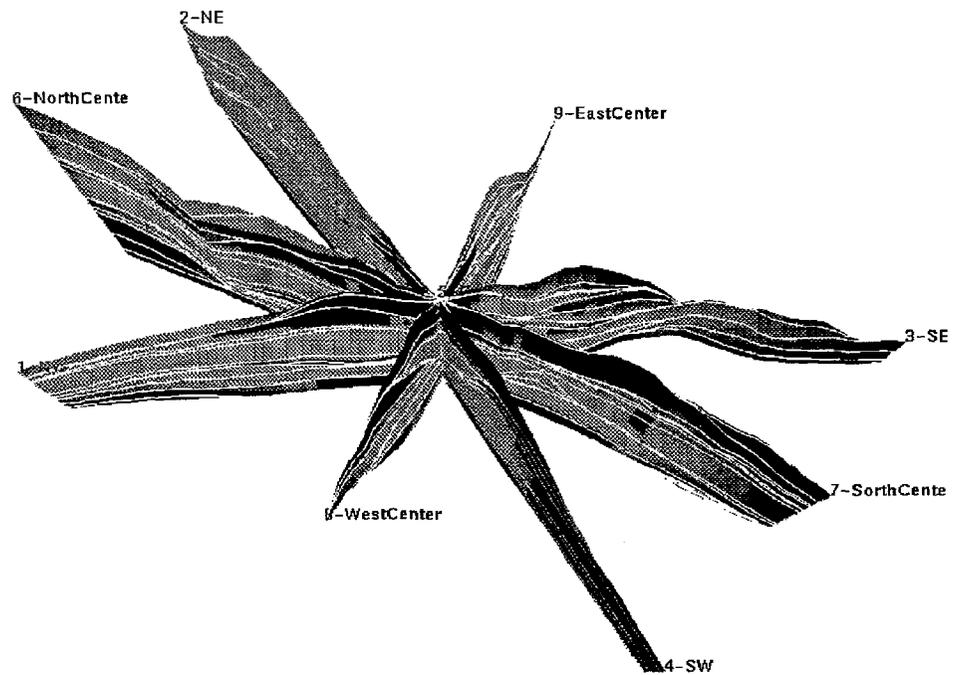


Figure 4. Cross-sections through central injector depict oil saturation (original oil is black) after injecting 0.82 pore volumes for the case of unimpeded flow across boundaries between either channels or lithofacies.

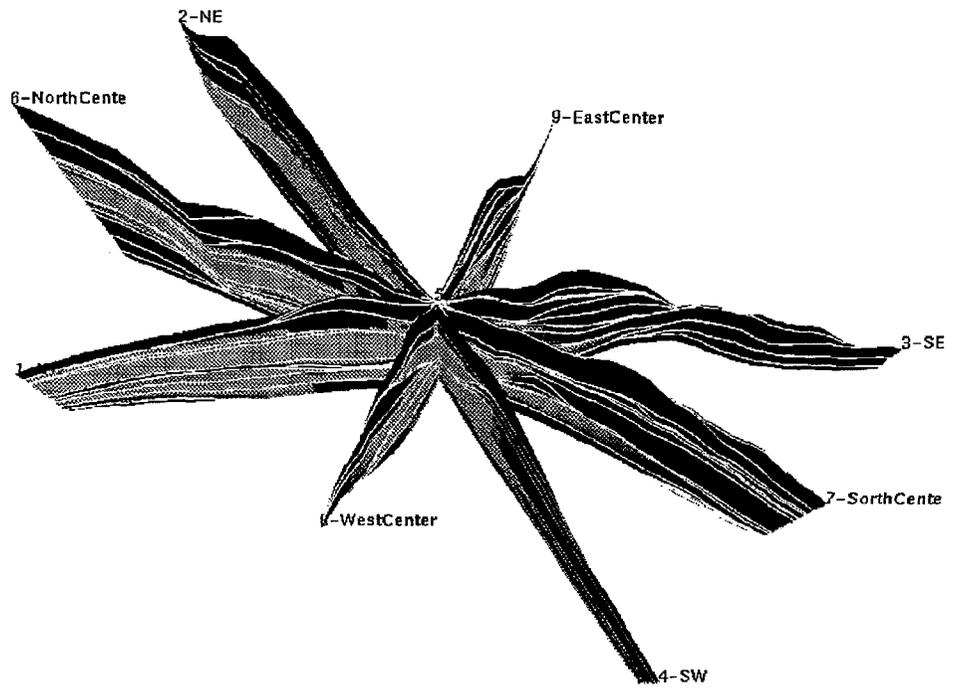


Figure 5. Cross-sections through central injector depict oil saturation (original oil is black) after injecting 0.82 pore volumes for the case of no flow across channel boundaries.

