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VISUAL DISPLAY OF RESERVOIR PARAMETERS AFFECTING
ENHANCED OIL RECOVERY

Final Report

By
James R. Wood

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Performed Under Contract No. DE-AC22-93BC14892

Michigan Technological University
Houghton, Michigan

National Petroleum Technology Office
U. S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

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FINAL REPORT

VISUAL DISPLAY OF RESERVOIR PARAMETERS AFFECTING ENHANCED OIL RECOVERY

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 were used in PC-based geologic mapping, evaluation, and visualization software programs to produce 2-D and 3-D representations of the reservoir. Petrographic and petrophysical measurements made on samples from Pioneer Field, including core, cuttings and liquids, were used to calibrate the log suite. In Part 2, these data sets were 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 illustrates 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 were demonstrated through a field trial in Pioneer Field, that produces from the Monterey Formation, a reservoir which is a candidate for thermal EOR.

EXECUTIVE SUMMARY

The Pioneer Anticline, 25 miles southwest of Bakersfield, California, which has yielded oil since 1926, was the subject of a three-year study aimed at recovering more oil. A team from Michigan Technological University of Houghton, Michigan (MTU), and Digital Petrophysics, Inc. of Bakersfield, California (DPI), undertook the study as part of the Department of Energy's Advanced Extraction and Process Technology Program. The program provides support for projects which cross-cut geoscience and engineering research in order to develop innovative technologies for increasing the recovery of some of the estimated 340 billion barrels of in-place oil remaining in U.S. reservoirs.

In recent years, low prices and declining production have increased the likelihood that oil fields will be prematurely abandoned, locking away large volumes of unrecovered oil. The major companies have sold many of their fields to smaller operators in an attempt to concentrate their efforts on fewer "core" properties and on overseas exploration. As a result, small companies with fewer resources at their disposal are becoming responsible for an ever-increasing share of U.S. production.

The goal of the MTU-DPI project was to make small independent producers who are inheriting old fields from the majors aware that high technology computer software is now available at relatively low cost. Most major oil companies rely on expensive computer workstations. In this project, a suite of relatively inexpensive, PC-based software packages, including a commercial database, a multimedia presentation manager, several well-log analysis program, a mapping and cross-section program, and 2-D and 3-D visualization programs, were tested and evaluated on Pioneer Anticline in the southern San Joaquin Valley of California. These relatively inexpensive, commercially available PC-based programs can be assembled into a compatible package for a fraction of the cost of a workstation program with similar capabilities.

A field trial of the technology was performed on the Monterey and Etchegoin Formations in Pioneer Field (Appendix 1, Fig. 1). Pioneer Field is a typical small, older field that contains wells with old logs, a few wells with modern logs, and limited sidewall core coverage. It is essential to be able to extract the most information from the old logs and to accurately assess their reliability. Phases of the field trial included: data gathering; calibration of core, cuttings and liquids to well-log suites; and input of geological, petrophysical and reservoir engineering data to the various software packages. Conventional and sidewall-core data from Pioneer and nearby Cymric fields were used to develop algorithms to correlate log response with geological and engineering measurements in order to extract a maximum amount of information from old wells that only possess old electric logs. Our final output includes: computed logs of lithology, porosity, and clay content for all project wells, including those which possess only old electric logs; 2-D and 3-D representations of the reservoir and structure; and an extensive database which contains logs, maps, cross-sections, and core data and analytical data for Pioneer Field and surrounding areas assembled in a Multimedia Database Management System designed and constructed by project staff in a commercially available multimedia software package.

This project demonstrated how to use existing, proven technologies to go into an old field, assemble relevant existing data into an organized database, calibrate log data using standard and special analytical techniques, process that data into a computer image of the field, and map the reservoir and structure using relatively inexpensive PC-based computer software.

SUMMARY OF TECHNICAL ACCOMPLISHMENTS 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 was carried out by C. Asiala. Forms were developed for entering various types of data (well-log, well-production, formation tops, fault traces, petrologic, geochemical, bulk chemical, Xray diffraction (XRD), and Fourier Transform Infrared Spectroscopy (FTIR) by means of keyboard entry. Excel macro programs were written for use in electronically transferring text-formatted data to the database manager (text format is a standard mode of data transfer between software applications that have application-specific data storage formats). Regional location maps of southern San Joaquin Valley oil fields, structure contour maps of the Pioneer area, core photos, core data, thin-section and SEM photomicrographs of core materials, 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 FTIR standards, and all quarterly and annual reports submitted to DOE for this project were scanned into the MDMS. All data and information are accessible through drop-down menus and hotlinks in a Table of Contents (Fig. 1). 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. Version 1.0 of the MDMS was written to CD ROM and distributed to participants in a Technology Transfer Workshop in Bakersfield, CA, in September, 1996. Version 1.1, which contains additional information and has been reorganized for easier use, is attached to this report.

All measured and computed log curves (computed curves represent parameters such as porosity, water saturation, and clay content, which were calculated from the measured log traces using specially developed algorithms) for the 45+ project wells on Pioneer Anticline are now in the MDMS in LAS (log ASCII) format, and can be exported to any commercial log evaluation program for manipulation and analysis. All log curves were written to the CD ROM in digital format.

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 tutorial describing how to use the search engine was written and is now available as on-line help. 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. Detailed information on the organization and use of the Toolbook MDMS and the Microsoft Access log database is presented in p. 7-19 of Appendix 1.

1.1.1 DATABASE INITIALIZATION

Database initialization is complete.

1.1.2 DATABASE MANAGEMENT

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

Microsoft Access is our relational database management platform. All of the log data are stored in Access in LAS format. All other data are stored Toolbook, in multimedia form, accessible via pulldown menus and a Table of Contents with hot links. Instructions for retrieving logs from the Access database are included in the Toolbook multimedia archive. Users can search the database by query and retrieve the logs from the main database table by well or by log type. Logs are then placed in smaller temporary Access tables from which they can be exported to applications programs. We 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.

The GeoGraphix software package was acquired in fall 1995 and installed on a PC in the Subsurface Laboratory at Michigan Technological University (MTU). Since that time we have acquired an academic license and three additional seats on GeoGraphix. Graduate students S. Chittick and W. Everham attended a training course at GeoGraphix' headquarters office in December, 1995, and Professor J. Huntoon and graduate student W. Houston attended in February, 1996. The USGS Digital Land Grid was acquired. This data set contains surface data, such as the locations of roads, rivers, towns, etc., for the entire United States. Production data for all of the wells in the Pioneer Field area were acquired from the California Division of Oil and

Gas. Both were loaded into GeoGraphix where they can be displayed as overlays on structure contour and other maps. Graduate student S. Chittick loaded all of DPI's formation-top, log, and fault-trace data into GeoGraphix. He produced excellent maps of the Miocene unconformity (including all fault traces) and contoured the maps to grid. Graduate student W. Houston constructed numerous cross sections through Pioneer Anticline (Fig. 2) and constructed structure contour maps on the tops of the principal formations (Fig. 3). For additional discussion of the GeoGraphix work, see Appendix 1, p. 36-37 and 41-42.

1.2 ORGANIZATION AND MANAGEMENT

1.2.1 PROJECT COORDINATION

The project was managed from MTU. J. Wood and W. Pennington were co-principal investigators. DPI performed much of the well-log analysis (using Crocker Petrolog and Symbilog), core-to-log calibration, and well-log correlation work in Bakersfield, CA. MTU faculty and graduates students performed additional well-log evaluations in QLA2 and Pfeffer and constructed maps and cross sections in GeoGraphix. Most of the petrographic, Xray diffraction, and geochemical work was also performed at MTU. J. Allan handled the technical reporting, technology transfer, and fluid inclusion analysis from Fullerton, CA. A. Nigrini completed the basin modeling work in La Habra, CA, and R. Robinson, who is the Director of the California Well Sample Repository, handled many of the arrangements for our Technology Transfer Workshop from Bakersfield, CA. Project coordination was facilitated by many trips between these various locations.

1.2.2 BUDGET MANAGEMENT AND QUARTERLY REPORTS

M. Gruener and A. Hein were responsible for daily management of the budget and expenditures. A. Hein prepares the quarterly financial reports and distributes all reports to DOE. J. Allan was 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 Reef Ridge Member were correlated between project wells. Top picks were made on all logs and corrected for well deviation. 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. 3). Fault intersections were mapped on the tops of the Etchegoin and Reef Ridge as well.

D. Crane of DPI later completed several cross sections through the Pioneer Anticline. Faults were correlated and mapped in a much more sophisticated fashion than previously, and fault-plane maps of all of faults which cut the Miocene section in the Pioneer area were prepared. These

included both normal and thrust faults. Crane picked the tops of the following formations in all project wells: the Etchegoin Formation, the Monterey Formation, the Reef Ridge Sandstone, and the Reef Ridge Shale. Formation tops are being contoured using GeoGraphix. Fault planes, with true azimuths and dips, and fault intersections with each formation were plotted in 3-D surface visualizations in MatLab. Geologic correlation and interpretation work performed by DPI is described in greater detail on p. 20-21 of Appendix 1.

Munger maps which cover the Pioneer Anticline and the entire area northward to the McKittrick Front area of Cymric Field were scanned into the Canvas (Deneba) drafting program and digitized into several "layers". 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 is continuing this work by preparing several additional maps and cross sections, including a geologic map and cross section of the Pioneer area which we recently acquired from Davis-Namson Associates.

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. 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. For further discussion of the Petrolog/Symbiolog work, see Appendix 1, p. 34 and 35.

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. Tops of the Miocene were picked in each of the 45 wells on the Pioneer Anticline, their X-Y locations at the appropriate depths were calculated for each well (to correct surface locations for well deviation), and both were placed in another spreadsheet from which they can be exported to any mapping or visualization program. A list of all logs in our database appears as Table 2 (after p. 19) in Appendix 1.

Log evaluation was 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. A comparison of the different programs was presented at our Technology Transfer Workshop in Bakersfield, CA in September, 1996, 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. Samples from all four wells underwent petrographic, petrophysical, and geochemical analysis at MTU and The University of South Florida (USF). Xray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscope (SEM) analyses were performed on selected samples by R. Kramer and D. Popko at MTU and bulk chemistry analyses by Inductively Coupled Plasma Spectroscopy (ICP) were performed by J. Ryan at USF.

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 Technology Transfer Workshop. The cores and core data from the two McKittrick Front wells are so outstanding that acquisition of core data from additional wells to calibrate our logs proved unnecessary. The cores 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. Petrophysical data from these cores were essential in the core-to-log calibration work performed by DPI.

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

The goal of this subtask was to develop FTIR techniques to differentiate Opal A from Opal CT in Monterey Formation reservoirs. Development of a reliable suite of standards has proved difficult. 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

R. Kramer performed XRD analyses of samples of sidewall core and cuttings from the Gary Drilling, KLC 44, Well No. 375x and of continuous core samples from the two UNOCAL McKittrick Front wells. She constructed spreadsheets and macros to store, reduce, and plot the XRD data. Reports on all Xray work were completed and written to the MDMS. 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

The fine-grained nature of the Monterey reservoir facies makes the material difficult to characterize petrographically using standard thin-section microscopy. However, the SEM provides at least an order of magnitude better resolution, particularly with regard to obtaining compositional data.

Grain mounts of selected samples were examined for morphological character and phase changes. The grainmount work was done prior to Image Analysis, since it provided valuable information about spatial variations in microporosity and helped guide the effort to understand and quantify porosity through Image Analysis.

Epoxy mounts of selected Pioneer samples were subjected to image analysis and Energy Dispersive Spectral (EDS) analysis on the SEM. Polished thin sections were prepared for experimental EDS point-count analysis. Electron photomicrographs were made for many samples. All electron photomicrographs and Energy Dispersive Elemental (EDS) analyses were archived in the Toolbook Multimedia Database Management System. Image Analysis work was begun, but cut short when R. Kramer left the project.

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. Results were presented by DPI at the AAPG Pacific Section Meeting in May, 1995.

