RECOVERY OF BYPASSED OIL IN THE DUNDEE FORMATION USING HORIZONTAL DRAINS

QUARTERLY TECHNICAL REPORT
01/01/1997 - 03/31/1997

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REPORT ISSUE DATE: 04/30/1997

DE-FC22-94BC14983

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Abstract

This Class II field project has demonstrated that economic quantities of hydrocarbons can be produced from abandoned or nearly abandoned fields in the Dundee Formation of Central Michigan using horizontal drilling technology. The site selected for the demonstration horizontal well was Crystal Field, a nearly abandoned Dundee oil field in Montcalm County, 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, the TOW 1-3, drilled as a field demonstration pilot was successful, producing at rate of 100 bbls of oil per day with a zero water cut. Although the well is capable of producing at a rate of 500+ bbls/day, the production rate is being kept low deliberately to try to prevent premature water coning. Cumulative production exceeded 50,000 bbls of oil by the end of April, 1997 and lead to the permitting and licensing of several dozen Dundee wells by project end. Twelve of these permits were for continued development of Crystal Field.

Two subsequent wells, the Frost 5-3 and the Happy Holidays 6-3, have not been as successful. Both are currently producing 10 BOPD with 90% water cut. Efforts are underway to determine why these wells are performing so poorly and to see if the situation can be remedied. The reasons for these poor performances of the new wells are not clear at this time. It is possible that the wells entered the Dundee too low and missed pay higher in the section. When the TOW 1-3 was drilled, a vertical probe well was also drilled and cored. That probe well penetrated the pay zone and helped guide the horizontal well. The important lesson may be that vertical probe wells are a crucial step in producing these old fields and should not be eliminated simply to save what amounts to a small incremental cost.

Core and logs from the Dundee interval were recovered from a vertical borehole at the same surface location. The addition of several horizontal wells will likely add another 2 million bbls (or more) to the cumulative production of the field over the next few years. If other abandoned Dundee fields are re-developed in a similar manner, the additional oil produced could exceed 80 million barrels.

Additional project work involved the characterization of 28 other Dundee fields in Michigan to aid in determining appropriate additional 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.

The project was a cooperative venture involving the U. S. Department of Energy, Michigan Technological University (MTU), Western Michigan University (WMU), and Terra Energy (now Cronus Development Co.) in Traverse City, MI.

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EXECUTIVE SUMMARY

The principal objective of this project was to demonstrate that economic quantities of hydrocarbons could be produced from abandoned or nearly abandoned fields in the Dundee Formation of Central Michigan using horizontal drilling technology. The project was a cooperative venture involving the U. S. Department of Energy, Michigan Technological University (MTU), Western Michigan University (WMU), and Terra Energy (now Cronus Development Co.) in Traverse City, MI.

The first demonstration horizontal well for the project was drilled at Crystal Field, a nearly abandoned Dundee oil field in Montcalm County, Michigan. This field had produced over 8 million barrels of oil, mostly in the 1930's and 1940's. This well, the TOW 1-3 was successful, producing at rate of 100 bbls of oil per day with zero water cut. Although the well is capable of producing at a of 500+ bbls/day, the production rate is being kept low deliberately to try to prevent premature water coning. Two subsequent wells, the Frost 5-3 and the Happy Holidays 6-3, have not been as successful. Both are currently producing 10 BOPD with 90% water cut. Efforts are underway to determine why these wells are performing so poorly and to see if the situation can be remedied.

Cumulative production exceeded 50,000 bbls of oil by the end of the project (April, 1997) and lead to the permitting and licensing of several dozen Dundee wells by project end. Twelve of these permits were for continued development of Crystal Field. Two long (1800 ft.) horizontal wells were drilled successfully in Crystal after the TOW 1-3, but were disappointing economically. Core and logs from the Dundee interval were recovered from a vertical borehole at the same surface location. The addition of several horizontal wells will likely add another 2 million bbls (or more) to the cumulative production of the field over the next few years. If other abandoned Dundee fields are re-developed in a similar manner, the additional oil produced could exceed 80 million barrels.

Additional project work involved the characterization of 28 other Dundee fields in Michigan to aid in determining appropriate additional 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 through the Michigan Oil Field Research Consortium (MOFRC) a project Newsletter, reviews and workshops.

INTRODUCTION

In this reporting period, two new horizontal wells were drilled and put on production at Crystal field (Fig. 1). These new wells, the Frost 5-3 and the Happy Holidays 6-3, produce about 10 POPD with a 90% water cut. This contrasts with the TOW 1-3, which has produced on average 100 BOPD with zero water cut for over 1 year. The reasons for these poor performances of the new wells are not clear at this time. It is possible that the wells entered the Dundee too low and missed pay higher in the section. When the TOW 1-3 was drilled, a vertical probe well was also drilled and cored. That probe well penetrated the pay zone and helped guide the horizontal well. The TOW 1-3 horizontal well was then deviated higher in the Bell Shale than initially planned and entered the Dundee 15-20 feet higher than would have been the case without the vertical probe well.

