DOE/BC/14983--9

RECOVERY OF BYPASSED OIL IN THE DUNDEE FORMATION USING HORIZONTAL DRAINS

Cooperative Agreement No.: DE-FC22-94BC14983

Contractor Name and Address: Michigan Technological University, 1400 Townsend
Drive, Houghton, MI 49931-1295

Date of Report: 30 April 1996

Award Date: 28 April 1994

Anticipated Completion Date: 27 April 1997

Government Award for Current Fiscal Year: \$800,000.

Principal Investigator: James R. Wood (906) 487-2894

Project Manager: Chandra Nautiyal, Bartlesville Project Office (918) 337-4418

Reporting Period: January 1, 1995 - March 31, 1996

RECEIVED
USDOE/PETC
25 MAY -5 AM 10:49
DEPARTMENT OF ASSISTANCE DIV.

OBJECTIVE

The principal objective of this project is to demonstrate the feasibility and economic success of producing oil from abandoned or nearly abandoned fields in the Dundee Formation of Central Michigan using horizontal drilling technology.

A site for a horizontal well was selected in Crystal Field, a nearly-abandoned Dundee oil field in Michigan. This field had produced over 8 million barrels of oil, mostly in the 1930's and 1940's. At the height of development, Crystal Field produced from 193 wells, but by 1995, only seven producing wells remained, each producing less than 10 bbls/day. A horizontal well was drilled as a field demonstration pilot, funded through this DOE project, and was immensely successful. Core and logs from the Dundee interval were recovered from a vertical borehole at the same surface location. The horizontal well was brought on production at a rate of 100 bbls/day and is probably capable of producing at a higher rate. The addition of several horizontal wells, similar to the demonstration well, will likely add another 2 million bbls (or more) to the cumulative production of the field over the next few years. The presence of untapped oil in this Dundee field was dramatically demonstrated and the favorable economics were made clearly evident. If

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

other abandoned Dundee fields are re-developed in a similar manner, the additional oil produced could exceed 80 million barrels. Horizontal drilling will likely revolutionize the development of old carbonate fields such as those in the Dundee of Michigan.

Additional project work comprises characterization of 30 other Dundee fields in Michigan to aid in determining appropriate candidates for development through horizontal drilling. Further quantification of reservoir parameters such as importance of fracturing, fracture density, and irregularity of the dolomitized surface at the top of the reservoir will help in designing the optimal strategy for horizontal drilling.

Technology transfer takes place continuously, through the Michigan Oil Field Research Consortium (MOFRC) and its *Newsletter*. Reviews in the popular press have helped reach additional audiences. The success of the demonstration well has been recognized by independent operators, who have requested copies of information published the *Newsletter*, and who have expressed interest in attending workshops which are being planned for this year. The creation of an "Atlas of Michigan Dundee Reservoirs" is planned as a no-cost addition to this project. The Atlas will greatly enhance the capability of small operators in the state to independently explore and develop this neglected resource.

SUMMARY OF TECHNICAL PROGRESS BY TASK

BUDGET PERIOD 2

TASK 1 PROJECT MANAGEMENT

1.1 COORDINATION

The management tasks have gone smoothly this quarter. Various subgroups met and worked on subtasks throughout the quarter. Weekly staff meetings were established at Michigan Technological University (MTU) and are held every Tuesday and Thursday. Postdoctoral Research Associate M. Luo, who has played an integral role in several other major research projects at MTU, began working on 3-D surface and volume visualizations in the statistical and visualization software package MatLab, aided by graduate student B. Wei.

In February, J. Allan and W. Harrison described and sampled cores of dolomitized Dundee reservoir from the demonstration well in Crystal Field and from five other fields in our seven-county study area. Thin sections and fluid inclusion slides are currently being prepared and petrographic, geochemical, and fluid inclusion analyses will be performed on these samples. During the quarter, J. Wood traveled to the University of South Florida, Tampa, to work with M. Luo on the MatLab visualizations and Luo traveled to Michigan Technological University (MTU) to work with Wood and his graduate students on MatLab and other computer applications. On April 17, Wood, Luo,

Chittick, and Suchoski attended the Michigan Oil and Gas Association meeting in Mt. Pleasant, MI.