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

In a reservoir study, log data is calibrated to ground truth. The preferred ground truth is whole core data over as much continuous interval as can be obtained given economic realities. Other valuable data include sidewall core data and well cuttings. For this project, one well from the study area has modern whole core analysis, several have sidewall cores, and one has a full suite of well cuttings. Core was also obtained for the project from two wells in a similar facies of the Monterey Formation from an area with extensive current production (the UNOCAL McKittrick Front 415 and 418 wells from Cymric Field). Data preparation and log calibration were performed on the 2 McKittrick Front wells and on 4 wells from Pioneer Field.

Routine core analysis data include measurements of porosity, fluid saturations, permeability, and often grain density on a foot-by-foot basis. Special core analysis can include lithology, flow tests, relative permeability, and capillary pressure measurements that are extremely useful in precise calibration of the log-core relationship. Routine core analysis data are currently available on all the cores included in the project, and some special core analysis data are also available.

All of the cored wells and selected uncored wells with good log suites were included in a preliminary log calibration study. Core data were plotted on a large-scale output log along with

raw log data and were compared with core photographs and with the core itself. Core data were also compared with log data using a variety of statistical techniques in order to obtain correct parameters for entry into standard algorithms for calculating matrix density, porosity, and water saturation. No published analytical models exist for diatomaceous rocks, so DPI used a model it developed in-house.

Log calibration is complete for all project wells.

3.3.1 DATA PREPARATION

Wireline logs for all of the wells for which we had obtained good logs were digitized (see Appendix 1, Table 2). This includes most of the wells on the structure. Data preparation consisted of the following steps:

Data verification: this involves plotting the digital data and overlaying the plot on the original blue-line copy of the log,

Data editing: this includes inspection of the logs to identify bad data and correcting them if possible, nulling unrecoverable bad data, and noting logging problems that will later affect the analysis,

Depth shifting: multiple logging runs in the same well are usually off depth from one another due to differential tool sticking and cable stretch. An experienced log analyst must correlate the different logs to one another and adjust them to the same depth,

Environmental corrections: all logging companies provide algorithms published in chart form to correct the readings of their tools for borehole conditions, and these corrections must be applied before any analysis is performed,

TVD correction: many of the wells on Pioneer Anticline are deviated, and it is necessary to calculate the deviation and the true vertical depth from the well survey records,

Normalization: well logs vary in their calibration, and if the same parameters are to be applied to all wells it is necessary to adjust them to one another to eliminate calibration errors.

Data preparation was completed 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 were 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.

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 used by M. Luo to construct 3-dimensional visualizations of the Pioneer Anticline in MatLab. The results of his 3-D

visualizations, with "slice and dice" capability, are quite impressive, and were presented at our Technology Transfer Workshop.

3.3.2 MODEL SELECTION

A number of analytical models have been presented over the years in the log analysis literature. Some are only appropriate for specific reservoir types, others require that special data be available. Many are general purpose and are based upon the more common reservoir lithologies and log types. Diatomite is an unusual rock type, and there is little published literature on analytical models for it.

There are several important measures of reservoir quality in diatomaceous lithologies besides porosity and saturation. Lithology and the presence of fractures are also very important. Many diatomaceous rocks have adequate porosity and oil saturation for hydrocarbon production, but have too little permeability for production. The measurement and/or prediction of lithology and fracturing are therefore important parts of a reservoir evaluation in diatomites.

The models that have been selected for this project can be applied to all wells with resistivity and density-neutron logs, and are capable of predicting matrix density, clay volume, diatomite facies, accessory minerals such as carbonates, porosity, permeability, water saturation, as well as providing a qualitative measure of fracturing and fracture potential. The rock analysis data that will be available from MTU will provide for better calibration of our standard models and will also allow us to apply several enhanced options that require good rock measurements. The output of these models is the primary input to the reservoir visualization program.

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.

The new parameters and algorithms were recently tested on the two McKittrick Front wells with modern logs suites by running one set of calculated logs utilizing all of the modern log and core data and a second set of calculated logs on the same intervals using only the spontaneous potential and one resistivity log. The output curves for the two runs were very similar, suggesting that output from the electric-log-only well runs will closely approximate the calculated curves which would be obtained if full modern log suites were available for all of the wells (Fig. 4).

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. These calculations were performed on all 45+ Pioneer project wells and computed curves were generated.

TASK 4. MODELING

4.1 GEOCHEMICAL MODELING

The geochemical modeling program CHILLER was used by J. Suchoski to model fluid-rock interaction. Results showed that identification and quantification of changes in porosity are possible. These results show that, for an arkosic assemblage undergoing reaction with seawater, the change in porosity is negligible. Addition of calcite to the reaction assemblage, and suppression of quartz and albite precipitation, can increase the change in porosity by as much as 5%. This has 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 also performed by J. Suchoski. The stable isotope modeling program ISOTOPIA was developed and was used successfully to model the stable isotopic evolution of the fluid and the minerals.

4.1.2 THERMODYNAMIC DATABASE

Two databases were 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. M. Luo developed a number of new applications for constructing 3-D surface and volume visualizations and pseudo-seismic cross sections using the program MatLab. These new applications were demonstrated at the Technology Transfer Workshop using data from Pioneer Anticline.

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 complete. Results were presented in a poster display at the AAPG National Meeting in San Diego, CA, in May and in a talk and poster display at the Technology Transfer Workshop in Bakersfield, CA, in September, 1996.

The Elk Hills 934-29R 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. This well is unique in that it bottoms in Cretaceous sediments, thus giving us as complete a Tertiary section in the sub-surface 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. In addition, estimates of the surface temperature history are available as determined from water depth information derived from abundant fossil evidence. A generalized paleo-heat flow model for the southern San Joaquin Basin 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 (Fig. 5).

The predicted Ro value at the base of the well, on the assumption that the downhole temperature data represent the regional temperature field, is 2.4 compared to the observed value of 1.56. As vitrinite is believed to equilibrate relatively rapidly, the results indicate that the observed temperature profile is not in equilibrium with the regional temperature field in this region. In fact, examination of the complex structure of the Elk Hills reservoirs, which includes en echelon anticlines, transform, normal and reverse faults (suggestive of a flower structure), numerous discrete pressure compartments with differing temperature profiles, and recent seismic and tectonic activity suggests that the observed temperature fields at Elk Hills are not likely to be in equilibrium but are reflective of migrating geothermal fluids that have been released episodically in the very recent past up to the present day. It appears that the elevated temperature profile may be due to episodic release of geothermal fluids. If correct, our interpretation suggests that all reservoirs 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.

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, providing evidence that hydrocarbon migration has occurred throughout this deep section.

The Elk Hills geohistory modeling study is discussed in greater detail in Appendix 1, p. 26-31. 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 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 formation-top and fault-trace data assembled by D. Crane of DPI into MatLab and constructed excellent 3-D surface and volume visualizations, which can be rotated to any orientation and sliced at any angle for viewing (Fig. 6). He added the capability to map accurate fault intersections on formation-top contour maps and project fault planes in 3 dimensions at any dip angle desired (Fig. 7). Results were presented at the Technology Transfer Workshop. The

capabilities of the MatLab programs, developed entirely in-house at MTU as part of the DOE project, are discussed in Appendix 1, p. 38-40.

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 (Fig. 8).

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 can now import aerial and satellite photos into GeoGraphix, where and overlay surface maps and surface data (roads, surface facilities, etc.) on the photographic images.

TASK 5. TECHNOLOGY TRANSFER

5.1 REPORTS

A Workshop Notebook that summarizes and illustrates all project activities, and a CD ROM, which contains the MDMS with all project data, maps, cross sections, interpretations, and reports, was distributed to Technology Transfer Workshop participants 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

The following is a summary of the Technology Transfer workshops, exhibits, and presentations made during the course of this project:

Technology Transfer Workshop

A Technology Transfer Workshop was held in the Walter Stern Library Building and at the California Well Sample Repository at California State University, Bakersfield on September 24, 1996. R. Robinson, the Director of the Repository, was instrumental in planning and arranging the event. Twenty two participants from major oil companies, independents, government agencies, and the oil and gas consulting community attended.

The Workshop included a core display and barbecue at the Repository. Cores from the McKittrick Front calibration wells (including portions of the 700-ft research core from the McKittrick Front 418 well) were on display, along with core from selected intervals in the Elk Hills 934-29R well that was used in our Geohistory modeling study. Poster displays accompanied the cores. All participants received a workshop notebook which summarized project results and Version 1.0 of the MDMS CD ROM.

American Association of Petroleum Geologists (AAPG) Annual Meetings

MTU ran a booths featuring the Pioneer Field DOE Project in the Exhibit Hall at the AAPG National Meetings in 1994, 1995, and 1996. Along with poster displays, the booths featured computer-graphics displays, projected onto a large screen, that presented overviews of project activities and results. F. Berry and D. Olson presented results of their log-evaluation work and held computer demonstrations of the Crocker Petrolog and Symbiolog programs. In 1996, 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, 1996, 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.

Community Energy Night in Bakersfield

On April 23, 1996, A. Nigrini and R. Robinson presented the results of the Elk Hills study (see Subtask 4.2.1) at the Third Annual Community Energy night in Bakersfield, CA. This exposition, which is sponsored by organizations representing all facets of the petroleum industry, attracted an audience composed of community leaders, energy industry management, and California Division of Oil and Gas officials. The presentation was well-received, and particular interest was focused on Nigrini's evidence that depth to economic basement is greater than previously believed in the Elk Hills area.

SEG Development and Production Forum

J. Huntoon and W. Pennington presented posters at the Society of Exploration Geologists (SEG) Development and Production Forum on "Cooperative Projects to Improve Reservoir Management" in Colorado in June, 1995. Pennington discussed the California Reservoir Visualization project and another DOE project which involves horizontal drilling in the Michigan Basin in which Michigan Tech is also 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. 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.

DOE Contractor Review Meeting

J. Wood attended the DOE Contractor Review Meeting in June, 1995, and presented an overview of the project. Our Multimedia CD ROM system for archiving data and distributing project results elicited favorable comment.

AAPG Pacific Section Meeting

DPI ran a booth in the Exhibit Hall at the Pacific Section AAPG Meeting in San Francisco in May, 1995. The booth featured our Pioneer Anticline project along with other projects and services offered by DPI. Posters and an album containing interpreted photomicrographs and SEM photographs prepared by R. Kramer were on display. A handout describing the project was distributed to many interested people.

Tampa Meeting

In January, 1995, a meeting of all project staff was held at the University of South Florida in Tampa (where Wood was on sabbatical) to review the DOE project. The meeting afforded project members an opportunity to learn what everyone else was doing and to discuss project plans and accomplishments in an open forum. The meeting was very successful at accomplishing these goals. R. E. Lemmon, our DOE Program Manager, attended the meeting.

FIGURE CAPTIONS

Figure 1. Table of Contents of Multimedia Database Management System. MDMS has been written to CD ROM and is the main project deliverable.

Figure 2. A structural cross section through Pioneer Anticline, prepared in GeoGraphix.

Figure 3. Structure contour map on top Miocene, Pioneer Anticline, prepared in GeoGraphix.

Figure 4: The results of the full-suite and e-log only analysis are compared for Well 72-30. Track 1 shows the lithology analysis from the full log suite, Track 2 shows the same analysis using e-log only. Track 3 compared the effective porosity computed from the full suite (PHIEDW) and from the e-log only model (PHESDW). In Track 4, the clay volume curves from the two models are compared (VCLWDW from the full suite, VCWSDW from the e-log only model).

Figure 5. Plot of equilibrated (shut-in) downhole temperature and vitrinite reflectance vs depth for Elk Hills 934-29R well. Note that downhole temperature profile is not in equilibrium with Ro profile and that Ro values indicate that temperatures in the recent past must have been significantly lower than they are today.

Figure 6. 3-D volume visualization prepared in MatLab illustrating "slice and dice" capability.

Figure 7. Structure contour map on the top Miocene, Pioneer Field area, displayed as a 3-D surface visualization in MatLab. Although in this version fault intersections with the top Miocene surface are displayed in their proper declinations as vertical planes, they can now be displayed at their true inclinations as well. Visualization was prepared in MatLab.

Figure 8. "Pseudo-seismic" display constructed from gamma-ray logs. Individual "pseudo-seismic" logs can be selected from wells shown in map view by drawing a section line on the screen. The color-coded logs are then displayed in cross section, as shown here.

