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VISUAL DISPLAY OF RESERVOIR PARAMETERS AFFECTING ENHANCED
OIL RECOVERY

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OBJECTIVE

MASTER

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, porosity, oil saturation, and other measured and model parameters. Petrographic and petrophysical measurements made on samples from Pioneer Field, including core, cuttings and liquids, are being used to calibrate the log suite. In Part 2, these data sets are being used to develop algorithms to correlate log response to geologic and engineering measurements.

This project provides a detailed example, based on a field trial, of how to evaluate a field for EOR operations utilizing data typically available in older fields which have undergone primary development. The approach utilizes readily available, affordable PC-based computer software and analytical services. This study will illustrate the steps involved in:

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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 in Pioneer Field, that produces from the Monterey Formation, a reservoir 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

The Multimedia Database Management System (MDMS) has been developed in the commercial software package Toolbook. Design and implementation, which was carried out by C. Asiala, is now essentially complete. Regional location maps of southern San Joaquin Valley oil fields, structure contour maps of the Pioneer area, core photos, core data, and thin-section and SEM photomicrographs of core materials were all scanned into the MDMS during the second quarter of FY 1996. During the past quarter, the following additional items were input to the MDMS: structural cross sections through Pioneer Anticline, an atlas of photomicrographs illustrating typical diagenetic features observed in San Joaquin Valley petroleum reservoirs, elemental and spectral data collected on Fourier Transform Infrared Spectroscopy (FTIR) standards, and all quarterly reports submitted to DOE for this project. All data and information are accessible through drop-down menus and hotlinks in a Table of Contents. A tutorial is presented up front to guide users through the MDMS and instruct them on the various ways in which data can be viewed and retrieved. The MDMS will be written to a CD ROM at the end of the project.

All measured log curves for the 45+ project wells on Pioneer Anticline are now in the MDMS in LAS (digital log ASCII) format, and can be exported to any commercial log evaluation program for manipulation and analysis. Computed log curves (curves representing parameters such as porosity, water saturation, and clay content, which were calculated from the measured log traces using specially developed algorithms) were received from Digital Petrophysics, Inc. (DPI) this past quarter in LIS (log binary) format and are currently being translated to LAS format before being input to the MDMS.

C. Asiala developed a search engine in Microsoft Access which can be used to retrieve logs from the CD ROM. Any desired log curve can be located using queries and then exported from the CD ROM to temporary Access tables created on the computer's hard drive. Once in the Access tables, log curves can be manipulated or transferred to log evaluation packages such as GeoGraphix's QLA2 or Crocker's Petrolog program for analysis and plotting.

A preliminary CD ROM of Version 1.0 the MDMS was pressed and circulated to project members for editorial review. During the next two months, additional data will be added and explanatory text will be written for each significant drop-down menu and data set. Version 1.1 of the CD ROM will be pressed shortly before our September 24, 1996 Workshop in Bakersfield, CA. Copies will be distributed to all attendees and will be made available to the general public. This CD ROM will contain not only all project results, but also *all project data including all well logs in digital format*, and will be the primary deliverable of the project.

1.1.1 DATABASE INITIALIZATION

Database initialization is complete.

1.1.2 DATABASE MANAGEMENT

All project data are being managed and archived in the Multimedia Database Management System that was developed in Toolbook (see Subtask 1.1). Log evaluation is being carried out at differing levels of sophistication in the programs Pfeffer, QLA2, and Crocker Petrolog. Maps and cross sections are being prepared using GeoGraphix Exploration System (GES) software. Three-dimensional visualizations are being prepared in the software package MatLab.

1.2 ORGANIZATION AND MANAGEMENT

The management tasks continued to go smoothly this quarter.

1.2.1 PROJECT COORDINATION

The following trips and meetings were held this quarter:

In April, M. Luo and J. Allan traveled to Michigan Technological University (MTU) to work on the Pioneer project with MTU faculty and staff.

In May, Allan traveled to DPI in Bakersfield to review progress on the Symbiolog analysis of Pioneer wells with F. Berry.

In May, MTU once again ran a booth in the Exhibit Hall at the AAPG National Meeting in San Diego, CA. The booth featured the Pioneer Field DOE Project. F. Berry and D. Olson presented computer demonstrations of their Symbiolog program in the booth. A. Nigrini presented a poster display of his Elk Hills study at the California Well Sample Repository core exhibit, which was located elsewhere on the Exhibit Hall floor.

In June, W. Pennington presented a talk entitled "3-D Visualization Techniques for Very Small Field Operators" at the Society of Exploration Geophysicists' (SEG) Production and Development Forum.