The lesson may be that vertical probe wells are a crucial step in producing these old fields and should not be eliminated simply to save what amounts to a small incremental cost. This suggestion is even more cogent considering that most of the old Dundee fields are not well characterized. While the Dundee Formation contains more than 137 fields, very few of the original wells in any field penetrated beyond the top of the Dundee. This study investigated 30 of these fields located in the central Michigan Basin (Fig.2), all of which are candidates for further recovery efforts and modern reservoir characterization studies need to be conducted on at least 2/3 of these fields.

SUMMARY OF TECHNICAL PROGRESS BY TASK

PROJECT MANAGEMENT

PROJECT END SUMMARY

In general, management of this project went smoothly this period. Considering that entities ranging from universities and companies to individual consultants were involved and were spread over wide distances, project management required flexibility and some novel approaches. The project is winding down, personnel are leaving the project as the remaining tasks mainly involve technology transfer and monitoring the wells already drilled.

Budget and Reports

The budget and reports subtasks are progressing smoothly. Rock Energy (formerly Terra Energy has recently offered an additional $300,000+ for additional cost share from the two new wells. If these costs can be included in the project, the private sector cost share will approach 70% or more.

RESERVOIR CHARACTERIZATION

Summary of the Frost and Happy Holidays Demonstration Wells

During the fall of 1996, two additional demonstration wells were drilled for this project, the Frost 5-3 and the Happy Holidays 6-3 in Crystal Field (Fig. 1). These wells were completed in the Dundee Formation and for the first three months of operation produced 10 bbl/day oil with 90% water cut. Rock Energy is currently studying these wells in an effort to see if production can be increased. It is possible that these wells will be taken off production.

Completion reports to the State of Michigan were not available in time for this report but should be ready for nest quarter. These reports will provide more details on the mechanics of the wells. No vertical wells were drilled and no logs were run, so extensive analysis is ruled out.

The information at hand for these wells was input into the GeoGraphix Exploration System software package and is running on a PC in the Subsurface Laboratory at MTU. Formation-top picks for all formations penetrated by all wells in Crystal Field and surrounding area are available for constructing structure and isopach maps.

The electronic version of the "Atlas of Michigan Dundee Reservoirs", using the maps and cross sections of our 30 project fields is moving along and data and maps for a number of fields is now available on the Internet. This Atlas will 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 The Michigan Basin Geological Society has expressed interest in publishing the Atlas.

We have acquired several existing seismic lines in the Crystal Field area and have been trying to get these lines read into our GeoGraphix software packages as well as sending it downstate for processing. This data will add a significant dimension to our study.

CORE AND LOG ANALYSIS

W. Harrison and his graduate students at WMU are finishing the well-log analysis and regional geological studies. Well data consisting of drillers' logs and wireline logs for the 8526 wells in our seven-county study area includes 4785 wells that penetrate the Dundee, were acquired from Maness Petroleum Co. and are now in our oil and gas well data set. Formation tops have been picked for all formations in all wells. 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 8 ½ 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.

Well-status and production-decline curves have been prepared for all 30 study fields and are now available on the Internet. Decline curves are proving to be a very useful tool for identifying fields that have significant remaining unrecovered oil and are good candidates for enhanced oil recovery programs.

FIELDS SELECTED FOR RESERVOIR CHARACTERIZATION

In addition to the proposed field trial at Crystal Field, 29 additional SSR fields in portions of seven counties have been selected for study in the reservoir characterization portion of this project. These reservoirs are located in parts of 88 townships in a 3170 square mile area of the central Michigan basin. Currently, these fields include (see Fig. 2):

COUNTY	FIELDS
Clare	Cranberry Lake, Cranberry Lake East, Freeman-Redding, Lake George, Winterfield
Gladwin	Skeels
Isabella.	Broomfield, Coldwater, Currie, Gilmore, Isabella, Leaton, Sherman, Vernon-Rosebush, Wise
Mecosta	Fork, Hardy Dam
Missaukee	Mcbain, Prosper, Prosper South, Riverside

Montcalm	Belly Achers, Cato, Crystal, Douglass, Reynolds
Osceola	Cat Creek, Cedar, Evart, Sylvan

Table 1. List of additional Dundee study fields for Michigan DOE project.

These reservoirs have produced over 110 million barrels of oil, about one-third of the production for the entire Dundee. Discovery dates for these reservoirs range from 1929 to 1979, but most were discovered and produced being during the 1930's and 1940's. A few fields have been abandoned but many have maintained at least a few producing wells. However these are at increased risk of abandonment in the near future. All of these fields have been produced through the primary production phase only; no secondary or enhanced recovery operations have yet been attempted.