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 - 2.3. GES Projects by W. Houston and S. Chittick
3. Petrography
 - 3.0. Petrography Thumbnails
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 - 3.2. North Coles Levee
 - 3.3. Elk Hills
 - 3.4. South Coles Levee
 - 3.5. North Tejon
 - 3.6. Tejon Grapevine
 - 3.7. Canfield Ranch
 - 3.8. Fruitvale
 - 3.9. Gosford
 - 3.10. Bellevue
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- 4.1.3.1 Core Photos
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- 4.1.3.3 Core Log Displays

Figure 1

STRUCTURAL CROSS-SECTION: EQUAL SPACE

Datum = Sea Level Domain = Depth

Scale = 1:24000 Vertical Exaggeration = 4X

Michigan Technological University
Department of Geological Engineering and Sciences
1400 Townsend Drive Houghton, Michigan 49931-1299

STRUCTURAL CROSS SECTION
PIONEER ANTICLINE LIMB
PIONEER FIELD - KERN COUNTY, CA
DATA AND LOGS PROVIDED BY DPI, BAKERSFIELD, CA

Drawn By: W. HOUSTON	Scale: 1 : 24,000
Geology By: W. HOUSTON	Project: PIONEER 100K Prospect: GLOBAL
Drawn For: D.O.E. WORKSHOP	Date: SEPT. 1996 Drawing No.: DOE2.GPF

Figure 2

Michigan Technological University
 Department of Geological Engineering and Sciences
 1400 Townsend Drive, Houghton, Michigan 49931-1205

STRUCTURE CONTOUR MAP
TOP MIOCENE UNCONFORMITY
 (FAULT TRACES SHOWN IN PURPLE)
PIONEER FIELD - KERN COUNTY, CA
 DATA PROVIDED BY DPI, BAKERSFIELD, CA

Drawn By: W. HOUSTON	Project: PIONEER 100K	Scale: 1 : 36,000
Geology By: S. CHITTICK	Date: SEPT. 1996	Prospect: GLOBAL
Drawn For: D.O.E. WORKSHOP		Drawing No.: DOE1.GPF

Scale 1:38000.

N

Figure 3

Figure 4

Standard Model Depth Plot

Elk Hills 934-29R

Figure 5

Figure 6

29-Aug-96

3-D Visualization of the Top Miocene, Pioneer Field

Figure 7

Figure 8 "Pseudo-seismic" display constructed from gamma-ray logs. Individual "pseudo-seismic" logs can be selected from wells shown in map view by drawing a section line on the screen. The color-coded logs are then displayed in cross section, as shown here.

APPENDIX 1

VISUAL DISPLAY OF RESERVOIR PARAMETERS AFFECTING ENHANCED OIL RECOVERY

A DOE Sponsored Workshop

California State University, Bakersfield

September 24, 1996

By

Michigan Technological University, Houghton, MI

Digital Petrophysics, Inc., Bakersfield, CA

California Well Sample Repository, Bakersfield, CA

Funded by the U.S. Department of Energy

Advanced Extraction and Process Technology Program

AGENDA

WORKSHOP ON VISUAL DISPLAY OF RESERVOIR PARAMETERS

at

California State University, Bakersfield
and the
California State Well Sample Repository

September 24, 1996

- 8:30 Coffee
- 8:45 Introduction and Logistics Gruener
- 9:00 Project Summary & Toolbook Multimedia Database Management System Wood
 - Project Summary
 - Multimedia Database Manager and CD ROM
 - Software Overview
- 9:45 Coffee Break
- 10:00 Pioneer Project: Geology and Reservoir Characterization Olson, Berry, Crane
 - Data Collection and Organization
 - Geological and Structural Framework
 - Reservoir Properties and Reservoir Characterization
- 11:00 Introduction to Core Layout and Geohistory Modeling Allan
 - The McKittrick Front 418 Core
 - Geohistory Modeling: Elk Hills 934-29R Well
- 11:30 Core Layout Robinson, Allan
- 12:00 Lunch
- 1:00 Log Analysis Introduction Pennington
- 1:15 Pfeffer and QLA2 Pennington, Suchoski
- 1:45 Symbiolog Berry
- 2:15 Coffee Break
- 2:30 Visualization of the Pioneer Anticline Luo, Houston, Wood
 - GeoGraphix 2D Visualization
 - MatLab 3D Visualization
- 3:30 GeoGraphix Case Study: Kern Front Field Houston
- 3:45 Session Summary and Future Plans Wood
- 4:00 Epilogue:
 - Computer Demonstrations
 - Core Layout
 - CD ROM
- 5:00 Adjourn

Project Summary

(J. Wood)

The Pioneer Anticline, 25 miles southwest of Bakersfield, California, which has yielded oil since 1926, was the subject of a three-year study aimed at recovering more oil. A team from Michigan Technological University of Houghton, Michigan, and Digital Petrophysics, Inc. of Bakersfield, California, undertook the study as part of the Department of Energy's Advanced Extraction and Process Technology Program. The program provides support for projects which cross-cut geoscience and engineering research in order to develop innovative technologies for increasing the recovery of some of the estimated 340 billion barrels of in-place oil remaining in U.S. reservoirs.

In recent years, low prices and declining production have increased the likelihood that oil fields will be prematurely abandoned, locking away large volumes of unrecovered oil. The major companies have sold many of their fields to smaller operators in an attempt to concentrate their efforts on fewer "core" properties and on overseas exploration. As a result, small companies with fewer resources at their disposal are becoming responsible for an ever-increasing share of U.S. production.

The goal of the MTU-DPI project was to make small independent producers who are inheriting old fields from the majors aware that high technology computer software is now available at relatively low cost. Most major oil companies rely on expensive computer workstations. In this project, a suite of relatively inexpensive, PC-based software packages, including a commercial database, a multimedia presentation manager, several well-log analysis program, a mapping and cross-section program, and 2-D and 3-D visualization programs, were tested and evaluated on Pioneer Anticline in the southern San Joaquin Valley of California. Relatively inexpensive, commercially available PC-based programs can be assembled into a compatible package for a fraction of the cost of a workstation program with similar capabilities. During this workshop, the various programs that project members used will be compared and evaluated and new applications developed at MTU and DPI will be discussed (Table 1).

A field trial of the technology was performed on the Monterey and Etchegoin Formations in Pioneer Field (Fig. 1). Pioneer Field is a typical small, older field that contains wells with old logs, a few wells with modern logs, and limited sidewall core coverage. It is essential to be able to extract the most information from the old logs and to accurately assess their reliability. Phases of the field trial included: data gathering; calibration of core, cuttings and liquids to well-log suites; and input of geological, petrophysical and reservoir engineering data to the various software packages. Conventional and sidewall-core data from Pioneer and nearby Cymric fields were used to develop algorithms to correlate log response with geological and engineering measurements in order to extract a maximum amount of information from old wells that only possess old electric logs. Our final output includes: computed logs of lithology, porosity, and clay content for all project wells, including those which possess only old electric logs; 2-D and 3-D representations of

the reservoir and structure; and an extensive database which contains logs, maps, cross-sections, and core data and analytical data for Pioneer Field and surrounding areas assembled in a Multimedia Database Management System designed and constructed by project staff in a commercially available multimedia software package.

In this workshop, we intend to demonstrate how to use existing, proven technologies to go into an old field, assemble relevant existing data into an organized database, calibrate log data using standard and special analytical techniques, process that data into a computer image of the field, and map the reservoir and structure using relatively inexpensive PC-based computer software.

VISUALIZATION PROJECT

SOFTWARE SUMMARY

PROGRAM	APPLICATION	COMPANY	COST
GES	VISUALIZATON/DATABASE	GEOGRAPHIX (HALLIBURTON)	\$4,000
QLA2	LOG ANALYSIS	GEOGRAPHIX (HALLIBURTON)	\$2,000
MATLAB	VISUALIZATION/PLOTTING		\$500
SIGMAPLOT	2D/3D Graphs	JANDEL CORP.	\$495
ROCKWELL UTILITIES	UTILITIES	ROCKWELL	\$350
PFEFFER	LOG ANALYSIS	U. KANSAS	\$350
TOOLBOOK	PROJECT DATABASE & SUMMARY	ASYMETRIX	\$300
CANVAS	DRAFTING - MAPS ETC.	DENEBA	\$200
EXCEL	SPREADSHEET	MICROSOFT	\$100
WORD	WORD PROCESSOR	MICROSOFT	\$100
ACCESS	DATABASE	MICROSOFT	\$100
PETROLOG	LOG ANALYSIS		\$20,000
SIMBIOLOG	ADVANCED LOG ANALYSIS	DIGITAL PETROPHYSICS INC.	NA
QUATTROPRO	SPREADSHEET	LOTUS/BORLAND	\$100
SPYGLASS	VISUALIZATION/PLOTTING		\$500
SURFER	VISUALIZATION/PLOTTING	GOLDEN SOFTWARE	\$500

Summary of major software packages evaluated for various aspects of this project. All of these packages can be recommended for use in the designated tasks. The GeoGraphix and Microsoft products form a good core for data storage, retrieval, analysis and display. SIMBIOLOG is a new product developed over the course of the project by Digital Petrophysics, Inc. to handle special cases.

Figure 1

Multimedia Database Management System

(C. Asiala, J. Wood)

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. After evaluating the pros and cons of using commercially available software versus "home grown" it was decided to use the commercial software package Toolbook from Asymetrix. In this document, we refer to this as the ToolBook Database Management system or TDM. Some advantages of using commercially available software include superior data handling and archiving, as well as attractive visual displays. In addition, documentation, tutorials, software support, and upgrades will all be taken care of by a commercial vendor.

Maps of the southern San Joaquin Valley oil fields and the Pioneer area are in the database, as well as core photos, core data, thin section photomicrographs, and SEM photomicrographs. Regional location maps of southern San Joaquin Valley oil fields and structure contour maps of the Pioneer Anticline were also scanned into the ToolBook Database Management (TDM) as well as 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 and annual 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 TDM and instruct them on the various ways in which data can be viewed and retrieved. The TDM will be written to a CD ROM at the end of the project.

All measured log curves for all the project wells on Pioneer Anticline are in the TDM in LAS (Log ASCII Standard) format, and are stored in a Microsoft Access file on the CD ROM. These data can be exported to log evaluation programs for manipulation and analysis. Computed log curves (curves representing parameters such as porosity, water saturation, and clay content, calculated from the measured log traces using specially developed algorithms) were translated from LBS (Log Binary Standard) format before being input to the TDM.

Special queries were developed in Microsoft Access that enable the user to easily retrieve these logs from the CD ROM. Any desired log curve can be located using queries and then exported from the CD ROM to 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. Access provides a log database which is independent of all of specific well-log evaluation programs (Crocker Petrolog, GeoGraphix QLA2, and TerraSciences TerraStation), but is capable of exporting data to any one of them.

A preliminary CD ROM (Version 1.0) is included in the workshop notes and contains the TDM as well as all the log files in LAS format. In Version 2.0, which will be completed by

the end of 1996, additional data will be added and explanatory text will be written for each topic and data set. Version 2.0 will also contain the project Geographix files. Appendices 1 and 2 provide more detailed information on how to use the TDM system and the Microsoft Access log database.

APPENDIX 1

Multimedia Database Management System: Instructions on the Use of the Pioneer Project Multi-Media Presentation Software (C. Asiala, J. Wood)

The CD-ROM for the Pioneer Project Presentation was produced using the visual authoring system, Asymetrix ToolBook 4.0. Text, photos, maps, screen displays, and scanned images pertaining to the Pioneer Project were imported into ToolBook files and organized with pull-down menus, push buttons, and hot links.

System Requirements

1. Microsoft Windows 95
2. Color Monitor set with at least 256 colors
3. Screen resolution is best at 1024 X 768 (lower resolutions require more scrolling)
4. A CD-ROM drive

Installation of the CD-ROM

1. Place CD in the CD-ROM drive
2. From the Start menu, Select RUN
3. Type d:\setup (if CD drive is not d:, use the appropriate letter)
4. Follow the Setup Instructions (choose Full Installation)

Startup Instructions

1. From Start Menu, Select Programs
2. Select Pioneer Project Multi-Media Presentation
3. Select Pioneer Project

The first 2 screens identify the program, show system requirements and a general outline of the project contents. Once past these screens, the user has full use of the pull-down menus, push buttons and hot links.

