VISUAL DISPLAY OF RESERVOIR PARAMETERS AFFECTING ENHANCED OIL RECOVERY

Cooperative Agreement No.: DE-AC22-93BC14892

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Date of Report: January 27, 1996

Award Date: 29 September 1993

Anticipated Completion Date: 28 September 1996

Government Award for Current Fiscal Year: \$272,827.

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Reporting Period: October 1, 1995 - December 31, 1995

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OBJECTIVE

This project consists of two parts. In Part 1, well logs, other well data, drilling, and production data for the Pioneer Field in the southern San Joaquin Valley of California were obtained, assembled, and input to a commercial relational database manager. These data are being used in PC-based geologic mapping, evaluation, and visualization software programs to produce 2-D and 3-D representations of the reservoir geometry, facies and subfacies, stratigraphy, original oil in place (OOIP) and present (estimated) OIP as well as measured and model parameters. Petrographic and petrophysical measurements made on samples from Pioneer Field, including core, cuttings and liquids, will be used to calibrate the log suite. In Part 2, these data sets are being used to develop algorithms correlating log responses with geologic and engineering measurements, and rock alteration due to interactions with hot fluids are being quantitatively modeled and used to predict the reservoir response if the rock were subjected to thermally enhanced oil recovery (TEOR).

This project will provide a detailed example, based on a field trial, of how to evaluate a field for EOR operations utilizing data typically available in an older field which has undergone primary

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development. The approach will utilize readily available, affordable PC-based computer software and analytical services. This study will illustrate the steps involved in: 1) setting up a relational database to store geologic, well-log, engineering, and production data, 2) integration of data typically available for oil and gas fields with predictive models for reservoir alteration, and 3) linking these data and models with modern computer software to provide 2-D and 3-D visualizations of the reservoir and its attributes. The techniques are being demonstrated through a field trial on a reservoir, Pioneer Field, a field that produces from the Monterey Formation, which is a candidate for thermal EOR.

SUMMARY OF TECHNICAL PROGRESS BY TASK

TASK 1. PROJECT ADMINISTRATION AND MANAGEMENT

1.1 THE SPATIAL DATABASE MANAGER

Development of the Spatial Database Manager proceeded along two parallel paths this quarter. B. Watkins continued to develop the Pioneer Management System in Visual Basic. Text and graphic data can now be easily displayed and written to CD ROM. An input interface was completed. It is now possible for any user to input text or graphic data directly into the Database Manager through a simple dialog box. C. Asiala has been testing the ability of the commercial software package Toolbook (by Asymetrix) to do many of the same things. The advantages of using commercially available software vs a home-grown program to handle our data archiving and display needs are discussed in Subtask 1.1.2.

1.1.1 DATABASE INITIALIZATION

Microsoft Access is our relational database management platform. During this quarter, C. 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.

A commercial database containing over 77,000 geochemical analyses of brines recovered from wells throughout the United States was organized and input to Microsoft Access. Analyses of samples from California wells are now easily retrievable for use in our DOE project.

1.1.2 DATABASE MANAGEMENT

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 PioneerBuilder which makes it possible for anyone in the project to easily input text or graphics to the Database Management System. With PioneerBuilder, 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. C. Asiala has developed 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 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 Michigan Technological University (MTU). Graduate students S. Chittick and W. Eversham 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.

S. Chittick wrote import files for loading well-location, deviation, formation-top, and log-trace data into GeoGraphix. Chittick then spent a week at Digital Petrophysics, Inc. (DPI) in Bakersfield in January loading their log and formation-top data into GeoGraphix. He has since produced excellent maps of the top of the Monterey Formation (including all fault traces), contoured the maps to grid, and is currently working on maps of the Etchegoin and Reef Ridge (see Task 2).

1.2 ORGANIZATION AND MANAGEMENT

The management tasks have gone smoothly this quarter. Subgroups met and worked on specific tasks and subtasks. Graduate students M. Slis and W. Eversham joined the project this quarter and have been working with the computer databases and applications.