1.2 BUDGET AND REPORTS

M. Gruener and A. Hein are responsible for daily management of the budget and expenditures. A. Hein is responsible for preparation of quarterly financial reports and for distribution of all reports to DOE. J. Allan is responsible for quarterly and annual technical reports.

TASK 2 RESERVOIR CHARACTERIZATION

During the fall of 1995, the demonstration well for this project, the TOW No. 1-3 well in Crystal Field, was completed in the Dundee and for the first three months of operation produced 50 bbl/day oil with no water cut. Because surface facilities were inadequate to handle full production, the well was produced for 12 hrs/day and shut in for 12 hrs/day. In January, 1996, new surface facilities were completed and production was raised to 100 bbl/day. Daily production has varied from about 75 to 100 BOPD since that time. To date, the well has produced over 10,000 bbls. The water cut remains at 0% and pressure has been maintained at 1445 psi by an active water drive. If expectations are met, the well will pay out in less than 1 year and continue on production for at least 5 years. Cronus Development Co. is tentatively planning to drill three more horizontal wells in the Dundee in Crystal Field. Thus, the play concept we chose to test, that bypassed attic oil remained in the Dundee reservoir between wells that had been produced at excessively high flow rates and had coned water during primary production, appears to be correct, and the TOW No. 1-3 HD-1 well is now a scientific, and appears soon to become an economic, success.

We will soon acquire several existing seismic lines in the Crystal Field area and have been offered free processing of the lines by a commercial vendor. This data will add a significant dimension to our study.

2.1 CORE AND LOG ANALYSIS

The TOW No. 1-3 HD-1 well in Crystal Field (our DOE project well) was spudded on September 20, 1995 and cored and logged through the Dundee. One and one half weeks later, 59.3 ft of core was recovered from the top of the Dundee and the well was then drilled 150 ft below the base of the core to TD at the top of the Detroit River anhydrite. The vertical well was then logged from TD at the base of the Dundee (3334 ft) to the base of casing (683 ft), which corresponds approximately to the base of the glacial till. Haliburton ran 3 consecutive log suites, which included: 1) a gamma ray and dual laterolog with microresistivity, 2) a lithodensity log (compensated formation density plus photoelectric factor), and 3) a compensated neutron log. The logs were then correlated with a high degree of confidence and combined. The top portion of the Dundee displayed good oil staining in the core. Therefore, the log suite has good coverage of both the oil

leg and the water leg in the Dundee Formation. This was later confirmed by residual fluid saturation analyses of core samples.

During this quarter, K. Moss and two other staff members from Western Atlas spent two days at MTU discussing the Crystal Field well, logging techniques, and, in particular, use of the Circumferential Borehole Imaging Log (CBIL) with W. Pennington and other faculty and graduate students. We may arrange to run a borehole imaging log (which is excellent for identifying fractures and vugs) in one of the upcoming Crystal Field wells.

2.2 DATA MEASUREMENT AND ANALYSIS

The uppermost Dundee reservoir was cored in the TOW No. 1-3 HD-1 well. The coring point was in the lowermost Bell Shale, immediately above the Dundee. 59.3 ft of core were recovered out of a possible 60 ft (Fig. 2). The core was shipped to OMNI Laboratories in Houston where a core gamma ray log was run and the core was photographed under plane and ultraviolet light to reveal sedimentary structures and heterogeneities in oil saturation. Porosity, permeability, and residual fluid saturation analyses were performed on whole-core samples taken at 1 ft intervals.

Dolomite extends almost to the top of the Dundee, and the nonporous cap limestone, which is normally 10-15 ft thick in much of Crystal Field, is only 2 ft thick in the TOW No. 1-3 well. The upper 15 ft of the Dundee is heavily fractured in core and contains centimeter-sized vugs. Most fractures are subvertical with highly variable azimuths, but some fractures are developed at lower angles. Most fractures and vugs are lined with white, sparry dolomite. The top of the Dundee in the demonstration well was encountered 8 ft lower than projected. Together, these observations suggest that a top-down solution process (karst?) led to fracturing and collapse of the uppermost Dundee, which resulted in development of enhanced porosity.

Twenty nine feet of higher residual oil saturations at the top of the Dundee (3190-3219 ft) in the core indicate significant unrecovered oil. Beneath that, seven feet of lower residual oil saturations (3219-3226 ft) indicate either a transition zone or a swept zone where the oil-water contact moved up as a result of primary oil production. In the water leg below 3226 ft, residual oil saturations are 0.0%.