Installation Directories

c:\pioneer

This is the destination directory of the startup ToolBook file, pioneerp.tbk

c:\windows\asym\runtime

This is the directory where the Toolbook runtime files are stored.

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- 4.1.3.1 Core Photos
- 4.1.3.2 Core Data Reports
- 4.1.3.3 Core Log Displays

4.2. Well N62-30

- 4.2.1. Core Logs

5. Database

5.1. Pioneer Well Log Database

5.2. FTIR Standards

User Procedures

The Table of Contents

The Table of Contents presents the content of the project in an outline format. The items in red are hot links to the corresponding presentation screen. Click on the item of interest and that page will come up.

Some of the items point to the first page of related items, from which you can use NEXT and PREVIOUS buttons to move around.

The Page commands (Next and Previous) from the Pulldown Menu are also available.

To return to the Table of Contents from any screen, Click on Pulldown Menu item, **Pioneer Project** and then **Table of Contents**.

The Pulldown Menus

The Pulldown menu at the top of the screen holds Subject titles with subtitles below. When these are clicked, the corresponding screen comes up.

The Pulldown menu can be used from any screen to go to any screen. Even if there are Next, Previous, or Return buttons, the user can switch to a different Subject and view any other item.

Page (ALT+left or right arrow key work as Next and Previous)

These commands move through the pages of each individual presentation book. The project is stored in several different files and the Page commands only work with the current file. The Table of Contents or the Pulldown Menu must be used to move to pages in different books.

Pioneer Project

The items under this heading are reports written about the Pioneer Project. They include the Public Abstract, Participants in the Project and the Quarterly and Annual reports submitted to the Department of Energy. They are all text screens which must be scrolled with the slide on the right.

Regional Geology

This heading shows maps and charts relating to the geology of the Project Study Area.

Petrography

This category is a series of Photomicrographs from 14 fields in the southern San Joaquin Valley. When Petrography Thumbnails is clicked, a screen showing thumbnail views of the photos is displayed and the individual photos can be clicked to see more detail.

If a field name is clicked, the first photo for that field is displayed and the NEXT and PREVIOUS buttons can be used to see the remaining photos.

The CAPTION button can be clicked to get a description of the photo.

Visualization

This category has specific photos and charts for the **Calibration wells**, the McKittrick Front 415 and 418 wells in Cymric field. This includes a Stratigraphy chart and Core Analysis Data for both wells, and Core Logs, Core Photos in plane and ultraviolet light and SEM Photos for McKittrick Front 418. Well N62X-30 is a well in Pioneer Field for which Core Logs are presented.

The thumbnail photos of the Core Photos are labeled with "mck" followed by a number. This number is the starting depth of the core in the photo. When the CORE ANALYSIS button is clicked, porosity, permeability, and saturation data are displayed for the depth range that corresponds to the photo.

Database

The Pioneer Well Logs in LAS format are stored on this CD-ROM. A Microsoft Access database holds the Well Header data and a form for extracting Log data from the LAS files into Access Tables. This section is a tutorial on how to use the Access Database.

Navigation Tips

Copy to Clipboard

This button in the upper right corner is clicked to select and copy the entire text of the screen to the clipboard. The text can then be pasted into a text editor or a word processor to be printed and/or saved.

After the text has been copied to the clipboard, the screen looks empty. Move the right scroll bar back to the top of the screen.

Scrolling

When the slides appear on the bottom and right, there may be more of the data or graphic to view. When a screen is scrolled to the bottom, and then a new page is brought up, the new page may be scrolled down to the bottom also.

For best results, make sure the scroll bars are at the top and left before or after moving to another screen.

Pop-up Descriptions

Pop-up windows appear for the Petrography photo and Core Photo descriptions. If the window is not closed before moving to another photo, refresh the description by clicking on the CAPTION or CORE ANALYSIS buttons.

Push Buttons

Other Push buttons have been set up to make it easier to move to related screens. Click on these to see related items or changed Subjects by using the Pulldown Menus.

Zooming

Some maps and charts and the thumbnail prints have areas set up for zooming in for a closer look at the details. When the cursor is passed over an image and it changes to a magnifying glass, click the mouse and a bigger image will come up.

APPENDIX 2

Multimedia Database Management System: Instructions on the Use of the Pioneer Well Log MS-Access Database (C. Asiala, J. Wood)

Overview

Loading the Pioneer well log collection into Microsoft ACCESS provides an easy, efficient means to archive and access the project well logs in LAS format. Access is readily available as a stand-alone program and Access files can be read by a number of applications, and the list is growing. By using the options (queries) available in Access, tables can be created that contain only the logs and wells of interest to the user. Several example Query files are provided.

The ACCESS log files created for this project have subsea depth in the left column and log curves in the columns to the right. The tables can be exported from Access in different formats, including text files and Microsoft Excel files.

Database File Organization

The Access database files and the LAS files for the Pioneer Project are in the **LOGS** subdirectory on the CD-ROM. These files contain:

1. 77 LAS files with raw log traces,
2. 46 of these 77 wells contain computed (interpreted) log values
3. 36 wells with well header information only (very old wells with wireline logs).

In the **LOGS** subdirectory, files which end with "in" (*in.las) are computed (interpreted) logs, files labeled *.las files are raw logs and the file **pioneer.mdb** is the Microsoft Access for Windows 95 Version 7.0 database file.

The LAS files can be accessed from any Software Package that accepts the LAS format, but the user must have Microsoft Access for Windows 95 Version 7.0 in order to use the Pioneer Well Log Database provided on this CD-ROM.

Installation of the Pioneer Well Log Access Database.

To use the Pioneer Well Log Database, first copy **pioneer.mdb** from the **LOGS** subdirectory on the CD-ROM to a directory on your own hard drive. Then

1. Start Microsoft Access and Open the database file, **pioneer.mdb**.

2. Select the FORMS tab and Open PioneerForm to bring up the screen to view the individual wells and to start the programs for creating the 2 types of tables (Multiple Log Curves for Current Well or One Log Curve Over Multiple Wells)
3. Select the TABLES tab and Open WellHeaders to view all the header information about the wells in the database.
4. Select the QUERIES or REPORTS tabs to use the queries and reports present or create new ones of your own.

Creating Tables using PioneerForm

PioneerForm Options

1. Select FORMS tab from database window.
2. Open PioneerForm
3. Select a specific well from WellName list if creating a table for Multiple Log Curves for Current Well.
4. Enter drive and directory of location of LAS files (d:\logs if d is the CD drive letter)
5. Click on either "Multiple Log Curves for Current Well" or "One Log Curve Over Multiple Wells"

If you select **"Multiple Log Curves for Current Well"**, then

1. Click on names in the Select Log Types list box to choose the Log Types to be included in the table.
2. The new table generated will have the Subsea Depth in the first column and one column for each log chosen in the Select Log Types list box.
3. The program generates a name shown on the bottom of the screen. (a "W" followed by the LAS file name). The user can change this name.
4. Click on the button called "Create Log Curve Table" to start the table generation. When complete, focus will go back to the PioneerForm screen and the table can be viewed under the TABLES tab from the main database screen.

If you select **"One Log Curve Over Multiple Wells"**, then

1. Click on one Log Name in the Log Curve list box to select one Log Curve for the table.
2. Click the Select All Wells in List button to select all wells with the chosen Log Type, or
3. Click on individual wells in the Select Wells for Curve list box to select only the wells needed. The wells shown in the Selected Wells for Log Curve list box will be included in the new table.

Note: as wells are selected for the table, records are appended to a temporary table to hold for processing. The following messages will appear and both need to be responded to with a YES.

“You are about to run an append query that will modify data in your table.

Are you sure you want to run this action query?” Yes

“You are about to append n row(s). Once you click Yes, you can’t use the Undo command to reverse the changes.

Are you sure you want to append the selected rows?” Yes

4. The new table generated will have the Subsea Depth in the first column and one column for each selected well which holds the log values of the selected Log Type.
5. The program generates a name shown on the bottom of the screen. (“LOG_” followed by the 1-4 character Log Type name). The user can change this name.
6. Click on the button called “Create Log Curve Table” to start the table generation. When complete, focus will go back to the PioneerForm screen and the table can be viewed under the TABLES tab from the main database screen.

Database Definitions

Tables within the Pioneer Well Log Database file, pioneer.mdb

Table: WellHeaders

This table holds Well Header information for each of the 159 logs and/or wells in the study. The table is ordered by wells with raw logs first, then the wells with no logs, then the wells with computed logs. The well names for the wells with computed logs will be the same as the raw logs, but they will have “(INTERP)” appended to the end of the well name. INTERP was used as a shortened term for interpreted logs, but it will be changed to “(COMP)”, for computed logs, on the second version of the CD-ROM.

When viewing the wells in the **Form**, PioneerForm, the wells will be shown in Well Name order for easier viewing. The attached reports give a list of the wells in the database and a field definition list for the fields in the WellHeaders table.

Table: LogsByWell2

This table holds general data about each log trace which is found in the LAS file for each well. The table is sorted by Well_ID and LogName. It is used by the programs for extracting log data by giving the top and bottom subsea levels of each log, and giving the place value of which column in the LAS file the log values are stored in.

Table: TempLogTable

This is a temporary table which holds the log trace names of which logs were selected for creating a table for Multiple Log Curves for Current Well. It is emptied before each use.

Table: WellsByLog2

This is also a temporary table which holds the wells which are selected with a common log trace for creating a table for Multiple Wells for One Log Curve. It is also emptied before each use.

Forms within the Pioneer Well Log Database file, pioneer.mdb

Form: PioneerForm

This form is shown under the FORMS tab in the database. Each Well can be viewed individually on this screen by choosing the well name from an alphabetic listing. General data about the well and a list of the log traces in the LAS file are displayed. The new log tables are generated from this screen.

Form: SelectLogs

This form appears when the user clicks on Multiple Log Curves for Current Well from the PioneerForm. Use the **Select Log Types** list box to choose the Log Traces to include in the table.

Form: SelectCurveAndWells

This form appears when the user clicks on One Log Curve Over Multiple Wells from the PioneerForm. Use the **Log Curve** list box to choose one Log Trace for the table. Use the **Select Wells for Curve** list box to select specific wells.

Queries within the Pioneer Well Log Database file, pioneer.mdb

GetLogList

Initiated from Form, Multiple Log Curves for Current Well

Fills **Select Log Types** list box with Log Types from current well.

ValidLogTypes

Initiated from Form, One Log Curve Over Multiple Wells

Fills **Log Curve** list box with valid Log Types from all wells.

GetWells

Initiated from Form, One Log Curve Over Multiple Wells

Reset when a Log Type is Clicked from the **Log Curve** list box.

Fills **Select Wells for Curve** list box with wells which have a log of the selected Log Type.

GetLASFiles

Initiated from Form, One Log Curve Over Multiple Wells

Called when **Select All Wells in List** button is pressed.

Fills **Selected Wells for Log Curve** list box with all wells which have the chosen Log Type.

Wells are appended to the WellsByLog2 table.

AddToWellList

Initiated from Form, One Log Curve Over Multiple Wells

Called when a well from the **Select Wells for Curve** list box is clicked.

Fills **Selected Wells for Log Curve** list box with one well at a time as they are chosen.

Wells are appended to the WellsByLog2 table.

FindDepthRange

Initiated from Module, OneCurveManyWells

Finds the Highest Top Depth and the Lowest Bottom Depth to initialize the table for One Log Curve Over Multiple Wells.

DeleteExample

This is an example of how a user can delete the half-foot and odd numbered depths from a table to decrease the size of the table. It can be altered to be used with any of the tables created from PioneerForm, and conditions may be changed, added, or deleted.

Query conditions

(Expression to determine if depth ends with .5)

Field : Expr1: [Subsea_Depth] - Fix([Subsea_Depth])

Delete : Where

Criteria : <> 0

(Expression to determine if depth is odd or even)

Field : Expr2: [Subsea_Depth] mod 2

Delete : Where

Criteria :

Or : <> 0

Modules within the Pioneer Well Log Database file, pioneer.mdb

ClearTempLogTable

Initiated from Form, Multiple Log Curves for Current Well

Called when Form is opened and also when the button, **Clear Selected Log List** is clicked.