CORE ACQUISITION AND ANALYSIS

No core was taken on the two new wells at Crystal Field. Cuttings samples from the wells are currently in the possession of Rock Energy, but will shortly be turned over to the repository at Western Michigan. We have recently become aware of a logging service being offered by Advanced Hydrocarbon Stratigraphy of Tulsa, OK. This company is producing well logs consisting of the HC signature from the fluid inclusions contained in well cuttings or core. This service is relatively inexpensive, $10/sample with a minimum of 100 samples and we have decided to have this log run on the TOW 1-3 core and cuttings. The technique was developed at AMOCO and is being offered by M. Smith, a consultant who was involved in the AMOCO development.

DATABASE MANAGEMENT

As reported previously, Microsoft Access was selected for a relational database management platform. All project data is now either in Access or being prepared for entry into Access. All of the log data are now stored in Access in LAS format. Nearly all project data, probably 90% is on the Internet and is accessible via pulldown menus and a Table of Contents with hot links. Instructions for retrieving logs from the Access database are included in the 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..

Several new databases related to the Michigan subsurface are under construction. A database containing data on the deepest wells in Michigan has been constructed and well logs from these wells are being digitized. In addition, the wealth of information recently acquired from CMS-NOMECO is being indexed. Details on the data are reported below.

Database Management System

As part of this project, a system based on CD-ROM technology was developed to track and report progress and to serve as a data repository. It was also decided that the project data would be available on the Internet as well as on a CD-ROM. After evaluating the pros and cons of using Asymetrix Toolbook and the HTML Internet Language, it was decided to use HTML coding and discontinue use of Asymetrix Toolbook. We found that Asymetrix Toolbook had a plug-in for viewing Toolbook applications online, but too many of the features would not work correctly. Instead of duplicating our efforts by bringing data into Toolbook and constructing a Web page with the same data, we made the decision to drop Toolbook and put everything on the Web page using HTML coding.

MODELING

BASIN MODELING

We have obtained a commercial data set that contains information on 51,359 Michigan wells. These data will be used extensively in 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, work has shifted to correcting and updating data errors and nomenclature problems. Well-location maps are being prepared in GeoGraphix, which will display all wells that intersect each of the deeper formations in the Michigan Basin. This has produced a more manageable data set (of 10,000 wells) by selecting the deepest well in each section in the state of Michigan. Work is now concentrated on constructing a grid of regional structural cross sections through the basin.

This work is being done to prepare the Angstrom data for use 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, and advection), fluid flow processes (compaction-driven, hydraulic-head driven), sealing mechanisms, and sedimentation/ erosion during the development of a sedimentary basin.

Students are organizing the Michigan Department of Natural Resources' bottom-hole temperature database for use in the modeling programs. Negotiations are proceeding to acquire a major organic geochemistry study of the Michigan Basin, completed by Brown and Ruth Co., through donation to the project.

The Aangstrom Precision Corp. database also contains lithologic sample descriptions (LSD) for the deepest well with the most log information in each section. These LSD data are available for 11,474 wells in the Lower Peninsula. Using GeoGraphix Exploration Systems software, a map was produced showing the location and a color-coded total depth of these LSD wells. These LSD data are listed in the Aangstrom database by depth interval followed by the dominant lithology for that interval. The lithologies are designated by two letter codes, e.g. LS = limestone, AN = anhydrite. A FORTRAN program (LithLog) was written to extract these lithology data directly from the database and output a Log ASCII Standard (LAS) file. The program creates a lithologic well log which is virtually the same as any "standard" well log, e.g. gamma ray or neutron density, but with the dominant lithology per depth step as output. The following is an abbreviated description of the program operation.

A poster titled "Subsurface Databases: Graphical Display and Error Detection for Stratigraphic Interpretation in the Michigan Basin" was presented at the 1996 GSA Annual meeting in Denver, CO October 28th. The poster focused on the graphical display of information derived from the FORTRAN lithology extraction program (LithLog) described above. The poster included sections on the utility of this type of lithology display for detecting errors in the database as well as its usefulness in correlating sequences in the basin. Further, the lithology log display was combined with conventional logs, e.g. gamma ray and neutron density. This has resulted in a graphical display that would prove quite useful as a tool to facilitate the recognition of conventional log responses to different lithologies. At this time, a paper is being prepared for publication in the Journal of Geological Education. This paper will include a copy of the LithLog program.

THERMAL MODELING

The thermal modeling study has focused to date on the use of one-dimensional models to determine the thermal history of the Michigan Basin. The Michigan Basin's thermal history is extremely complex and although extensively investigated, no previous study has resulted in a model that satisfies the observed thermal maturity data for the basin.