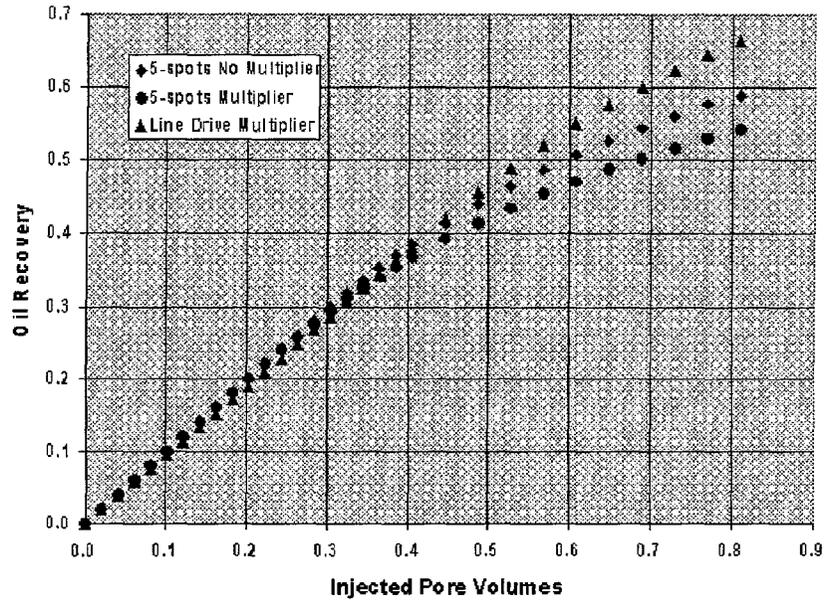


Figure 6. Oil recovery (in pore volumes) as a function of water injected (pore volumes) for three cases: five spot with unimpeded flow direction transmissibility multipliers dependent on lithofacies, line drive along channels with Z direction transmissibility multipliers dependent on lithofacies.

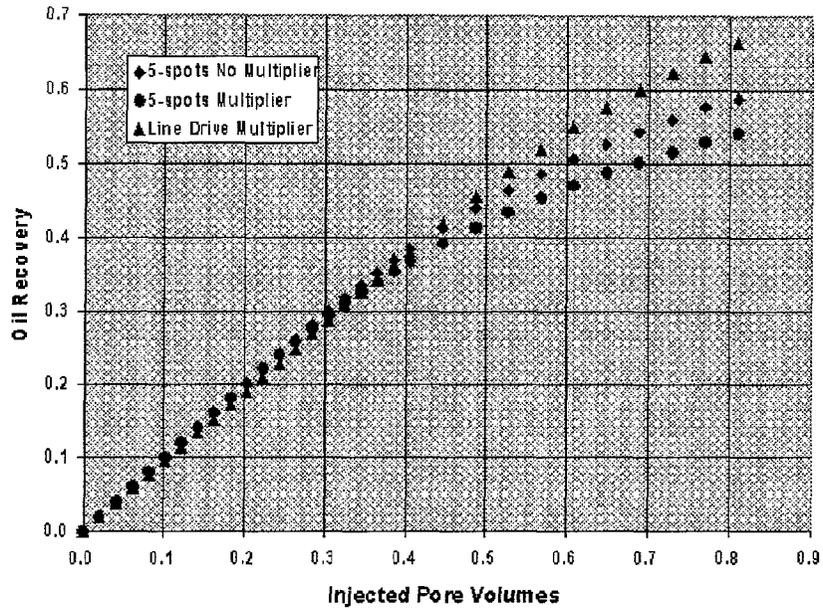


Figure 7. Oil recovery (in pore volumes) as a function of water injected (pore volumes) for three cases: five spot with unimpeded flow direction transmissibility multipliers dependent on lithofacies, line drive along channels with Z direction transmissibility multiplier lithofacies.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.