1.2.1 PROJECT COORDINATION

The following trips and meetings were held this quarter:

On November 13 and 14, Wood, Pennington, Gruener, Allan, and Nigrini traveled to DPI in Bakersfield to review progress on the log evaluation part of the project and to plan and make arrangements for a Technology Transfer Workshop to be held in September, 1996.

On November 14, Wood, Allan, and Nigrini met with R. Robinson, the Director of the California Well Sample Repository at California State University, Bakersfield, to make arrangements for holding the Workshop there (see Subtask 5.2).

In early December, Nigrini visited Davis-Namson Consulting Geologists in Glendale, CA to discuss the Elk Hills deep well study. Davis-Namson recently completed a structural study of Pioneer Anticline and provided us with a copy of their geologic map of the Pioneer area and one of their structural cross sections and promised access to six more.

On January 15 and 16, Wood, Gruener, Chittick, Allan and Nigrini visited DPI to review project progress and to set up the GeoGraphix Exploration System software on a computer in their office. On January 16, Wood and Allan visited the California Well Sample Repository to continue discussions with R. Robinson about our September 1996 Workshop. Chittick remained at DPI until January 21 to work with D. Olson of DPI on the importation and manipulation of log data to GeoGraphix.

On January 17, D. Olson and W. Berry of DPI presented a talk on their log evaluation program Symbiolog to the Society of Professional Well Log Analysts (SPWLA) at their luncheon in Bakersfield and used the Pioneer DOE project as their principal case study to illustrate application of the new program.

1.2.2 BUDGET MANAGEMENT AND QUARTERLY REPORTS

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

TASK 2. DATA COLLECTION

2.1 WELL LOGS AND WELL DATA

The tops of the Etchegoin Formation, the Monterey Formation, and the top of the Reef Ridge Member have been correlated. Top picks have been made on all logs and corrected for well deviation. Our spreadsheet now contains tops picked in 76 wells. The top of the Monterey was mapped in detail. Fault cuts were picked from log cross sections and fault traces were plotted on the top-Monterey contour map. All of the Monterey data were loaded into GeoGraphix and a structure contour map was produced with all faults displayed (Fig. 1). Our next effort will concentrate on mapping the faults and structure on the tops of the Etchegoin and Reef Ridge. S. Chittick is handling all of the GeoGraphix work. M. Luo is creating rotatable 3-D images of the Monterey reservoir in the statistical and visualization program MatLab.

J. Alex completed the digitization, editing, and coloration of the surface geological maps of the southern San Joaquin Valley which were originally prepared by Dibblee of the California Division of Mines and Geology. Alex has begun to do the same with several additional maps and cross sections, including the geologic map and cross section of the Pioneer area which we recently acquired from Davis-Namson.

2.1.1 LOG DATABASE MANAGEMENT

All well log calibration and analysis has, to date, been performed at DPI in the Crocker Data Processing Petrolog Program. Last quarter, C. Asiala completed the construction of a Microsoft Access database to archive digitized log traces. The logs are stored in LAS format and can be exported to any log evaluation or applications program. Thus, independent operators can use the database which she designed to archive their log data, but are not constrained by it to use a specific applications package to evaluate their data. All of our Pioneer logs are now archived in the Access database.

A. Nigrini has prepared tables of engineering data (hole diameter, casing points, perforations, etc.) and log-run histories for export to GeoGraphix.

2.1.2 LOG DIGITIZATION

Digitization of all of the wells which will be used to construct maps and 3-D visualizations of the Miocene reservoir on Pioneer Anticline is complete.

2.2 CORE AND SAMPLE ACQUISITION

2.2.1A CORE AND CUTTINGS

Our conventional and sidewall core library of samples is now essentially complete. It consists of conventional cores and core analysis data from the UNOCAL McKittrick Front Nos. 415 and 418 wells in Cymric Field and the Tenneco 62x-30 well in Pioneer Field. Sidewall core and cuttings samples and core analysis data from the Gary Drilling, KLC 44, Well No. 375x in Pioneer Field are also in our possession.

2.2.1B ARCO/UNOCAL CORE

Conventional cores and core analysis data from the UNOCAL McKittrick Front Nos. 415 and 418 wells in Cymric Field have been in our possession for some time. ARCO has divested its interests in the Pioneer area, so core from their wells may no longer be available. However, the cores and core data from the two McKittrick Front wells are so outstanding that acquiring data from additional wells is probably unnecessary.