During the summer of 1996, graduate student W. Houston is working at Santa Fe Energy Resources in Bakersfield, CA, as a geological trainee. His summer project is to use GeoGraphix to evaluate reservoir continuity and heterogeneity in a 130-well lease in a San Joaquin Valley oil field. The skills he is acquiring while carrying out this project will put him in a position to make important contributions to our DOE projects when he returns to MTU in the fall.

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

During this quarter, DPI completed the analysis of all Pioneer project wells using their newly developed log-evaluation program Symbiolog. An innovative procedure was developed for using modern log suites, calibrated to core data, to evaluate wells for which only old electric logs (e-logs) are available. This procedure was used to calculate parameters such as porosity, water saturation, and clay content, which are not directly measured by these old logs. The evaluation procedure is based on an iterative process in which petrophysical data collected on core material are calibrated to logs in wells with full modern log suites. Porosity, water saturation, clay content, etc., are calculated from the full log suite using algorithms and then cross-checked against values measured in core. The same parameters are then calculated using only the basic electric-log suite. Algorithms are adjusted until parameters derived from the core, the full-log suite, and the e-log-only suite all show reasonable agreement within the logged interval. When an acceptable level of agreement is achieved, the algorithms can be used to calculate porosity, saturation, and lithology in old e-log-only wells.

Successful results were achieved during this quarter. Porosity, saturation, and lithology were calculated for all wells in the Pioneer study area, including wells with full modern log suites, wells with intermediate-aged log suites, and wells drilled in the 1930's and 1940's for which only e-log suites are available. The computed curves for all 45+ project wells were delivered to MTU where they will be used to construct maps and cross sections of internal heterogeneities within the Monterey reservoir using the GES.

2.1.1 LOG DATABASE MANAGEMENT

All measured and computed log curves are stored in the MDMS in LAS format and are retrievable using Microsoft Access as a search engine. Log evaluation is being carried out using the programs Pfeffer, QLA2, Crocker Petrolog, and Symbiolog. Pfeffer is a simple, inexpensive (\$290.) log-evaluation software package developed by University of Kansas researchers; QLA2 is an intermediate-level log-evaluation package suitable for general use by exploration and development geologists that is provided as a module with the GeoGraphix Exploration System; and Crocker Petrolog and Symbiolog are sophisticated log-evaluation programs suitable for use by formation-evaluation specialists.

W. Pennington is responsible for log analyses using Pfeffer and QLA2, while DPI is responsible for log evaluations using Crocker Petrolog and Symbiolog. We hope to present a comparison of the different programs at our September Technology Transfer Workshop in order to provide attendees information that will enable them to perform a simple cost/benefit analysis and choose the software that is best fits their needs.

2.1.2 LOG DIGITIZATION

Digitization of all of the well logs necessary for construction of maps and 3-D visualizations of the Miocene and Pliocene reservoirs 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 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 sample library.

2.2.1B ARCO/UNOCAL CORE

J. Allan arranged for the core and core data from the UNOCAL McKittrick Front Nos. 415 and 418 wells in Cymric Field to be released by UNOCAL to the California Well Sample Repository at California State University, Bakersfield for our September 1996 Technology Transfer Workshop. The cores and core data from the two McKittrick Front wells are so outstanding that acquiring core data from additional wells to calibrate our logs has proved unnecessary. They were shipped to the Repository and are now in storage there. 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

3.1.1 POROSITY, PERMEABILITY, FORMATION FACTOR (KPF) MEASUREMENTS

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 were used to analyze existing logs and produce computed logs in uncored wells which penetrate the same stratigraphic intervals on the Pioneer Anticline (see Subtask 2.1).

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. More problems were experienced in the calibration of FTIR standards. Current efforts concentrate on obtaining better standards for Opal A and CT. Since the FTIR work represents the M.S. thesis research project of graduate student N. Popko, it will continue after the completion of this DOE contract.

3.2 PETROLOGY

3.2.1 XRD

Xray work is essentially complete. Any additional work that is performed will be done in conjunction with Popko's FTIR work.

3.2.2 SCANNING ELECTRON MICROSCOPY (SEM)/IMAGE ANALYSIS

All SEM images collected to date were scanned into the MDMS. They will be available on Version 1.1 of the CD ROM.

3.2.3 PETROLOGY

Optical petrographic analyses are complete for 44 thin sections of the Monterey reservoir in our cored wells. Results include petrographic descriptions, 35mm slides, and 35mm

prints of thin sections which are characteristic of each lithologic type. All photomicrographs and thin section descriptions were scanned into the MDMS.

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 were scanned into the MDMS.

3.3 LOG CALIBRATION

Log calibration is complete.