Previous studies have produced two main hypotheses about the basin's thermal history. The two hypotheses are that:

1) elevated basal heat flow affected the basin during its early history, and

2) significant amounts of Pennsylvanian and Permian strata must have at one time been present in the basin.

Our study demonstrates that both of the previously proposed hypotheses must be accounted for in any model that produces results consistent with the observed data. Our results also demonstrate that a successful model must incorporate a significant erosional event at approximately the Silurian/Devonian Systems boundary. The Silurian/Devonian boundary corresponds to the transition from the Tippecanoe II to Kaskaskia Sequence, and an erosional unconformity at that stratigraphic level has been recognized and used for correlation for over thirty years.

The results of the modeling are best displayed in graphical form. Figure 3 is a graphical representation of the burial history used in the preferred model and described above. The tops of the labeled stratigraphic units lie directly above the labels. Other lines represent tops of different depositional units. Figure 4 a semi-log plot of %Ro vs. depth, shows the values obtained by modeling, compared directly to the observed data. This Figure in particular demonstrates that the model produces an excellent fit to the observed data.

TECHNOLOGY TRANSFER

PROFESSIONAL MEETINGS AND PUBLICATIONS

SEG Development and Production Forum

J. Huntoon and W. Pennington presented posters at the SEG Development and Production Forum on "Cooperative Projects to Improve Reservoir Management" in Colorado in June, 1995. Pennington discussed the Michigan Dundee Project and another MTU DOE project involving computer visualization of reservoirs in the San Joaquin Valley, California, in which Michigan Tech is participating. Huntoon presented a poster display on Technology Transfer. The Technology Transfer talk, entitled "Facilitating interaction between universities and industry: mechanisms for personnel and technology transfer", elicited much favorable comment. Huntoon was asked to re-present it as an invited paper at the SEG Annual Meeting. Our representatives at this meeting found it to be very successful in facilitating communication (and Technology Transfer) between various groups carrying out DOE sponsored projects.

Professional Papers and Presentations

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.

INTERNET HOMEPAGE

The Dundee Project now has its own Homepage on the Internet, which is networked to the Geology Department at WMU, can be reached at http://www.geo.mtu.edu/svl/.

We are using Microsoft Internet Explorer as our browsing program. For our end users that do not have Internet access, we can put all of our files and HTML code onto a CD-ROM with Microsoft's Internet Explorer as a browser. Microsoft Internet Explorer is available for

us to re-distribute royalty-free as long as we register the number of copies we distribute on a quarterly basis and we must use the Microsoft Internet Explorer Logo on our Web page.

Some advantages of putting project data onto the Internet include downloading capabilities, easy access for our viewers, and attractive visual displays. In addition, although Microsoft Internet Explorer is our chosen Internet browser, other viewers can be used as long as they can handle the Table feature of HTML.

Click on Michigan Project to view data from this project. The following information is now available on the MTU Web site:

Michigan Project	Michigan Basin Geology	TOW 1-3 Well	Data Download Files
All Annual & Quarterly reports	Stratigraphic Column for Michigan Basin	Cronus Development Letter	Oil Field Production Data
Project personnel; biographies & vita	Table of Michigan Basin Formations	Core Analysis Charts: TOW 1-3	Well Data
Well rig photos for TOW 1-3	Isopach and structure contour maps	TOW 1-3 Core Gamma Surface Log	Oil Field Statistics
Large-scale Dundee structure contour map	3-D isopach and structure contour maps	TOW 1-3 Core Description & core photos	TOW 1-3 HD Data
Link to WMU DOE WWW site	Bouguer Anomaly Map	Location Map of Horizontal Well in Crystal Field	
Regional geology of study area		Diagram of Proposed Horizontal Leg	
	1996 & 1997 AAPG slides	Horizontal Well Cross Section	
Project Oil field location Maps	Sample drillers log	Horizontal Well Diagram	
Table of general information		TOW 1-3 HD Production chart	
Atlas of Dundee reservoirs		Static Pressure Gradient	
AutoCAD maps, production graphs, tables for 30 Dundee fields		Pressure Build-up Test	

Table 2. Contents of Michigan Tech Web site arranged by topic.

We have recently begun to count the visits to the project WEB site. The data up to May show a steady increase, particularly following the mailing of the last MOFRC Newsletter (Table 3).