J. Allan contacted UNOCAL during the last quarter and arranged for the core and core data from the two McKittrick Front wells to be released to the California Well Sample Repository at California State University, Bakersfield for our September 1996 Technology Transfer Workshop.

We hope to be able to arrange the eventual donation of the core and samples to the Repository, where they will reside in perpetuity and can be used as a resource by both industrial and research geologists.

2.2.2 FLUIDS

A data set containing over 77,000 geochemical analyses of brines recovered from wells throughout the United States was acquired from a commercial database vendor. C. Asiala designed a Microsoft Access database and archived the brine data in it.

TASK 3. DATA ANALYSIS AND MEASUREMENT

3.1 PETROPHYSICS

Extensive petrophysical data sets were acquired from UNOCAL for the cores from the UNOCAL McKittrick Front No. 415 and 418 wells in Cymric Field. A petrophysical data set for the Tenneco 62x-30 well in Pioneer Field was acquired independently. Petrophysical data from the cores were used to calibrate the logs in these wells. The calibrations will be used to analyze existing logs and produce computed logs in uncored wells which penetrate the same stratigraphic intervals on the Pioneer Anticline.

3.1.1 POROSITY, PERMEABILITY, FORMATION FACTOR (KPF) MEASUREMENTS

Conventional core data were acquired for the UNOCAL McKittrick Front and the Tenneco 62x-30 wells. Sidewall core data is available for several additional wells.

3.1.2 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR) SPECTRA

Elemental analyses of ten Pioneer samples were completed using the Inductively Coupled Plasma Spectrograph (ICP) at MTU. Calibration of FTIR standards is now complete. Twenty samples from Pioneer field were analyzed, but because of contamination and instrumentation problems, will have to be rerun. Graduate student N. Popko is doing this work.

3.2 PETROLOGY

3.2.1 XRD

Reports on completed Xray work were prepared by R. Kramer. Kramer left the project for another position last fall, but had completed a significant amount of work at the time of her departure.

3.2.2 SCANNING ELECTRON MICROSCOPY (SEM)/IMAGE ANALYSIS

Epoxy mounts of selected Pioneer samples were prepared. They will be subjected to image analysis and Energy Dispersive Spectral (EDS) analysis on the SEM.

We have made arrangements with J. Boles of UC Santa Barbara to continue the optical image analysis work begun by Kramer. Boles, who is currently the Chairman of the Geology Department at UCSB, has a state-of-the-art petrographic and image analysis laboratory.

3.2.3 PETROLOGY

Optical petrographic analyses are complete for the 44 thin sections which have been prepared to date. Results include petrographic descriptions, 35mm slides, and 35mm prints of thin sections which are characteristic of each lithologic type. Additional work will be performed as necessary.

An atlas of thin section petrology of representative reservoir samples from the southern San Joaquin Basin was acquired for the project. The atlas was compiled by M. Hayes at Chevron Research under the direction of J. Wood in 1988. The atlas, which consists of several hundred described and interpreted photomicrographs from many fields, emphasizes diagenetic alteration. The photomicrographs and their captions will be scanned into the Multimedia Database Management System, where they can be readily accessed on hard disk and eventually on CD ROM.

3.3 LOG CALIBRATION

Data preparation and log calibration were completed on the 13 wells in the nine-section Pioneer Field area plus the 2 McKittrick Front wells.

3.3.1 DATA PREPARATION

Data preparation is complete for the 45+ wells in the original Pioneer Anticline study area plus five additional "regional" wells which were added to the data set to extend our picture of the Anticline up-plunge to the west. Data from these wells has been entered into GeoGraphix. The additional 26 wells in our formation-tops spreadsheet are old wells which do not have usable borehole geophysical logs. The picks in these old wells were made from drillers' logs.

3.3.2 MODEL SELECTION

Preliminary model selection was completed for all 13 wells in the nine-section Pioneer area plus the 2 McKittrick Front wells. Results curves were generated for these wells. The results curves are calculated curves showing lithology, % clay, % shale, matrix type, porosity, and S_w .