3.3.1 DATA PREPARATION

Data preparation is complete.

D. Crane of DPI picked the tops of the Etchegoin Formation, the Monterey Formation, the Reef Ridge Sand, and the Reef Ridge Shale, in all project wells, and constructed fault-plane maps for all faults in the vicinity of Pioneer Field. The data were delivered to MTU and are being used by M. Luo to construct 3-dimensional visualizations of the Pioneer Anticline in MatLab.

3.3.2 MODEL SELECTION

Final analysis of all well logs from all Pioneer project wells was completed using the program Symbiolog, developed by log analysts and programmers at DPI. Symbiolog uses a newly developed technique called multi-facies zone summation analysis. Conventional log analysis packages apply one set of cutoffs (porosity, residual water saturation, etc.) to a reservoir. 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 this way than with the conventional approach.

Customized parameter tables were developed from core data and modern log suites for use in special algorithms that compute lithology, % clay, % shale, matrix type, porosity, and S_w from old electric-log data and plot the results in log form. During the last quarter, these calculations were performed on all 45+ Pioneer project wells and computed curves were generated. The computed curves were delivered to MTU where they will be input to GeoGraphix and maps and cross sections will be prepared showing the distribution of porosity zones, highly oil-saturated zones, and permeability barriers within the Monterey reservoir.

TASK 4. MODELING

4.1 GEOCHEMICAL MODELING

The geochemical modeling program CHILLER was 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.

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 on fluid flow out of the deep San Joaquin Basin continued. This quarter, work continued on 3-D surface and volume visualizations and pseudo-seismic cross sections of the anticline using the program MatLab.

4.2.1 GEOHISTORY

A. Nigrini's one-dimensional basin modeling effort using the program BasinMod, which 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, is essentially complete. Results were presented in a poster display at the AAPG National Meeting in San Diego in May.

4.2.2 2-D AND 3-D FIELD VISUALIZATIONS AND BASIN MODELS

MatLab 3-D Visualizations: 3-D visualizations of the Pioneer Anticline continue to be developed 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 top Miocene and fault-trace data assembled by D. Crane of DPI into MatLab and produced an excellent 3-D surface visualization, which accurately portrayed all of the fault discontinuities. He is currently constructing 3-D surface visualizations for the other formation tops picked by DPI, and will soon add the mapped fault planes so that accurate fault intersections can be displayed on all formation tops and fault planes can be displayed with true dip angles. Cross sections can be made

through the anticline at any desired angle. Luo is also performing more basic program development work in MatLab that will increase its capabilities for other project work.

B. Wei is continuing to use 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.

ER Mapper - J. Suchoski is developing our ability to use ER Mapper, Version 5.0, to input and output several types of graphics files to GeoGraphix. ER Mapper is a module that provides the GES with Geographic Information System (GIS) capabilities. We hope to be able to import aerial and satellite photos into GeoGraphix, where we can overlay surface maps and surface data (roads, surface facilities, etc.) on the photographic images.

TASK 5. TECHNOLOGY TRANSFER

5.1 REPORTS

The main technical reports prepared and distributed have been quarterly technical reports to DOE and internal progress reports. A CD ROM, which contains the MDMS with all project data, maps, cross sections, interpretations, and reports, will be available for distribution in September. 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

Technology Transfer Workshop

A Technology Transfer Workshop is scheduled for September 24 and 25, 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 been engaged to help us arrange the event. Rooms and facilities have already been reserved for the Workshop. As presently planned, the Workshop will be one day in length, with an informal session held for interested parties on the second day, and will include a core display at the Repository. The cores from the McKittrick Front calibration wells (including the 700 ft research core from the McKittrick Front 418 well) will be on display, along with core from selected intervals in the Elk Hills 934-29R well that was used in our Geohistory modeling study.

American Association of Petroleum Geologists (AAPG) 1996 Annual Meeting

MTU once again ran a booth featuring the Pioneer Field DOE Project in the Exhibit Hall at the AAPG National Meeting in San Diego, CA, in May, 1996. Along with our normal poster display, the booth featured a computer-graphics display, projected onto a large

screen, that presented an overview of project activities and results. F. Berry and D. Olson were also present in the booth and presented computer demonstrations of their Symbiolog program. The California Well Sample Repository hosted a special core exhibit at the meeting and A. Nigrini presented a poster display of his Elk Hills study at their core exhibit.

Society of Exploration Geophysicists' Production and Development Forum

In June, W. Pennington presented a talk entitled "3-D Visualization Techniques for Very Small Field Operators" at the Society of Exploration Geophysicists' (SEG) Production and Development Forum in Vail, CO.

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