RECOVERY OF BYPASSED OIL IN THE DUNDEE FORMATION USING HORIZONTAL DRAINS

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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 other abandoned Dundee fields are re-developed in a similar manner, the additional oil produced domestically will probably be about 80 to 100 million bbls. 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. Two new students, W. Everham and M. Slis, joined the project and are correcting formatting problems and errors in the 51,359-well Angstrom database, which is currently being used in the GeoGraphix Exploration System. Part of Terra Energy was sold in September. The new company which holds the rights to Crystal Field is called Cronus Development Co. All of the people at Terra who were involved in planning and drilling our project demonstration well are now with Cronus, so project continuity is assured.

In November, 1995, J. Wood, W. Harrison, and M. Gruener traveled to Traverse City, MI to review well results with Cronus staff. In January, 1996, project members from MTU and Western Michigan University (WMU) met for two days at MTU to review project results and plan next year's program. In early February, 1996, J. Allan and W. Harrison described and sampled cores of the Dundee reservoir from other fields in the seven-county study area. Petrographic and geochemical analyses will be performed on these samples in the coming months.

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 last quarter, 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. The water cut remained at 0% and pressure was 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 currently planning to drill a second horizontal well in the Dundee in Crystal Field in the second quarter of 1996.

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 destined to become an economic, success.

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 (see Fig. 1). 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 (Table 1).

Well-log analysis and regional geological studies are being carried out by W. Harrison and his graduate students at WMU. Well data, including drillers' logs and wireline logs for the 8526 wells in our seven-county study area, which includes 4785 wells that penetrate the Dundee, are now in our oil and gas well data set. Maps and cross sections have
been completed for Crystal Field and for the 30 other Dundee oil fields in the study area. All these maps have been plotted on 81/2 x 11 pages and have been assembled by field into single "folio" sized poster sheets. These maps and cross sections are currently being compiled into notebooks for each field, along with field and reservoir data, field production histories and decline curves, type logs, and core data. These notebooks will be combined with an overview and summary evaluation volume to form an "Atlas of Michigan Dundee Reservoirs" (see discussion under Task 3.2).

Well-log analysis using TerraSciences TerraStation software is continuing. Lithologies and water saturations continue to be calculated for selected wells in the 30 fields in our seven-county study area using density/porosity and Pickett crossplots. Digitized logs were loaded into the GeoGraphix Exploration System well-log package QLA2 and a few trial log cross sections were constructed.

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 (Table 1).

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% (Table 1).

About 50 cores of the Dundee Formation from throughout the state of Michigan have been identified and are currently available in public repositories. Many of these cores will be described and samples will be taken for thin section, X-ray diffraction, SEM, and geochemical analyses to determine mineralogy and porosity characteristics. Cuttings samples from 60 to 100 Michigan wells are also available. In early 1996, Harrison and Allan examined core from several Dundee fields near Crystal Field and collected samples for petrographic and geochemical analysis.

**Fourier Transform Infrared Spectroscopy (FTIR)** - FTIR spectral analyses and Inductively Coupled Plasma Spectroscopy (ICP) chemical analyses were collected on a suite of mineral standards by graduate student N. Popko. Data reduction was completed during this quarter. Spectral data from standards were input to MatLab, a numerical computation and visualization software package, which was then used to generate non-negative least-squares (NNLS) fits to the data. ICP elemental analyses were converted to oxides, and mineralogies were calculated and used to cross-check the FTIR results.

The FTIR technique will next be used to analyze Dundee core samples. Popko is doing this work as his Master's research under the direction of W. Pennington.

**Fluid Samples** - Hydrocarbon and produced-water samples will be collected from the demonstration well in Crystal Field. If possible, arrangements will be made to sample fluids from other Dundee fields as well. Inorganic geochemical analyses of produced brines will be used in conjunction with isotope and fluid inclusion analyses of core and cuttings to determine the origin and history of the porosity-producing dolomitizing fluid.

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A data set containing over 77,000 geochemical analyses of brines from wells throughout the United States, was acquired from a commercial database vendor. The database was organized and input to a Microsoft Access database by C. Asiala and the well locations for all Michigan wells which contain brine analyses were plotted on a basemap using GeoGraphix.