In February, W. Harrison and J. Allan examined the TOW No. 1-3 core and identified several cyclic grainstone-to-mudstone units, which range in thickness from 5 to 15 ft. The grainstones appear to be leached and have high porosities and permeabilities. They may account for a large proportion of the reservoir volume. More importantly, most open fractures are subvertical and are confined to the top of the reservoir, while grainstone beds may form sheet-like fluid-flow conduits that extend down to the oil/water contact. These high permeability grainstones, rather than fractures, may be responsible for the early watering out of many wells. Core samples were collected for thin section and fluid inclusion analysis. Allan and Harrison will undertake a detailed core study this summer.

Fourier Transform Infrared Spectroscopy (FTIR) - Calibration of FTIR standards is now complete. Additional samples were analyzed, but because of contamination and instrumentation problems, will have to be rerun. During this quarter, graduate student N. Popko ran error backgrounds on standards to help solve these problems. Graduate student B. Wei is handling the computer analysis of the data.

TASK 3 DATABASE MANAGEMENT

C. Asiala has completely transferred the Multimedia Database Management System to the commercial software package Toolbook. There are many advantages to using commercially available software vs a home-grown program to handle our data archiving and display needs. Documentation, tutorials, software support, and upgrades will all be taken care of by a commercial vendor and will relieve our project team of those responsibilities.

Microsoft Access is our relational database management platform. All of the log data is stored in Access in LAS format. All other data is stored Toolbook, in multimedia form, accessible via pulldown menus and a Table of Contents with hot links. Instructions for retrieving logs from the Access database are included in the Toolbook multimedia archive. Users can search the database by query and retrieve the logs from the main database table by well or by log type. Logs are then placed in smaller temporary Access tables from which they can be exported to applications programs. We now have a log database which is independent of all of our well-log evaluation programs (Crocker Petrolog, GeoGraphix QLA2, and TerraSciences TerraStation), but is capable of exporting data to any one of them.

The GeoGraphix Exploration System software package was acquired in fall 1995 and installed on a PC in the Subsurface Laboratory at MTU. Since that time, we have acquired an academic license and three additional seats on GeoGraphix. Graduate students S. Chittick and W. Everham attended a training course at GeoGraphix' headquarters office in December and Professor J. Huntton and graduate student W. Houston attended in February. We now have four Dongal keys to GeoGraphix and can run the program at multiple sites, which will greatly enhance progress.

S. Chittick loaded the Angstrom data base of 51,359 wells into GeoGraphix, along with initial production (IP) data for Winterfield Field. 3-D surface visualizations of structure and production data were constructed for the Dundee reservoir. Crystal Field data was loaded into GeoGraphix this quarter and IP contour and bubble maps were prepared. W. Everham and M. Slis have been highgrading and editing the Angstrom database. They created a new database composed of the deepest well in each section in the state of Michigan. This reduced the number of working wells from over 50,000 to about 10,000, while still providing sufficient information to produce the necessary stratigraphic and structural framework for our modeling effort.

3.1 TOPICAL REPORTS

W. Harrison has collected reservoir data for the 30 fields in our study area and is organizing and reformatting it into tables of reservoir parameters for the Topical Reports required by DOE and for inclusion in our "Atlas of Michigan Dundee Reservoirs" (see below). As he completes each field, he is forwarding the data to C. Asiala who is entering it in a Microsoft Access database, where it will eventually be input to the Toolbook Multimedia Database Management System and written to CD ROM..

3.2 DUNDEE ATLAS

We plan to create an "Atlas of Michigan Dundee Reservoirs", using these maps and cross sections as a cornerstone of the publication. As envisioned, such an Atlas would include a regional overview of Dundee stratigraphy and reservoir variability; development history of the trend, including comparisons between different fields; production history, including a discussion of engineering and completion techniques; and a table of important reservoir parameters for use in characterizing the Dundee reservoir in other old fields for which little data is available. The main body of the Atlas will consist of individual discussions of reservoir geology, engineering practices, and tables of reservoir parameters for each Dundee field. Discussion of the importance of fracturing, fracture density, and irregularity of the dolomitized surface will aid in the design of the optimal strategy for horizontal drilling. This Atlas will undoubtedly enhance the capability of the small operators in the state to independently explore and develop this neglected resource. The Michigan Basin Geological Society has expressed interest in publishing the Atlas.