Deletes all records in the TempLogTable

ClearWellsByLog2

Initiated from Form, One Log Curve Over Multiple Wells

Called when Form is opened and also when the button, **Clear Selected Wells List** is clicked.

Deletes all records in the WellsByLog2 table.

OneWellLogCurve

Initiated from Form, Multiple Log Curves for Current Well
Called when the **Create Log Curve Table** button is clicked.

Creates Table: First column is Subsea_Depth
Additional columns hold log values for each Log Type
chosen

Reads the LAS file corresponding to the Current Well and fills the table with the selected Log values.

Table Name : first character is "W"
Followed by the LAS file name up to the .las

Field Names: Subsea_Depth and names of Log Types

OneCurveManyWells

Initiated from Form, One Log Curve Over Multiple Wells
Called when the **Create Log Curve Table** button is clicked.

Creates Table: First column is Subsea_Depth
Additional columns (1 per selected well) hold log values
for the Log Type chosen from each of the selected wells.

Reads the LAS files corresponding to the list of Selected Wells and fills the table with the selected Log values.

Table Name : First 4 characters are "LOG_"
Followed by 1-4 character log name

Field Names: Subsea_Depth and ("W" & LAS file names of wells)

Macros within the Pioneer Well Log Database file, pioneer.mdb

The Macros are called as a result of an event (a click of a button).

ClearTempLogTable

Calls Module to delete records from TempLogTable

ClearWellsByLog2

Calls Module to delete records from ClearWellsByLog2

OneCurveManyWells

Calls Module to create Table of Multiple Log Curves for Current Well

OneWellLogCurve

Calls Module to create Table of One Log Curve Over Multiple Wells

SelectCurveWells

Opens Form, One Log Curve Over Multiple Wells

SelectLogCurves

Opens Form, Multiple Log Curves for Current Well

WELL LOG INVENTORY

Well Name	LASFileName	Top	Bot	No. of Logs	TD	KB	Date Drilg	Operator
1				0	3502			Texaco
12				0	903	1175	2/25/11	Western Minerals
2				0	3533			Texaco
8				0	2050	1209	11/30/09	Western Minerals
ARCO 46X-19 REDRILL 1 (COMP)	46x19in.las	632	6758	17	6808	990	1/10/93	Western Continental
CCMO 58-20	5820.LAS	350	6860	15	6860	963	2/1/54	Tenneco (ARCO)
CCMO 58-20 REDRILL	5820RD1.LAS	350	6780	15	6777	963	3/12/54	Tenneco (ARCO)
CCMO 67-20	6720.LAS	350	7630	15	7520	929	5/26/53	Tenneco (ARCO)
CCMO 78-20	CCMO7820.LAS	350	6830	15	7259	948	10/3/82	Tenneco (ARCO)
CCMO 78-20 (COMP)	78-20in.las	350	7250	9	7259	948	10/3/82	Tenneco (ARCO)
CCMO 85-20	85-20.LAS			0	9395	872	7/11/56	Tenneco (ARCO)
CCMO 85-20	85-20.LAS	620	10322	9	10414	872	8/6/54	Tenneco (ARCO)
CCMO 85-20 (COMP)	85-20in.las	620	10322	9	10414	872	8/6/54	Tenneco (ARCO)
CCMO 87-20	87-20.LAS	600	8200	9	8159	907	9/6/53	Tenneco (ARCO)
Core Hole				0				Shell (SWEPI)
KCL 12-27	KCL1227.LAS	360	7920	11	7903	968	3/4/61	MACPET
KCL 13-X	KCL13X.LAS	370	6980	7	6982	1009	1/13/67	Kenneth Sperry
KCL 18-34	KCL18-34.LAS	1040	4600	7	8791	1393.2	6/29/64	Occidental Pet. Co.
KCL 18-34 (COMP)	18-34in.las	1040	4600	9	8791	1393.2	6/29/64	Occidental Pet. Co.
KCL 1A-8-32 (COMP)	8-32in.las	670	4300	9	4870	1351.8	4/19/39	Shell (SWEPI, Cal Resources)
KCL 24-32	KCL24-32.LAS	200	1850	7	1850	1084.7	5/24/46	Standard (Texaco)
KCL 24-32 (COMP)	24-32in.las	200	1850	9	1850	1084.7	5/24/46	Standard (Texaco)
KCL 24-37	KCL2437.LAS	200	3880	7	5162	1032	4/4/46	Standard (Chevron)
KCL 24-37 (COMP)	24-37in.las	200	3880	9	5162	1032	4/4/46	Standard (Chevron)
KCL 31				0	5663	938	4/7/05	Standard (Chevron)
KCL 44 34RD1				0	4030	1258	6/29/59	Standard (Chevron)
KCL 44-12	KCL44-12.LAS	10	6350	9	6350	1248	1/4/60	Standard (Chevron)
KCL 44-12 (COMP)	44-12in.las	10	6350	9	6350	1248	1/4/60	Standard (Chevron)
KCL 44-23	KCL44-23.LAS	30	4840	11	4835	1258	12/10/59	Standard (Chevron)
KCL 44-23 (COMP)	44-23in.las	30	4840	9	4835	1258	12/10/59	Standard (Chevron)
KCL 44-25	KCL44-25.LAS	20	4330	11	4330	1290	5/26/64	Standard (Chevron)
KCL 44-25 (COMP)	44-25in.las	20	4330	9	4330	1290	5/26/64	Standard (Chevron)
KCL 44-32	KCL44-32.LAS	29	4770	9	4760	1209	12/28/59	Standard (Chevron)
KCL 44-32 (COMP)	44-32in.las	29	4770	9	4760	1209	12/28/59	Standard (Chevron)
KCL 44-34	KCL4434.LAS	400	3500	8	10022	1258	6/29/59	Standard (Chevron)
KCL 44-34 (COMP)	44-34in.las	400	3500	9	10022	1258	6/29/59	Standard (Chevron)
KCL 44-375	KCL44375.LAS	600	3500	37	3211	1216.3	7/4/90	Gary Drilling Co.
KCL 44-375 (COMP)	44375in.las	600	3500	17	3211	1216.3	7/4/90	Gary Drilling Co.
KCL 44-43	KCL44-43.LAS	30	6850	11	6851	1212	11/18/59	Standard (Chevron)
KCL 44-43 (COMP)	44-43in.las	30	6850	9	6851	1212	11/18/59	Standard (Chevron)
KCL 44-45	KCL44-45.LAS	40	4330	11	4326	1258	10/5/59	Standard (Chevron)
KCL 44-45 (COMP)	44-45in.las	40	4330	9	4326	1258	10/5/59	Standard (Chevron)
KCL 45-58	KCL45-58.LAS	35	6500	8	6500	1176	2/10/60	Standard (Chevron)
KCL 45-58 (COMP)	45-58in.las	35	6500	9	6500	1176	2/10/60	Standard (Chevron)
KCL 65-33	KCL6533.LAS	600	2702	7	2700	1304.86	12/5/64	Standard (Chevron)
KCL 65-33 (COMP)	6533in.las	600	2702	9	2700	1304.86	12/5/64	Standard (Chevron)
KCL M-1	KCLM-1.LAS	1000	8280	9	8331	1041	10/17/47	Conoco
KCL M-1 (COMP)	kclm-1in.las	1000	8280	9	8331	1041	10/17/47	Conoco
KCL SAN EMIGDIO #1	KCL1.LAS	20	3550	7	3548	1330.3	11/26/45	Western Gulf (Chevron)
KCL SAN EMIGDIO #1 (COMP)	kcl-34in.las	20	3550	9	3548	1330.3	11/26/45	Western Gulf (Chevron)
KCL San Emigdio 3-A				0				Western Gulf (Chevron)
KCL-SAN EMIDIO #3	SE3.LAS	30	4020	9	4019	1318.9	9/30/46	Western Gulf (Chevron)
KCL-SAN EMIDIO #4	SE4.LAS	20	3810	7	3818	1059	10/1/46	Western Gulf (Chevron)

CALIFORNIA . . .ER FIELD
WELL LOG INVENTORY

KCL-SAN EMIDIO #4 (COMP)	se4-10in.las	20	3810	8	3810	1059	10/1/46	Western Gulf (Chevron)
KCL-SAN EMIDIO #4 REDRILL	SE4RD.LAS	2690	3210	7	3206	1056	10/1/46	Western Gulf (Chevron)
KCL-San Emidio 6				0	745	1051	1/17/47	Standard (Chevron)
LL.U. A 18-21 (COMP)	18-21in.las	650	8020	9	8006	913	6/27/52	Richfield (ARCO)
LL 76-30 OR MUDDY CREEK 76-30	LL76-30.LAS	90	2000	28	2000	1162.6	10/22/81	Tenneco (ARCO)
LLU 18-21	LLUA1821.LAS	550	8020	9	8006	913	6/27/52	Richfield (ARCO)
LLU 38-21	LLU3821.LAS	360	7900	9	7893	916	4/15/53	Richfield (ARCO)
LLU 41-28	LLU4128.LAS	510	7204	9	7204	945	2/21/53	Richfield (ARCO)
LLU 48-21	LLU4821.LAS	540	8500	9	8500	904	8/26/58	Richfield (ARCO)
LLU 67-20 OR CCMO 67-20	LLU5720.LAS	350	6900	9	6870	953	1/7/53	Tenneco (ARCO)
LLU56-20 OR CCMO 68-20	LLU5620.LAS	450	8370	15	8370	924	7/23/58	Tenneco (ARCO)
LOS LOBOS "D" 26 - 27 (COMP)	sd2627in.las	850	6800	17	6739	1088	6/15/81	Tenneco (ARCO)
LOS LOBOS 61X-30	61X-30.LAS	100	3000	33	2963	1059	10/7/81	Tenneco (ARCO)
LOS LOBOS 51X-30 (COMP)	51X-30in.las	100	3000	17	2963	1059	10/7/81	Tenneco (ARCO)
LOS LOBOS 62X-30	N62X-30.LAS	120	3000	55	3000	1153.8	5/16/81	Tenneco (ARCO)
LOS LOBOS 62X-30 (COMP)	62x-30in.las	120	3000	17	3000	1153.8	5/16/81	Tenneco (ARCO)
LOS LOBOS 82X-30	82X30C.LAS	318	2700	30	2700	1065	5/27/81	Tenneco (ARCO)
Los Lobos 82X-30	82X30C.LAS			0	2702	1061	5/25/81	Tenneco (ARCO)
LOS LOBOS 82X-30C (COMP)	82x30in.las	318	2700	17	2700	1065	5/27/81	Tenneco (ARCO)
Montera-McFarland 1				0	1585	1180	9/10/76	McFarland Energy
MORRISON #1	MORR1.LAS	40	2065	7	2070	1287		Union (Unocal)
MORRISON #1 (COMP)	morr1in.las	40	2065	9	2070	1287		Union (Unocal)
MUDDY CREEK 76-30 (COMP)	76-30in.las	90	2000	17	2000	1162.6	10/22/81	Tenneco (ARCO)
MUDDY CREEK A #65-30	MC6530.LAS	700	4020	33	4000	1142.9	7/29/81	Tenneco (ARCO)
MUDDY CREEK A #65-30 (COMP)	65-30in.las	700	4020	17	4000	1142.9	7/29/81	Tenneco (ARCO)
Pioneer 1				0	1508	1260	6/8/26	Milham Exploration Co.
Pioneer 2				0	1758	1226	8/31/26	Milham Exploration
Pyramid-Ripley Trust 3				0	3750	1080	9/17/74	Montera Petroleum
Ripley 41				0	7509	1084	12/2/53	C.Ray Robinson
Ripley 44				0	2010	1152	7/18/55	Norbel Oil
Ripley Trust 1				0	6612	1113	12/16/72	Arcady Oil
Ripley Trust 2				0	4500	1101	4/6/74	Lawbar Petroleum
Ripley Trust 2RD				0	4090	1101	2/24/76	Lawbar Petroleum
SAN EMIDIO #27-21	SEA2721.LAS	660	9080	15	9110	877	3/5/54	Richfield (ARCO)
SAN EMIDIO #61-28 REDRILL	SEA6128R.LAS	530	8230	15	8225	953	12/1/53	Richfield (ARCO)
SAN EMIDIO 1A #8-32	KCL8-32.LAS	670	4300	7	4870	1351.8	4/19/39	Shell (SWEPI, Cal Resources)
SAN EMIDIO 35-19 REDRILL #2	A3519RD2.LAS	370	6710	9	6708	986	1/9/55	Richfield (ARCO)
SAN EMIDIO A #61-28 (COMP)	61-28in.las	630	8230	9	8258	953	12/1/53	Richfield (ARCO)
SAN EMIDIO A #11-28 REDRILL	SEA1128R.LAS	656	6988	15	6980	948	6/11/55	Richfield (ARCO)
SAN EMIDIO A #17-20	SEA1720.LAS	360	6850	15	6980	948	6/11/55	Richfield (ARCO)
SAN EMIDIO A #25-28	SEA2528.LAS	350	3310	9	3310	1048	4/27/53	Richfield (ARCO)
SAN EMIDIO A #25-28 (COMP)	25-28in.las	350	3310	9	3310	1048	4/27/53	Richfield (ARCO)
SAN EMIDIO A #34-27	SEA3427.LAS	720	7270	15	7284	1034	1/11/52	Richfield (ARCO)
SAN EMIDIO A #47-20	SEA4720.LAS	500	6920	9	6920	951	7/11/53	Richfield (ARCO)
SAN EMIDIO A #56-19	SEA5619.LAS	350	6830	15	6830	982	10/1/54	Richfield (ARCO)
SAN EMIDIO A #61-28	SEA6128.LAS	530	8230	9	8256	953	12/1/53	Richfield (ARCO)
SAN EMIDIO A #62-28	SEA6228.LAS	419	7100	15	7100	982	9/20/55	McPharlin
SAN EMIDIO A #62-28 (COMP)	62-28in.las	419	7100	9	7100	982	9/20/55	McPharlin
SAN EMIDIO A #66-19	SEA66.LAS	374	6320	9	6436	974	9/3/54	Richfield (ARCO)
SAN EMIDIO A #68-19 REDRILL	SEA68RD.LAS	374	6834	9	6840	974	9/3/54	Richfield (ARCO)
SAN EMIDIO A #76-19	SEA7619.LAS	350	6970	15	6958	972	7/24/54	Richfield (ARCO)
SAN EMIDIO A #76-19 (COMP)	76-19in.las	350	6970	9	6958	972	7/24/54	Richfield (ARCO)
SAN EMIDIO A #81-29	SEA8129.LAS	330	8560	15	8659	956	12/6/52	Richfield (ARCO)
SAN EMIDIO A #81-29 (1ST SIDETRACK) (COMP)	81-29in.las	330	7023	9	7024	956	12/6/52	Richfield (ARCO)
SAN EMIDIO A #81-29 (COMP)	81-29in.las	330	8560	9	8659	956	12/6/52	Richfield (ARCO)