**TASK 3 DATABASE MANAGEMENT**

Currently, project personnel at Western Michigan University (WMU) are using TerraSciences' TerraStation software to analyze and archive project data, while the MTU group is using GeoGraphix to analyze project data. C. Asiala is developing Microsoft Access databases to archive analytical data and digitized log traces at MTU. Once in Access, this data can be transferred easily to a variety of applications software packages.

During this quarter, Asiala completed the construction of Microsoft Access databases to archive analytical data and digitized log traces. She solved the problem of slow retrieval speed in the log database by creating two tables in Access: a) a log header table, which serves as a directory to the locations of the LAS log files in b) the main Access log database table. Logs can be retrieved from the main database table by well or by log type. They 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.

B. Watkins continues to improve the Multimedia Database Management System which has been written in Microsoft Visual Basic 3.0. He completed the input interface CrystalBuilder which makes it possible for anyone in the project to easily input text or graphics to the Database Management System. With CrystalBuilder, data input now consists of calling up a List Box of Files and a List Box of Destinations, then simply clicking and dragging the files to their desired destinations. The Database Management System is fully operational. Interim project results have been written to CD ROM for another DOE project being carried out at MTU, and we will begin construction of a Multimedia presentation for the Michigan project this quarter. C. Asiala has developed a routine for easily retrieving archived LAS log files from the CD ROM for use in applications programs.

Asiala has been testing the ability of the commercial software package Toolbook (by Asymetrix) to do many of the same things that are handled by the VB Database Management System. There are several 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. In addition, Toolbook performs several tasks better than the VB Database Management System, e.g., it can scroll much more quickly through logs, maps, and other large graphics displays.

The GeoGraphix Exploration System software package was acquired last quarter and installed on a PC in the Subsurface Laboratory at MTU. Graduate students S. Chittick and W. Everham attended a training course at GeoGraphix' headquarters office in December. Chittick later gave a course on the use of the GeoGraphix Exploration System for other graduate students at MTU.

W. Pennington arranged for MTU to get three additional seats on GeoGraphix for free, as part of the company's academic incentive program. We now have four Dongal keys to GeoGraphix and can run it at multiple sites, which will greatly enhance progress toward achieving project objectives.

S. Chittick wrote import files for loading well-location, deviation, formation-top, and log-trace data into GeoGraphix. Chittick has since 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. The United States Geological Survey (USGS) Digital Land Grid was also acquired. This data set contains surface data, such as the locations of roads, rivers, towns, etc., for the entire United States. The National Geophysical Data Center's Gravity Data CD ROM was acquired and the Michigan portion of the data set was input to GeoGraphix. Bouguer anomaly and second-derivative contour maps were constructed and displayed at several scales, including the state, seven-county study area, and field levels.

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Thirty Dundee fields are being studied in this project. Well data (drillers' logs and scout tickets), log data, and production data sets for all 30 fields are now complete. Structure contour maps of the top Dundee, the top Dundee porosity, and the tops of several other formations, as well as contour maps of initial production (IP) and simple cross sections have been completed for all 30 study fields using TerraSciences' Terrastation at WMU. The data are currently stored in the TerraSciences' database at WMU, but will soon be available at MTU as well. Digitized well logs from selected wells were read into the WMU database and many intervals were evaluated for $S_o$ and other calculated parameters during the last quarter. These calculations are continuing and will be made for the Dundee reservoir interval in most wells in the seven-county study area which contain modern log suites.

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 Multimedia Database Management System and written to CD ROM.

3.2 DUNDEE ATLAS

Plans to create an "Atlas of Michigan Dundee Reservoirs", using these maps and cross sections as a cornerstone of the publication, are under consideration. 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. Discussion of the importance of fracturing, fracture density, and irregularity of the dolomitized surface would aid in the design of the optimal strategy for horizontal drilling. This Atlas would 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

The project purchased the numerical computation and visualization software package MatLab. J. Wood input gamma-ray logs from wells in Winterfield Field. A "pseudoseismic" cross section of the field was generated and the results were encouraging. M. Luo recently used MatLab to create rotatable 3-D images of the structurally contoured tops of several reservoirs and is working on 3-D volume visualizations.