3.3 PSEUDO-SEISMIC VISUALIZATION

3-D visualizations of the Michigan Basin have been constructed in MatLab. This commercially available statistics and visualization package is both flexible and powerful and can easily perform both 3-D surface and 3-D volume visualizations. M. Luo loaded the Angstrom database into MatLab and produced a 3-D volume visualization of the basin that shows the thickness and distribution of the Dundee and other key formations (Fig. 1). Cross sections can be made through the basin at any desired angle.

B. Wei is using MatLab to produce "pseudo-seismic" sections from SP and gamma ray-logs. Using Wei's program individual pseudo-seismic logs (log traces whose amplitudes have been color-coded to resemble seismic amplitude traces) can easily be selected from a map-view window and then displayed as well-log or pseudo-seismic cross sections (Fig. 2). This capability adds another useful dimension to our visualization capabilities. Current efforts are concentrating on using geostatistical methods to perform interwell correlations.

TASK 4 MODELING

4.1 GEOCHEMICAL MODELING

The geochemical modeling program CHILLER is being used to model fluid-rock interaction. The feasibility of porosity prediction using CHILLER is being investigated. Geochemical mass transfer work using CHILLER is being carried out by J. Suchoski. Two databases are currently being used. The thermodynamic database SOLTHERM contains thermodynamic information on fluid species, gases, and minerals. Over 400 species are contained in the database. The data are valid over a temperature range of 0°C to 300°C. The database OXYBASE is being used for oxygen isotope calculations.

4.2 BASIN MODELING

The following progress was made in the Basin Modeling subtask:

Michigan well data set: The same Angstrom data set which contains information on 51,359 Michigan wells will be used both in GeoGraphix and in our Basin Modeling programs. The data set includes well locations, formation tops, lithologies, etc., in a form that can be read directly into our GeoGraphix Exploration System software. After solving numerous formatting problems, S. Chittick loaded the data into GeoGraphix. W. Everham and M. Slis have been correcting data errors and nomenclature problems and have drawn well-location maps in GeoGraphix which display all wells that intersect each of the deeper formations in the Michigan Basin. They have produced a more manageable data set (of 10,000 wells) by selecting the deepest well in each section in the state of Michigan. They are now constructing a grid of regional structural cross sections through the basin. The cross sections serve two purposes. First, they make it easy to spot and correct bad picks and bad data. Second, once the errors are corrected and the structural cross section grid is completed, *stratigraphic* cross sections, hung on key marker horizons, will be constructed. These stratigraphic cross sections will enable our project staff to visualize the evolution of 3-D basin geometry through time and focus in on the times and areas of greatest interest for geologic modeling (e.g., the areas of rapid and maximum subsidence, where sourcerock maturation and oil generation are favored, will be immediately apparent).

This work is being done in preparation for using the Angstrom data in the modeling programs BasinMod and Akcess.basin. BasinMod will be used for 1-D and 2-D thermal maturation modeling. Access.basin uses a finite-element formulation to examine the effects of thermal processes (conduction, convection, advection), fluid flow processes (compaction-driven, hydraulic-head driven), sealing mechanisms, and sedimentation/erosion during the development of a sedimentary basin.

Everham is organizing the Michigan Department of Natural Resources' bottomhole temperature database for use in the modeling programs. Negotiations are still proceeding to have a major organic geochemistry study of the Michigan Basin, completed by Brown and Ruth Co., donated to the project.

The Angstrom database contains lithologic information on each formation in each well. The lithologic information is now in text format, but a project to numerically encode it will soon begin. A. Wylie and one of J. Huntoon's summer students will undertake this effort. Once the lithologic data is in numerical format, it can be used in facies mapping and sequence stratigraphic modeling programs. GeoGraphix management in Denver are interested in supporting this work, which will be part of Wylie's doctoral dissertation. If successful, they intend to incorporate facies mapping capability into the GeoGraphix Exploration System.

TASK 5 TECHNOLOGY TRANSFER

This task involves the transfer of information and useful products derived from this study to our target audience, the oil industry.