WELL LOG INVENTORY

SAN EMIDIO A #81-29 REDRILL	SEA8129R.LAS	5300	7023	9	7024	956	12/6/52	Richfield (ARCO)
SAN EMIDIO A #86-19	SEA8619.LAS	400	6820	15	7070	967	3/9/54	Richfield (ARCO)
SAN EMIDIO A 11-28	SEA1128.LAS	658	7084	9	7084	948	5/6/55	Richfield (ARCO)
SAN EMIDIO A 11-28 (COMP)	11-28in.las	658	7084	9	7084	948	5/6/55	Richfield (ARCO)
SAN EMIDIO A 11-28 (REDRILL) (COMP)	11-28in.las	658	6986	9	6980	948	6/11/55	Richfield (ARCO)
San Emidio A 17-20				0	6840	964	6/16/54	Richfield (ARCO)
SAN EMIDIO A 25-19	A2519.LAS	450	6780	9	6958	980	3/24/55	Richfield (ARCO)
SAN EMIDIO A 25-19 REDRILL	A2519RD1.LAS	6300	6960	9	6780	980	4/7/55	Richfield (ARCO)
SAN EMIDIO A 27-20	A2720.LAS	350	7250	9	7246	958	10/22/53	Richfield (ARCO)
SAN EMIDIO A 27-20 (COMP)	27-20in.las	350	7250	9	7246	958	10/22/53	Richfield (ARCO)
SAN EMIDIO A 27-20 REDRILL	A2720RD1.LAS	350	6660	9	6659	958	12/13/53	Richfield (ARCO)
SAN EMIDIO A 27-20 REDRILL #2	A2720RD2.LAS	6050	7250	9	7246	958		Richfield (ARCO)
SAN EMIDIO A 27-20 REDRILL (COMP)	2720r1in.las	350	6660	9	6659	958	12/13/53	Richfield (ARCO)
San Emidio A 34-27RD				0	6624	1034	1/11/52	Richfield (ARCO)
San Emidio A 35-19				0	6615	986	12/7/54	Richfield (ARCO)
SAN EMIDIO A 35-19 REDRILL #1	A3519RD1.LAS	6780	6850	9	6858	986	12/26/54	Richfield (ARCO)
San Emidio A 37-20				0	6770	967	2/15/55	Richfield (ARCO)
San Emidio A 45-19 Redrill	45-19R.LAS	365	6758	9	6688	983	11/23/54	Richfield (ARCO)
San Emidio A 45-19RD2				0	6760	983	11/23/54	Richfield (ARCO)
SAN EMIDIO A 45X-19	45-19.LAS	365	6820	9	6815	983	11/23/54	Richfield (ARCO)
SAN EMIDIO A 46X-19	46X19.LAS	632	6392	18	6898	990	1/10/93	Western Continental
SAN EMIDIO A 46X-19 REDRILL	46X19RD.LAS	632	6808	32	6808	990	1/10/93	Western Continental
San Emidio A 62-28RD				0	6515	982	9/20/55	McPharlin
San Emidio A 82-28				0				McPharlin
SAN EMIDIO A 84-28	A8428.LAS	740	7200	9	7200	1041	1/14/51	Richfield (ARCO)
SAN EMIDIO A 84-28 REDRILL	A8428RD1.LAS	740	6380	15	5378	1041	1/14/51	Richfield (ARCO)
San Emidio A 86-19RD1				0	6629	967	3/9/54	Richfield (ARCO)
San Emidio A 86-19RD2				0	6825	967	3/9/54	Richfield (ARCO)
SAN EMIDIO A NO. 45-19 (COMP)	4519r1in.las	365	6820	9	6815	983	11/23/54	Richfield (ARCO)
SAN EMIDIO A NO. 45-19 RD (COMP)	4519r2in.las	365	6758	9	6688	983	11/23/54	Richfield (ARCO)
San Emidio A SWD-2				0				Tenneco (ARCO)
SAN EMIDIO C-1	SEC1.LAS	20	4800	5	4805	1222	3/25/37	Union (Unocal)
SAN EMIDIO C-1 (COMP)	c1-34in.las	20	4800	9	4805	1222	3/25/37	Union (Unocal)
SAN EMIDIO C-2	SEC2.LAS	47	1830	5	1839	1265	4/12/37	Union (Unocal)
SAN EMIDIO C-2 (COMP)	c2-33in.las	47	1830	9	1839	1265	4/12/37	Union (Unocal)
San Emidio C-3				0	3226	1109	4/28/37	Union (Unocal)
San Emidio 1				0	4826			Shell (SWEPI)
Santiago 1				0	1200	1237	9/16/56	Robt.W. Moore
Sanfago 1				0	4217	1344	10/30/91	Stone Exploration
SANTIAGO A 72-30	72-30.LAS	28	3500	28	3503	1063	9/24/80	Tenneco (ARCO)
SANTIAGO A 72-30 (COMP)	72-30in.las	28	3500	17	3503	1063	9/24/80	Tenneco (ARCO)
SANTIAGO B 73-29	SB7329.LAS	800	5530	33	5527	1011	9/10/80	Tenneco (ARCO)
SANTIAGO B 73-29 (COMP)	73-29in.las	800	5530	17	5527	1011	9/10/80	Tenneco (ARCO)
SANTIAGO C 65-28	65-28.LAS	805	6010	40	6000	1068	8/28/80	Tenneco(ARCO)
SANTIAGO C 65-28 (COMP)	65-28in.las	805	6010	17	6000	1068	8/28/80	Tenneco(ARCO)
SANTIAGO C 65-28 (DUAL LATERAL LOG)	65-28DLL.LAS	805	6010	40	6000	1068	8/28/80	Tenneco(ARCO)
SANTIAGO D #26-27	SD2627.LAS	850	6800	33	6739	1088	6/16/81	Tenneco (ARCO)
UNION 76-31	76-31.LAS	670	4028	7	4314	1348	5/23/39	Shell (SWEPI)
UNION 76-31 (COMP)	76-31in.las	670	4028	9	4314	1348	5/23/39	Shell (SWEPI)
USL-Woodward 1				0	13131	1200	2/9/87	Peafey Petroleum
Western Minerals 37-25				0	1700	1213	3/24/42	Tidewater Assoc.

Pioneer Field: Reservoir Characterization

(W. Berry, D. Olson, D. Crane)

Introduction

The Pioneer Field, adjacent Los Lobos Field, and other nearby wells are located in a 10-section area on the crest and northern flank of the eastward-plunging Pioneer Anticline. Production in these fields and in the area has come from the mid-Miocene Temblor sands, the late Miocene shales of the Monterey and Reef Ridge Formations, a sand in the uppermost Reef Ridge Formation, and from various Etchegoin sands. A reservoir characterization of the entire area was performed, with special emphasis on the Monterey shale reservoirs and lesser attention to the Etchegoin and Reef Ridge reservoirs. The Temblor sands were not characterized. This study was used as an example to show the methodology of a computer-assisted reservoir characterization project, and also to provide research and demonstration examples for the testing and use of the computer programs that are presented here.

Reservoir Description: Organization and Overview

For reservoir characterization, the following tasks are necessary:

1. Identifying and collecting data, then processing it into useful form
2. Describing the local geologic framework
3. Determining rock and reservoir properties
4. Mapping the distribution of these properties
5. Ensuring that everyone who will use the results of the reservoir characterization understand what they need to know

Data Collection and Processing. Data collection is often not a trivial task, and was not for this project either. An attempt was made to locate logs, well histories, directional surveys, core analysis data, core and/or cuttings materials, fluid samples and analysis, and any previous studies that had been done in the area. Data were located for most wells shown on the area maps. As is typical for many old fields in California and elsewhere, many wells had been drilled in the area (over 50) but a minority had modern logging suites from which porosity and saturation could be determined. However, both old and new logs are suitable for correlation and definition of the local geologic framework.

All log data were digitized, edited, depth shifted, and environmentally corrected. A consistent set of curve names was established and used throughout the project. This work was performed using the Petrolog system from Crocker Data Processing. Well locations were calculated in state plane coordinates from the well surveys and from recorded section corners.

Cuttings were available from one well in the study area (Gary Drilling 375X), but no physical core could be located from any well. Core analysis data were used from one well

(Tenneco 62X-30). To improve the accuracy of the log calibration, extensive data and rock material were released from two UNOCAL core wells in the diatomaceous zone of the Cymric Field, the McKittrick 415 and 418 wells. These were used to assist the model calibration since the lithologies were similar to those encountered in the Pioneer area.

Selected core samples were analyzed using conventional thin section microscopy, Scanning Electron Microscopy (SEM), Xray diffraction analysis, and Fourier Transform Infrared Spectroscopy (FTIR). Results are archived in the Toolbook TDM.

Data were originally stored in the various project databases: well information and logs in GeoGraphix and the log analysis programs that were used for the project, visual data like core photographs in the TDM. Recently, all data, including logs, have been consolidated in the TDM.

Geologic Framework. After the log database was finished, cross sections were drawn through the study area and available data were used to determine correlations and structural/stratigraphic relationships. This work was performed first with edited but unprocessed logs to provide tops and a geologic setting for the petrophysical work. Cross sections were constructed both in GeoGraphix and Petrolog.

After the preliminary petrophysical work was completed, the results were used to refine the formation tops and to identify stratigraphic changes in the mapped units. The lithology and porosity evaluations were particularly useful in correlating intervals of clean and shaly diatomite within the Monterey. Examples of cross-sections using raw log data and computed log data are shown in Figures 2 and 3

Tops were stored in GeoGraphix, in Petrolog, and in Symbiolog to be used for further processing and easy retrieval.