Month	Visits
Oct-96	14
Nov-96	23
Dec-96	16
Jan-97	16
Feb-97	19
Mar-97	43
Apr-97	104

Table 3. Tabulation of visits to Michigan Tech web site, www.geo.mtu.edu/svl/michproj

MICHIGAN OIL FIELD RESEARCH CONSORTIUM (MOFRC)

The 3rd issue of the MOFRC Newsletter was send to MOFRC members in March. This newsletter was established to disseminate information on our project to interested parties in the Michigan oil and gas community and has proven very successful. It is useful not only to update the gas and oil community in Michigan on project activities but also to let companies know where they can send their old files and other materials that have archival value. Since the inception of this project, Michigan Tech has received enough material to become one of the leading data repositories for gas and oil related data in the state. The following data is part of what has been donated to Michigan Tech in the past year:

1. 15,000 scout tickets on Michigan well
2. 10,000 well site reports
3. 2000 acetate well log films
4. 1000 mud logs
5. 200,000+ pages of driller's reports (285 3-ring binders organized by Township-Range-Section)
6. 45,000 drilling permit records
7. 18,000 – 20,000 paper well logs
8. 100+ digital well logs
9. 500+ scanned well logs
10. 16,000 digital well headers and formation top picks.

These items are currently being indexed and processed for electronic distributions. Some is already on the WWW and more will follow. Michigan Tech hopes to become one of the most complete data repositories for the Michigan gas and oil industry in the state.

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

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.

Other oral and poster presentations at numerous venues include:

1994	Ontario Petroleum Institute Annual Meeting Oral Presentation
1995	Ontario Petroleum Institute Annual Meeting Oral Presentation
1995	Geology Department, University of Illinois, Chicago Oral Presentation
1995	Michigan Basin Geological Society, Monthly Meeting Oral Presentation
1995	DOE Annual Contractors Meeting, Oral Presentation
1996	Michigan Department of Natural Resources Symposium, Michigan, Geology and Resources Keynote Luncheon Speaker
1996	Michigan Academy of Sciences Annual Conference Poster Presentation
1996	PTTC Focused Technology Workshop on Horizontal Drilling Oral Presentation
1996	IOGCC Annual Meeting Oral Presentation
1996	DOE Class 2 Reservoirs Workshop Oral Presentation
1996	MOGA Crystal Field Seminar and Poster Session

Project members also handled numerous requests for information from independent oil companies and consultants for general project data, maps, and specific field information. Two papers were published in Oil and Gas Journal, October, 1996, and a paper version of the Dundee Fields Atlas is scheduled to be published by the Michigan Basin Geological Society.

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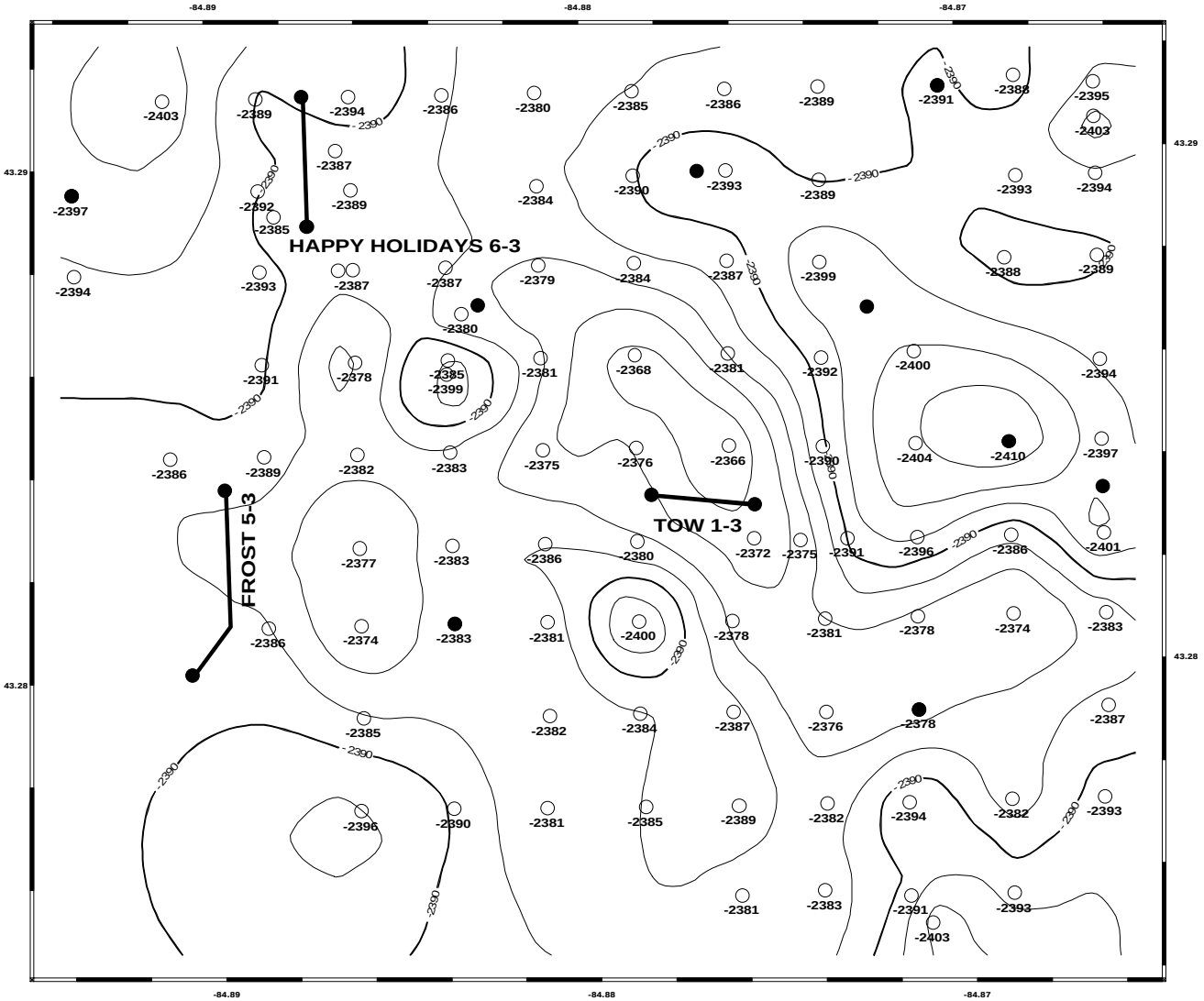
FIGURE CAPTIONS