The wells are now undergoing final analysis using the program Symbiolog, developed by log analysts and programmers at DPI. Symbiolog uses a newly refined technique called multi-facies zone summation analysis. Conventional log analysis packages apply one set of cutoffs (porosity,

residual water saturation, etc.) to a unit. Multi-facies zone summation analysis allows the user to define different facies within a reservoir and to assign a different cutoff value to each facies. Expected production within a heterogeneous reservoir can be estimated much more precisely than with the conventional approach.

TASK 4. MODELING

4.1 GEOCHEMICAL MODELING

The geochemical modeling program CHILLER is being used to model fluid-rock interaction. This has very practical significance because of active steamflooding of the Monterey and Etchegoin Formations elsewhere in the southern San Joaquin Valley. Investigations of the feasibility of porosity prediction using CHILLER are continuing.

4.1.1 GEOCHEMICAL MASS TRANSFER

Geochemical mass transfer work using CHILLER was continued by J. Suchoski.

4.1.2 THERMODYNAMIC DATABASE

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 containing information on oxygen isotopes, OXYBASE, is complete.

4.2 BASIN MODELING

Basin modeling work again focused on fluid flow out of the deep San Joaquin Basin.

4.2.1 GEOHISTORY

One-dimensional basin modeling activities using the program BasinMod have focused on analysis of the Elk Hills 934-29R well in the Naval Petroleum Reserve, the deepest well (24,442 feet) in the San Joaquin Valley. This well is unique in that it bottoms in Cretaceous sediments, thus giving as complete a Tertiary section in the subsurface as has been found to date. The well has excellent equilibrated downhole temperature profiles based on continuous temperature logging and a good vitrinite reflectance (Ro) profile that provide for calibration of the paleo-heat flow. A generalized paleo-heat flow model is provided by model studies of lithospheric plate interactions which predicts the thermal consequences of the complex plate interactions affecting the southern San Joaquin Valley.

The results of the 1-D modeling study of Elk Hills 934-29R demonstrate that the downhole temperature profile observed in the well is *not* in equilibrium with observed Ro data. The predicted Ro value at the base of the well is 2.4 compared to an observed value of 1.56.

It appears that the elevated temperature profile may be due to episodic release of geothermal fluids. If correct, our interpretation suggests that any reservoir rocks shallower than approximately 17,000 feet are prospective. This is much deeper than any of the reservoirs presently being produced in the San Joaquin Valley, which are generally shallower than 10,000 feet. This phenomenon is also observed at North Coles Levy Field to the north and suggests that economic basement may be much deeper than previously believed.

J. Allan completed a fluid inclusion study of vein carbonate samples taken from core recovered from between 12,000 and 24,000 ft in the EH 934-29R well. All of the samples contain petroleum fluid inclusions that range from light oil in the shallowest samples, through condensate in the intermediate samples, to wet gas in the deepest sample.

Several deep wells in Sand Hills, Yolumne, and Wild Flower fields have been identified to extend the heat flow modeling to the east of the Pioneer Anticline. A paper describing the burial and temperature history of the EH 934-29R well is currently in preparation.

4.2.2 2-D AND 3-D BASIN MODELS

Akcess.basin - 2-D, 3-D Basin Modeling Software: 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. Modeling of the southern San Joaquin Valley will commence soon.

TASK 5. TECHNOLOGY TRANSFER

5.1 REPORTS

To date, the main technical reports prepared and distributed have been quarterly technical reports to DOE and internal progress reports. A. Nigrini is currently preparing a paper on the BasinMod study of the deepest well in the San Joaquin Valley for publication.

5.2 MEETINGS AND WORKSHOPS

Project Workshop

A Technology Transfer Workshop is scheduled for September 1996 in Bakersfield, CA. It will be held at the California Well Sample Repository at California State University, Bakersfield. R. Robinson, the Director of the Repository, has generously committed his time to help us arrange the event. As presently planned, the Workshop will be two days in length and will include a core display at the Repository. A Workshop Manual is being prepared for distribution to all

participants. Figure 2 is a current working outline of the Manual contents and Workshop presentations.