Rock and Reservoir Properties. Rock properties were primarily derived from the log data using laboratory measurements to calibrate and refine the parameter selection. Approximately one-fifth of the wells in the project area had porosity logs; the rest were old wells with ES and IES logs only. All analysis and zone summations were done using the Symbiolog system, running as an add-on to the Petrolog program. (A more detailed discussion of Symbiolog occurs in the Log Analysis of the workshop notes).

The McKittrick core wells were analyzed first, and a preliminary set of parameters was developed. These were then applied to the Pioneer area wells with porosity logs. Necessary refinements were made until a good fit was obtained to field data. Then, these same wells were re-analyzed with a subset of their curves similar to that available in the E-log only wells. First, a clay volume curve was computed from the SP log, with the resistivity curve used to supplement it where needed. Then, after extensive data analysis, a depth-based porosity transform was developed to compute a total-porosity curve. From this and the clay-volume curve, effective porosity was calculated using the same

parameters as had been used for the porosity-log wells. A comparison of the results from the full-suite and e-log only analysis methods is shown in Figure 4.

Water saturation was not calculated for wells without an induction log, since the old lateral logs do not give a valid true resistivity on a foot-by-foot basis.

Zone summations were performed on all wells using the correlated tops developed from cross sections. Since water saturation data were not available from many wells, only clay volume and porosity were summed to give values for reservoir rock and pay values were not computed.

Mapping. Many maps were drawn during the course of this project, and many more can be made using the log curve data and the summation results. The regional surface geologic map was digitized and entered into the project database. Cultural features (e.g., roads and other surface facilities) were extracted from commercially available databases and loaded to GeoGraphix for use as overlays on the maps.

With the sparse well spacing and complex structure present at Pioneer Anticline, computer gridding and contouring is not adequate for accurate representation of the geology. To ensure that the maps and cross sections tie properly in this type of setting, structure maps were drawn by hand, digitized, and gridded from the contours. The grids were then used for mathematical manipulations. Drafted maps can be created from combinations of the cultural overlays and contoured grids. Several isopach and properties maps, such as clay volume and porosity, were also made.

The computed curves for all 45+ project wells were delivered to MTU where they will eventually be used to construct more maps and cross sections of internal heterogeneities within the Monterey reservoir using the GeoGraphix Exploration System.

Data Distribution. In a field study project at an oil company, many people commonly have input and an interest in the results. The increasing integration of various engineering disciplines, geology, operations, and finance/accounting into project teams demands that information be exchanged efficiently among individuals with diverse requirements. Each team member needs somewhat different output from the field study, and needs it presented in different formats. A primary deliverable of this project is a database structure in the Toolbook Multimedia Database Management System, populated with data and results from the study, that can serve as a model for storage and dissemination of information for other field studies.

This database has the capability of storing graphic images, as well as text and digital data. This is very important, because visualization of the results of field study projects is becoming a critical need. Often, the visualizations are the best vehicle for conveying understanding of a complex reservoir to team members who may not be used to "seeing" three-dimensional reality from two-dimensional cross sections and maps.

Visualization images are being generated for this project in GeoGraphix and in MatLab, using the results from the reservoir characterization.

Figure Captions

Figure 2: A stratigraphic cross section is shown through several wells on Pioneer Anticline that include the entire Etchegoin and Monterey section. Wells 65-30, 76-30, and KCL 44-375 all had full suites of modern logs. Wells KCL 44-32 and KCL 44-43 had old electric logs. Lithologic changes in the Monterey are difficult to see.

Figure 3: The same cross section shown in Figure DPI-1, except using the computed log results with the lithology track shown in colorfill. The Monterey lithologic changes are much clearer using the computed results logs.

Figure 4: The results of the full-suite and e-log only analysis are compared for well 72-30. Track 1 shows the lithology analysis from the full log suite, Track 2 shows the same analysis using e-log only. Track 3 compared the effective porosity computed from the full suite (PHIEDW) and from the e-log only model (PHESDW). In Track 4, the clay volume curves from the two models are compared (VCLWDW from the full suite, VCWSDW from the e-log only model).

65-30 76-30 KCL44-32 KCL44-43 KCL44375

DPI

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STRATIGRAPHIC CROSS SECTION
WITH RAW LOGS

FIG. 2

GEOLDDY BY D.O. M. RUBEN/D. J. GRANE

9/96

65-30

76-30

KCL 44-32

KCL 44-43

KCL 44375

DPI P.O. BOX 8816 BAKERSFIELD, CA 93388
(805) 322-8667

STRATIGRAPHIC CROSS SECTION
WITH COMPUTED RESULTS

FIG. 3

GEOLGUY BY: O.N. OLSON/O.J. GRANE

4/76

72-3.0

Figure 4

McKittrick Front 418 Core, Cymric Field:

Log-to-Core Calibration

(J. Allan)

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. The study illustrates the steps involved in: 1) setting up a relational database to store geologic, well-log, engineering, and production data, 2) calibrating logs to core and developing techniques to compute clay content, effective porosity, and fluid saturations from old electric logs, and 3) linking data and models with PC-based computer software to provide 2-D and 3-D visualizations of the reservoir and its attributes. The techniques were demonstrated through a field trial in the Monterey Formation on Pioneer Anticline in the vicinity of Pioneer Field.

In a reservoir study, log data is calibrated to ground truth. The preferred ground truth is whole-core data over as much continuous interval as can be obtained given economic realities. Additional information can be derived from sidewall-core data and well cuttings. For this project, one well from the Pioneer study area has modern whole-core data, several wells have sidewall-core data, and one well has a full suite of well cuttings. Because of limited core coverage of the Monterey reservoir in the Pioneer area, core was also obtained from two wells, with exceptionally complete core coverage, which produce from similar facies in the Monterey Formation in the McKittrick Front area of Cymric Field. The McKittrick Front 418 well has over 700 ft of conventional core that covers the interval from above the top-Miocene unconformity to the middle of the Opal A/Opal CT transition zone in the the Monterey Formation. A complete suite of routine core analyses and many special core analyses are available for this well. Selected core intervals from the McKittrick Front 418 well are on display at this workshop. The McKittrick Front 415 well was drilled into higher-grade diagenetic facies in the Monterey. Core from this well provides good coverage of the Opal-CT and Opal-CT/Chert transition zone facies in the Monterey. Routine core analyses for these wells include porosity, fluid saturations, permeability, and grain density on a foot-by-foot basis. Special core analyses include mineralogy, grain size, relative permeability, and capillary pressure. Special thanks go to Unocal for providing our project members access to the McKittrick Front cores and core data.

At the beginning of the log-to-core calibration, core data were plotted alongside raw log traces on a large-scale hard-copy output and were compared with core photographs and with the core itself. Core data were also compared with log data using a variety of statistical techniques in order to obtain correct parameters for entry into algorithms for calculating matrix density, porosity, and water saturation. Computed logs were then generated at the same scale and also compared to core data.

A number of analytical models have been presented over the years in the log analysis literature. Some are only appropriate for specific reservoir types, others require that special data be available. Many are general-purpose and are based upon the more common reservoir lithologies and log types. Diatomite is an unusual rock type, and there is little published literature on analytical models for it, so Digital Petrophysics, Inc., used an in-house model to handle diatomaceous facies. There are several important measures of reservoir quality in diatomaceous lithologies besides porosity and saturation. Clay content, diagenetic grade (Opal A, Opal CT, and Chert) and the presence of fractures are important to consider. Many diatomaceous rocks have adequate porosities and oil saturations but insufficient permeability to sustain economic production. The measurement and/or prediction of lithology and fracturing are therefore important components of a reservoir evaluation in diatomites. The models that were selected for this project can be applied to all wells with resistivity and density-neutron logs, and are capable of predicting matrix density, clay volume, diatomite facies, accessory minerals such as carbonates, porosity, permeability, water saturation, as well as providing a qualitative measure of fracturing and fracture potential.

An innovative procedure was developed for using modern log suites, calibrated to core, to evaluate old wells for which only electric logs (E-logs) were available. This is very important on Pioneer Anticline, where many wells were drilled more than 50 years ago and only possess old E-log suites. The procedure was used to calculate parameters such as porosity, fluid saturation, and clay content, which are not directly measured by old E-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., were calculated from the full log suites available in the McKittrick Front 415 and 418 wells in Cymric Field and the Tenneco 62x-30 well in Pioneer Field using standard algorithms and then cross-checked against values measured in core. The same parameters were then calculated using only the basic electric-log suite. Special algorithms were developed and adjusted until parameters derived from the core, the full-log suite, and the E-log-only suite all showed reasonable agreement within the logged intervals. When an acceptable level of agreement was achieved, the algorithms were used to compute lithology, % clay, % shale, matrix type, porosity, and S_w from old electric-log data and plot the results in log form. Successful results were achieved 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. Computed curves were generated for all wells used in the Pioneer project (about 50 wells).

Thermal History Studies

(A. Nigrini)

Abstract

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. 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 for the southern San Joaquin Basin 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. 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.

It appears that the elevated temperature profile may be due to episodic release of geothermal fluids that began within in the last 30,000 years. If correct, our interpretation suggests that all reservoirs 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.

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 was completed. 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, providing evidence that hydrocarbon migration has occurred throughout this deep section.

Well History of EH934-29R

Location: Naval Petroleum Reserve #1 at Elk Hills in the southern San Joaquin Valley west of Bakersfield and due north of Taft (Figure 5). It is one of 3 deep wells drilled by the Department of Energy during the late 70's and 80's.

Purpose: To explore the potential for deep hydrocarbon reserves.

Drilling started: May 30, 1985

Drilling ended: August, 1987

Drilled Depth: 24,426 feet -- It is the deepest well ever drilled in California.

Maximum Temperature: 431°F at total depth.

Results: Oil was produced from several deep intervals down to 18,000 feet with some shows as deep as 23,000 feet. Gas shows were found in all sandstone units and production tests recovered gas in varying amounts to depths near 24,000 feet.

Stratigraphic Column

The stratigraphic column (Figure 6) summarizes the geologic data obtained from Elk Hills 934-29R and shows the formation boundary ages used in modeling the geohistory of the well. This is the only well in the San Joaquin Valley to penetrate sediments of Cretaceous age at this depth. Hatched boxes represent zones of current oil production at Elk Hills. Gas and oil shows are those found in well 934-29R during drilling or from production tests after completion of the well.

Source-rock Maturity

- Two observations are frequently used to determine the potential for oil and gas reserves in a basin: vitrinite reflectance (Ro) and downhole temperature measurements taken during well logging operations.
- Source-rock maturity is estimated by measuring light reflectance from Vitrinite, a thermally altered component of plant material. As plant material is exposed to higher temperatures vitrinite reflectance increases. Therefore, vitrinite reflectance measures the amount and intensity of heat experienced by the plant material during its burial history.
- Downhole temperatures measured after drilling are frequently used to estimate source-rock maturity (by empirical correlation based on paired data from other wells in the basin) when Ro data are not available. Because temperature data are collected during well logging, shortly after drilling and before well-bores temperatures have had sufficient time to equilibrate with the true formation temperatures, temperature data are in most cases unreliable estimates of in-situ formation temperatures.
- EH934-29R temperature data sets are unusual in that they were collected 1 - 2 years after drilling ended and represent a "true equilibrium temperature" profile.
- Therefore the vitrinite reflectance and temperature sets derived from this well provide an excellent opportunity to more realistically calibrate the thermal history at Elk Hills. These data are shown in Figures 7, 8 and 9 and are further discussed in the following discussion

Thermal History

The thermal history of a well can be determined (using Platte River Associates BasinMod program) from reconstruction of the burial and structural history of a well. Required data are: formation ages, thicknesses, lithologies, porosities and thermal properties. In addition, models of the basal heat flow and surface temperature histories for the southern San Joaquin Valley are required. Fortunately, the San Joaquin basin and its tectonic history has been studied extensively and the data requirements are satisfied. Of particular importance to developing a useful thermal history for this well is the understanding of the heatflow history of the region.