Figure 1. Location map for the TOW 1-3, the Frost 5-3 and the Happy Holidays 6-3, demonstration wells in the Crystal Field, Montcalm County, MI. The wells trend between two rows of vertical production wells that were active in the early stages of development but are now abandoned.

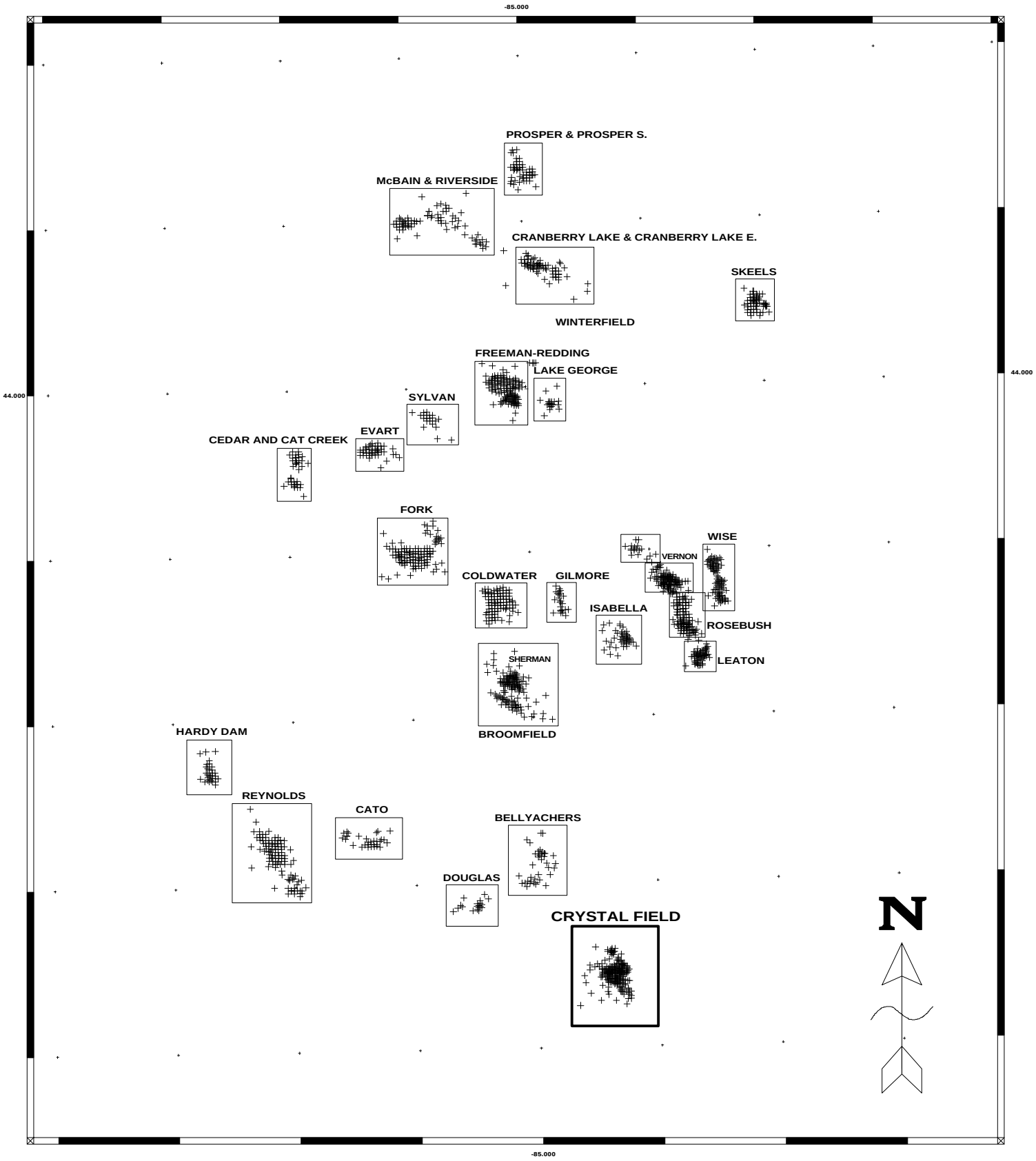
Figure 2. Location map for the 30 SSR Dundee fields selected for characterization in this project..