Arrangements have been made for the core and core data from the McKittrick Front No. 415 and 418 wells to be released to the Repository for the Workshop. Since >700 ft of core and many unconventional core analyses were taken in the 418 well alone, we think that the core display will attract a wide audience.

American Association of Petroleum Geologists (AAPG) 1996 Annual Meeting

Once again MTU will run a booth that features the Pioneer Field DOE Project in the Exhibit Hall at the AAPG National Meeting in San Diego, CA in May, 1996. The California Well Sample Repository will have a special core exhibit at the meeting and A. Nigrini may present his Elk Hills study as part of their core exhibit.

Multimedia Presentations on CD-ROM

Development of the Spatial Database Manager proceeded along two parallel paths this quarter. B. Watkins continued to develop the Pioneer Management System in Visual Basic. C. Asiala has been testing the ability of the commercial software package Toolbook (by Asymetrix) to do many of the same things (see Subtasks 1.1 and 1.1.2).

The current contents of the Visual Basic Database Management System were written to CD ROM. The CD's are now available for use in presentations and distribution to interested parties.

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PIONEER ANTICLINE, KERN COUNTY, CALIFORNIA

MIOCENE STRUCTURE CONTOUR MAP

Figure 1. Structure contour map of Pioneer Anticline study area displaying all faults that cut the Monterey Formation in the area. Map was prepared in the GeoGraphix Exploration System.

DOE VISUALIZATION PROJECT ON PIONEER ANTICLINE						
OUTLINE FOR WORKSHOP MANUAL			# Pages		Minutes	# Figures
	LEAD	TEAM	MIN	MAX	TIME	
INTRODUCTION	JRW	ALL	5	8	15	4
WELL LOGS	DPI	AN & JRA				
DATA CAPTURE					30	10
Digitize logs			5	8		
Digitize Well Locations, Mechanical Data, Header Data			3	5		
Digitize Reservoir Data (Core, Rock and Fluid Data)			3	5		
Digitize Production Data			1	2		
DATA PREPARATION					45	10
Build Log Database (Edit, Depthshift, Environ. Corrections)			6	8		
Build Cross Sections			3	5		
Build Base Maps			3	5		
DATA ANALYSIS					45	10
Interpretation			5	8		
Correlation			3	5		
Mapping Reservoir Properties						
Porosity			1	2		
Permeability			1	2		
Lithology			1	2		
Oil Saturation			1	2		
REPORTING					45	10
Methodology			3	5		
Case history - Pioneer Field			8	10		
LOG VISUALIZATION					45	10
Export Data			3	5		
Demonstrations of Applications			20	25		
LAB MEASUREMENTS						
SOLIDS						
X-Ray Diffraction	DCP	SDM	15	20	20	10
FTIR	DCP		15	20	20	10
California	DCP		15	20	20	10
California	DCP	SDM	15	20	20	15
Petrographic Image Analysis	JRW/JRB	SDM	15	20	20	15
FLUIDS			15	20		
Oils (Literature search; company files)	JRA	AN	10	12	20	10
Formation Waters (Lit. search; company files)	JRW	JRA;AN	10	12	20	10
VISUALIZATION						
GEOLOGY						
Maps	WDP	DPI;CJA	15	20	20	10
Cross Sections	WDP	DPI;CJA	15	20	20	10
3D Rendering ("Pseudo-seismic")	WDP	DPI;CJA	15	20	45	10
ENGINEERING (?)			20	30	45	20
MODELING						
GEOCHEMICAL						
Fluid-rock Interactions (CHILLER)	AN	JRW;JPS	20	30	45	20
Thermodynamic Database	JRW	JPS;AN	10	15	20	10
BASIN ANALYSIS						
Geohistory	AN	JRW	20	30	30	10
Thermal History	AN	JRW	20	30	30	10
DATA MANAGEMENT						
PC Databases	AN	DPI	10	15	30	10
CD ROM	CJA	JRW; MJG	20	30	45	10
SUMMARY	JRW	JRA;AN;DPI	15	15		5
TOTALS			365	511	695	259

Figure 2. Outline of Workshop Manual Contents and Workshop Presentations.