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.
in both 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 maps in GeoGraphix of the locations of all wells intersecting each of the deeper formations in the Michigan Basin. They have also constructed several regional cross sections across the basin. This work is being done in preparation for inputting the Angstrom data to Akcess.basin (see below).

**Akcess.basin - 2-D, 3-D Basin Modeling Software:** Late last year, Akcess.basin was acquired and installed on the Sun Workstation in the Subsurface Laboratory at MTU. This software 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. The program also predicts hydrocarbon generation (timing, location, and rate) and migration patterns. A 3D version is now running.

**Brown and Ruth Report:** Arrangements are being made to have a major organic geochemistry study of the Michigan Basin, completed by Brown and Ruth Co., donated to the project. The study contains a very complete set of thermal indicator data: vitrinite reflectance (Ro), thermal alteration index (TAI), conodont alteration index (CAI), and spore coloration index (SCI), that will be very useful in our modeling effort.

**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 now 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](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. During November and December, 1995, J. Huntoon, J. Wood, W. Pennington, and W. Harrison all received at least five phone calls per week about the project. Geologists and managers from KEP Exploration of Traverse City, MI, and Richland Petroleum of Denver, CO, visited Harrison at WMU to review well results and well data. Several project members have been contacted repeatedly by Unocal staff members. Unocal plans to drill several horizontal wells to the Dundee Formation in Porter Field in 1996.

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. Since publication of the first MOFRC Newsletter last summer, our group has received twenty five requests for inclusion on the mailing list.

5.2 REPORTS

Professional Papers and Presentations
In October, 1995, W. Harrison presented talks entitled "Improved Oil Recovery from Old Fields in the Dundee Formation, Michigan Basin" to the Geology Department at the University of Illinois-Chicago; "Improved Oil Recovery Using Horizontal Drilling in Oil Fields, Michigan Basin" to the Geology Department at Western Michigan University; and "Improved Recovery Using Horizontal Drilling in the Dundee Formation, Michigan Basin" to the Ontario Petroleum Institute in London, Ontario, Canada.


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.

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Upcoming Events
In March, 1996, two presentations featuring project accomplishments will be made at the Michigan Department of Natural Resources' Annual Symposium on "Michigan, It's Geology, Environment, and Resources". W. Harrison will be the keynote speaker at the symposium luncheon and S. Chittick will present a poster session. Also in March, W. Harrison and J. Wood will present a project overview at the Petroleum Technology Transfer Council (PTTC) Regional Meeting in Grayville, IL. In May, J. Wood and W. Pennington will present project results at the DOE Class 2 Project Review Meeting. Also in May, various project members will run a booth in the Exhibit Hall at the American Association of Petroleum Geologists (AAPG) National Meeting in San Diego, CA.

5.3 CD ROM AND MEETINGS

Multimedia Presentations on CD-ROM
Work continued on the Visual Basic programming for the Multimedia Database Manager. A parallel pilot program to determine the viability of using the commercial software program Toolbook (by Asymetrix) to perform the same function is underway. This approach has some advantages over using a home-grown program. 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. In addition, Toolbook performs several tasks better than the VB Database Management System, e.g., it can scroll much more quickly through logs, maps, and other large graphics displays.

Meetings
In September and October, 1995, Wood, Harrison, Huntoon, Pennington, Gruener, Chittick, and several WMU students traveled to the Crystal Field drill site to be present for drilling, coring, logging, and testing of the Crystal Field test well. E. Taylor of Terra Energy (now Cronus Development Co.) acted as the well-site geologist on the well. In November, 1995, Wood, Harrison, and Gruener traveled to Traverse City, MI, to review the drilling and completion results with Cronus' staff.

In early February, 1996, Allan and Harrison logged and sampled cores of Dundee reservoir from other fields in the seven-county study area. Petrographic and geochemical analyses will be performed on these samples in the coming months.

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.

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Figure 1. Diagram showing wireline log traces for vertical borehole and trajectory of horizontal borehole in Dundee project demonstration well.

Figure 2. Core-description log for cored interval in Dundee project demonstration well.

Table 1. Results of porosity, permeability, and fluid saturation analyses performed on whole-core samples taken at 1 foot intervals from cored interval in the Dundee project demonstration well.

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