Figure 3. . Graphical representation of the burial history used in the preferred model and described above. The tops of the labeled stratigraphic units lie directly above the labels. Other lines represent tops of different depositional units.

Figure 4. A semi-log plot of %Ro vs. depth, showing the values obtained by modeling, compared directly to the observed data.



Michigan Technological University		
DOE CLASS II FIELD PROJECT NEW WELL LOCATION MAP		
jrw	CI = 5 FT.	5/13/97
	Scale 1:15000.	NEW WELLS LOCATION M



DOE CLASS II MICHIGAN PROJECT		
FIELD LOCATION MAP		
Michigan Technological University		
MICHIGAN ATLAS		5/13/97
jrw	Scale 1:700000.	GLOBAL

Scale 1:700000.

2. 0. 2. 4. 6. 8. 10. miles

10. 0. 10. 20. 30. 40. 50. kilometers

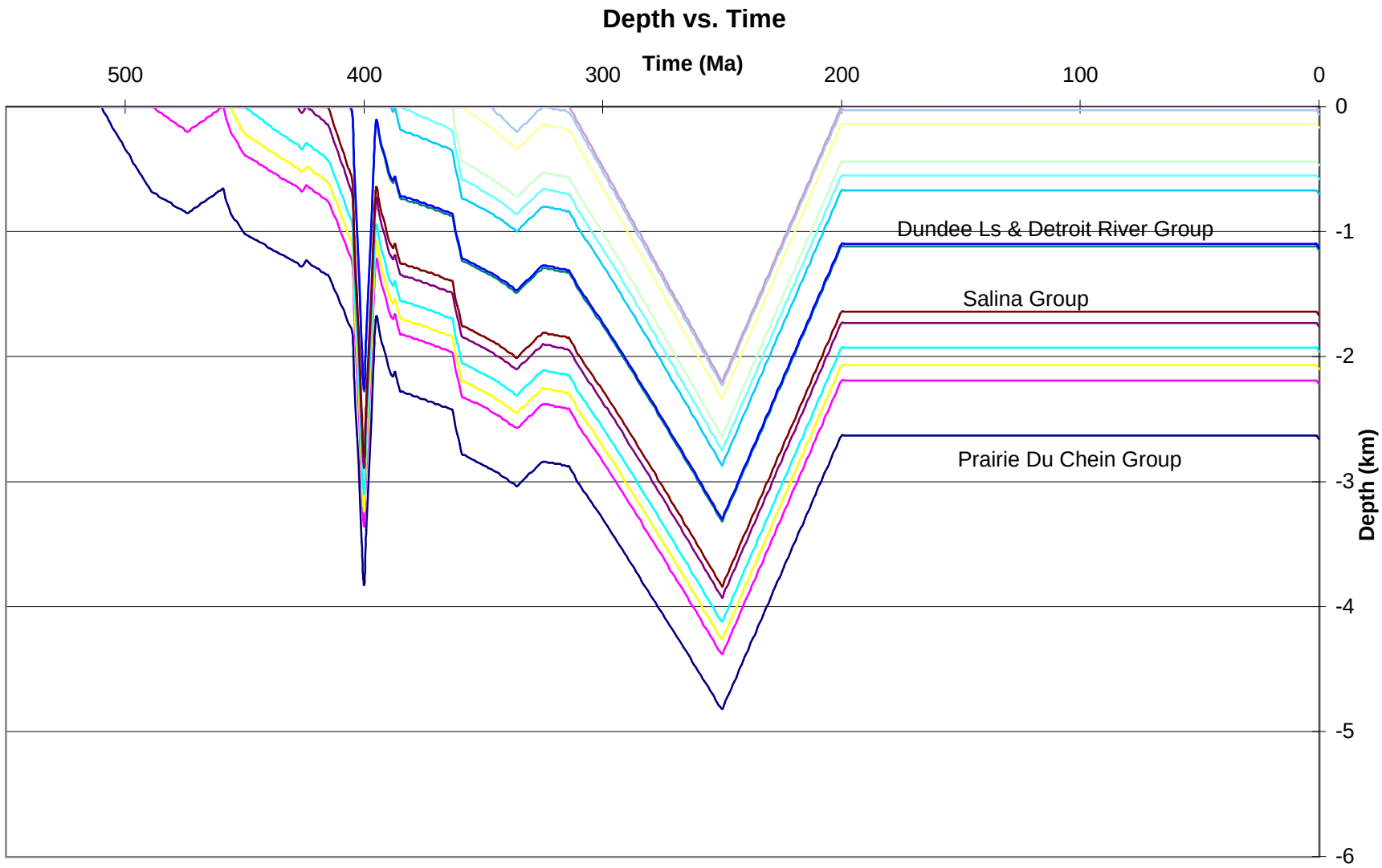
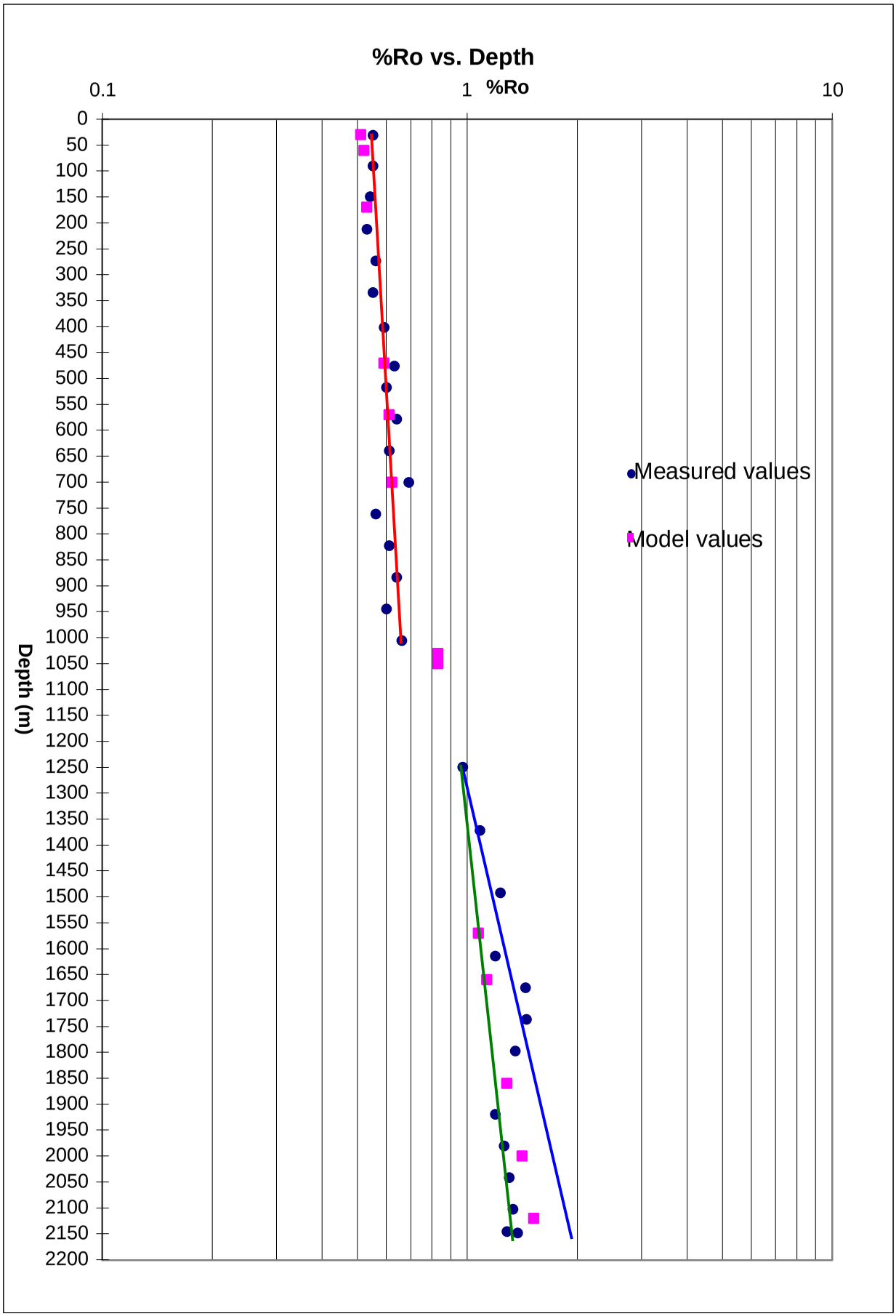


Figure 3: Graph of Depth vs. Time for Mobil-Jelinek well.


%Ro vs. Depth
0.1
1
%Ro
10
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
Measured values
Model values