Internet Homepage

The Dundee Project has its own Homepage on the Internet, which is networked to the Geology Department at WMU. It can be reached at:
<http://www.wmich.edu/geology/corelab/coreres.htm>

5.1 MICHIGAN OIL FIELD RESEARCH CONSORTIUM (MOFRC)

Because of the MOFRC *Newsletter* and press releases, many people who are interested in horizontal drilling and the development of shallow shelf carbonate reservoirs, both within the Michigan Basin and in other areas, have contacted project personnel. Project members have heard that companies are starting to tie up Dundee acreage, presumably as a result of the success of our project well. Several calls were from principal officers of independent oil companies who requested information to help them initiate horizontal drilling programs.

5.2 REPORTS

Professional Papers and Presentations

In March, 1996, two presentations featuring project accomplishments were made at the Michigan Department of Natural Resources' Annual Symposium on "Michigan, It's Geology, Environment, and Resources". W. Harrison was the keynote speaker at the symposium luncheon and S. Chittick presented a poster session. Also in March, W. Harrison presented a project overview at the Petroleum Technology Transfer Council (PTTC) Regional Meeting in Grayville, IL. In April, Wood, Luo, Chittick, and Suchoski attended the Michigan Oil and Gas Association meeting in Mt. Pleasant, MI, where they informally discussed project results with members of the Michigan oil and gas community.

A paper describing the DOE Michigan Dundee project and the results of the Crystal Field demonstration well is in the final stages of preparation. It is entitled "Recovery of

Bypassed Oil Through Horizontal Drilling, Dundee Reservoir, Crystal Field, Michigan” and will be submitted the Oil and Gas Journal.

AAPG Computer Applications in Geology Volume

A. Wylie and J. Huntoon are editing a volume entitled "Practical Reservoir Characterization", which is to be published as a volume in the AAPG Computer Applications in Geology series. Wylie is writing the first six chapters, which constitute a "how-to" guide to computerized reservoir characterization. The remaining chapters will be case studies in reservoir characterization. One of the case studies will be a paper on the Dundee reservoir in Winterfield Field, co-authored by S. Chittick and W. Harrison.

Upcoming Events

In May, W. Harrison, J. Wood, and W. Pennington will present project results at the DOE Class 2 Project Review Meeting in Midland, TX. Also in May, project members will run a booth in the Exhibit Hall at the American Association of Petroleum Geologists (AAPG) National Meeting in San Diego, CA. Tentative plans have been made to take our AAPG exhibit to the June meeting of the Michigan Oil and Gas Association.

5.3 CD ROM AND MEETINGS

Multimedia Presentations on CD-ROM

C. Asiala has completely transferred the Multimedia Database Management System to the commercial software package Toolbook. The Toolbook archive will be featured in our booth at AAPG.

Meetings

In February, Allan and Harrison logged and sampled cores of Dundee reservoir from the TOW No. 1-3 well in Crystal Field and from five other fields in the seven-county study area. Petrographic, Xray diffraction, and fluid inclusion analyses will be performed on these samples in the coming months.

In February and March, Wood traveled to the University of South Florida, Tampa, to work with Luo on the MatLab visualizations and Luo traveled to MTU to work with Wood and his graduate students on MatLab and other computer applications.

In April, Allan traveled to MTU to work on the project. During his visit, P. Goodwin of Temple University visited MTU. Goodwin has been working on small-scale sedimentary cycles in Devonian rocks in Iowa that he believes are controlled by Milankovitch perturbations in the earth's orbital parameters. Allan, Wood, and Huntoon viewed the TOW No. 1-3 core with Goodwin and identified cycles similar in size and character to those in the Devonian of Iowa. Cycle-bottom grainstones have high porosities and permeabilities, and if the Iowa analogy is correct, also have great lateral continuity.

These small grainstone units may be as important as fractures and dolomitization in controlling reservoir architecture.

5.4 WORKSHOPS

In January, 1996, project members from MTU and WMU held a two-day workshop at MTU to examine the core from the demonstration well, to discuss project results, and to plan next year's technical program and publication schedule.

Figure 1. 3-D volume visualization of the Michigan Basin prepared in MatLab. The lower surface is the top Silurian. The Dundee Formation, Bell Shale, and Antrim Shale are shown above the Silurian surface. North is to the right along the X-axis.

Figure 2. "Pseudo-seismic" display constructed from gamma-ray logs. Individual "pseudo-seismic" logs can be selected from wells shown in map view by drawing a section line on the screen. Logs of wells along the section line are then displayed in cross section, with amplitudes color-coded according to amplitude, as shown here.