The heatflow model used in this study involves the existence of a low constant heat flow until 25 million years ago at which time heatflow began to increase to present day values. The existence of this lower heat flow in the late Cretaceous and early Tertiary has been postulated based on structural studies (Dickenson and Snyder, 1979) and plate subduction model studies that calculate the heatflow consequences of Farallon Plate subduction beneath the North American Plate (Lachenbruch and Sass, 1980; Zandt and Furlong, 1982; Furlong, 1984; Heasler and Surdam, 1985; Dumitru, 1986). The relatively recent rise in heatflow is a result of cessation of subduction and the northward migration of a thermal pulse associated with the movement of the Mendocino Triple Junction (MTJ). The thermal pulse is associated with what has been called a "slabless window" beneath the North American Plate where the Farallon Plate used to exist but which subsequently migrated northward along with the MTJ. Hot asthenosphere subsequently filled the void below the thin (~20km) North American Plate. Recent Apatite Fission Track studies by Dumitru (1988, 1989, 1990) have confirmed the existence of low temperature gradients (~9°C/km) in the late Cretaceous and early Tertiary. These temperature gradients are consistent with the early, low heat flow value calculated in the heat flow model studies cited and used herein.

The heatflow model described above was adjusted to match downhole temperature data in EH934-29R and vitrinite reflectance values were calculated for the resultant heat flow model (Standard Model). Figure 7 shows a plot of predicted downhole temperatures and vitrinite reflectance as a function of depth in the well. Note the close match of the calculated temperature curve with a subset of the downhole temperature data indicating a successful calibration of the heatflow model with the observed temperature data. However the predicted Ro maturity curve is dramatically higher than the observed Ro data indicating that the vitrinite is not in equilibrium with the present day temperature field. In addition it suggests that the present day temperature field must have existed for a relatively short time as vitrinite is known to equilibrate relatively rapidly.

A new heat flow history model (Proposed Model) developed that would match both downhole temperature and Ro data. This was done by first calibrating the heatflow model against the Ro data and then iteratively adjusting the magnitude and duration of a recent heat pulse until the present temperature profile was predicted without significantly

changing the Ro prediction. Figure 8 shows that both calculated Ro and downhole temperature curves now show a close correspondence to the data.

Figure 9 compares the temperature histories at the base of the well for the Standard and Proposed heatflow model. In the Proposed Model the basal temperature does not rise as rapidly near present day as in the Standard Model until about 30,000 years ago when the temperature begins to rise rapidly to the present day temperature.

The Proposed Model indicates that within the last 30,000 years there has been a dramatic increase in heat flow. We suggest that this increase in heatflow is probably related to increased seismic activity in this period. The seismic activity probably reflects increased movements along faults in the area causing migration of hot fluids from the deep basin to basin margin structures close to the San Andreas Fault, such as those found at Elk Hills.

Supporting Data

Fluid inclusion data from core samples containing calcite-rich veins have been used to estimate temperatures of geothermal fluids. The depth-temperature plot in Figure 10 shows that measured fluid inclusion temperatures approach the presently observed downhole temperatures and above the temperature curve that is in equilibrium with the observed vitrinite reflectance data. Because fluid inclusion temperatures are minimum temperature estimates, these data are reasonably consistent with the present day temperature profile suggesting that the fluids were trapped at times within the last 30,000 years depending on where each data point lies between the two curves.

It is also observed that many fluid inclusions in vein calcites were found to contain abundant oil and gas fluids indicating that the crystals were formed while hydrocarbon fluids were migrating to the Elk Hills reservoirs. This further implies that hydrocarbons are probably intermittently migrating to reservoirs in Elk Hills at the present time.

Observations from water wells close to the field and along structural strike show high temperature and salinity anomalies. Surface water temperature anomalies of 4 to 5°F above background values of 69 to 70°F were observed at the southeast end of the field in line with a major axial fault and around the periphery of the northeast side of the field. Conductance values in these same wells were elevated to values of 3000 to 8000 micromhos as compared with background values of approximately 300 micromhos when compared to regional averages. These data suggest that hot geothermal fluids are migrating to near surface aquifers at the present time.

The implications of this study are that the likelihood of deeper hydrocarbon bearing reservoirs at Elk Hills is high if reservoir quality is satisfactory. In addition, if Elk Hills is a representative analogue for the structurally complex fields along the western side of the San Joaquin basin, then disequilibrium between present day temperatures and thermal maturity of the sediments is more likely than not. Therefore using bottom-hole temperature data alone as an indicator of the depth of the base of the "oil window" will

lead to the erroneous elimination of deeper targets, and thus downplay the significant deep exploration potential of the basin.

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Figure 5

Elk Hills 934-29R

Figure 6

Standard Model Depth Plot

Elk Hills 934-29R

Figure 7

Proposed Model Depth Plot

Elk Hills 934-29R

Figure 8

Temperature History

Elk Hills 934-29R

Figure 9

Elk Hills 934-29R

Fluid Inclusion Temperatures

Figure 10

Log Analysis

Pfeffer and GeoGraphix' QLA2

(W. Pennington, J. P. Suchoski)

Four wells with complete log suites were selected for a comparative study. These four wells were analyzed using Pfeffer, QLA2, and Symbiolog (which was also used to analyze all the wells in the project), leading to various calculations of lithology and/or water saturation. The strengths and limitations of the various computer packages are demonstrated by this comparison (Figs. 11-17).

Pfeffer

Pfeffer is a simple, inexpensive (\$290) log-evaluation software add-in to Microsoft Excel, developed by University of Kansas researchers. It is extremely useful for quick-look analysis, and provides considerable insight into the petrophysical behavior of reservoir rocks. It is, however, also quite limited in its capabilities, and currently does not have a shaly-sand interpretation scheme. The four wells demonstrate a very fast data-load (from LAS) and an attractive and intuitive (to users of spreadsheets) interface. When data are loaded, and the proper curves identified, Pfeffer automatically creates an apparent resistivity curve, a water saturation curve, and a Bulk Volume Water curve. A "Super Pickett" plot can be constructed, which is basically a Pickett plot with additional lines superimposed for Bulk Volume Water, providing additional insight to possible water-cut problems during production. However, in the Pioneer data set, the formation is thin-bedded and shaly, and a clean Archie-type analysis is insufficient. The Pfeffer program can be highly recommended for clean formations and for teaching purposes, but its lack of treatment of shaly sands limits its usefulness in the Monterey. Log displays are not necessarily the standard displays commonly used by petrophysicists, but can be modified by the Excel charting procedures to satisfy most users' needs.

GeoGraphix' QLA2

QLA2 is an intermediate-level log-evaluation package suitable for general use by exploration and development geologists that is provided as an addition to the GeoGraphix system. Its interface is highly intuitive, and operation is fast and easy on medium-speed computers. The analysis of the four wells revealed a standard set of log displays, commonly used by petrophysicists, with modifications that are easy to make. Templates can be stored readily, for use or modification in later projects. The Archie-type analysis is not as straightforward as in Pfeffer, requiring the user to employ a formula, rather than a pre-packaged module. That formula, however, is included in the tutorial for the package, and is ready to implement. The results from the Archie analysis and the Pickett plot displays are, of course, identical to those obtained by Pfeffer.

There are dual-water shaly-sand interpretation modules built into the "model-maker" part of QLA2. These were applied to the four wells and the results compared with the clean Archie-type analysis. Considerable attention had to be paid to the determination of clay

content in these extremely high-porosity Monterey rocks in order to obtain reasonable answers. A simple clay volume determined from gamma ray was useful, but improved responses resulted from more careful clay determinations obtained through other methods. These wells demonstrate the difficulty in shaly-sand interpretation in tight, high porosity rocks without core control.

The final analysis of formations such as the Monterey must include zoned studies, where the rocks, as their properties change with depth, age, etc., are treated differently in the computations. When one deals with one well at a time, this zonation is easily treated. It becomes more difficult when a large number of wells are being studied in the same field. For this reason, a more sophisticated treatment (described in the following Symbiolog section) was developed and applied by DPI.

Pfeffer example of Tenneco 62x-30 Los Lobos showing resistivity

Figure 11

Figure 12

Figure 13

Tenneco 62x-30 Los Lobos

Figure 14

Tenneco 82x-30c Los Lobos

Figure 15

Gary Drilling KCL 44-375 Pioneer

Figure 16

Tenneco Muddy Creek 76-30

Figure 17

Symbiolog/Petrolog

(W. Berry, D. Olson)

Petrolog is a multi-featured, sophisticated log analysis system that is very powerful yet is easy to use. It was used to perform all log data capture, editing, depth shifting, and environmental corrections. Much of the log graphics work for this project was also done using Petrolog's very capable output modules. The analytical work was performed using Symbiolog's advanced clastics models, user programming, and multi-facies zone summation modules. Symbiolog is a multi-well/multi-zone analysis system which has recently been introduced to the log analysis software market. Symbiolog reads and writes log data using the digital database for the system that the user already owns, thus not requiring any data duplication. It provides capabilities that are lacking at least to some degree in every commercial log interpretation system on the market today, while letting the user keep the log input/output, editing, and graphics tools with which he/she is familiar.

The main zone of interest in this study, the Monterey Formation, consists primarily of diatomite and its diagenetic equivalents. The Etchegoin sands are shaly and feldspathic, and the formation waters are brackish in both formations. These rocks present log analysis problems very typical for California, but for which no available system today supplies adequate tools to obtain accurate reservoir values. Lithology and porosity are very important in any reservoir, but in diatomaceous intervals diagenetic grade is also a critical factor.

Clay volume is the most important log-derived reservoir parameter, and the one for which currently available analysis packages have the least diagnostic tools. Symbiolog incorporates a rule-based, geologically-driven clay analysis model that was crucial in calculating clay volumes in the lithologically diverse rocks of the Pioneer area. For the wells with modern logs (full-suite wells), a clay volume was computed from both gamma ray and SP using Symbiolog's unique three-slope transform. A parameter set was developed for the SP log which gave a clay volume closely matched to the core data and to the clay volume from the gamma ray. These parameters were then applied with confidence to the SP logs from the E-log only wells in the area. A few wells had poor-quality SP's, and for these a clay volume was derived from the shallow resistivity curve and compared for verification with the results from nearby wells in the same formations.

In the same way, total and effective porosity were computed for the full-suite wells, calibrating the results to the available core data. A rule-based total porosity transform was developed as a function of lithology and depth, using comparisons to the computed porosity from the full-suite wells. Through iteration, this transform was made to be predictive of porosity over all the lithologies and depth ranges in the study area. It was then applied to the older E-log only wells. With a clay volume and total porosity, it was possible to compute an effective porosity using the same crossplot techniques that had been used for the full-suite wells (Fig. 4). Water saturation was not computed for the e-

log only wells, since the deep-reading lateral resistivity curves are asymmetrical in their response to lithology changes and varying bed thickness, and therefore are invalid for calculation of a foot-by-foot saturation.

Zone summations have always been important output from a petrophysical study, but with the increasing use of reservoir modeling it is becoming necessary to generate more accurate summation values. As more attention is focused on the oil from low-resistivity pay zones, shaly sands, and thin-bedded reservoirs, it is clear that the old methods of using single-valued cutoffs for summations of porosity, clay volume, and water saturation will either under-count intervals that do not meet the criteria for clean intervals, or will over-count non-pay that is included when the criteria are widened to include less conventional reservoirs. Symbiolog features a new and unique solution to this problem: multi-facies zone summations. To use this program option, the user first computes a facies curve using any lithology model desired. For the simplest of model, a facies type (expressed as a number) is assigned to each depth level depending on the value of the clay volume parameter. More sophisticated facies computations that could be used include probabilistic or neural network models, or predictions from geostatistics. All that is needed for the Symbiosum program is an input curve with integers for each depth level representative of the chosen facies type. For this study, a rule-based deterministic model was used based on values of clay volume and porosity.

Within Symbiosum, a set of cutoffs for the summation can be defined individually by facies for clay, porosity, shale, water saturation, and permeability. The program output, which is stored in a database, includes net thickness and average value for each input curve by facies and by geologic zone.

Visualization of the Pioneer Anticline: The GeoGraphix Exploration System

(W. Houston, W. Everham)

The GeoGraphix Exploration System (GES) software package was acquired in fall 1995 and installed on a single PC in the Subsurface Visualization Laboratory (SVL) at Michigan Technological University (MTU). Since then, an academic license has been obtained allowing GeoGraphix to be installed on three additional machines. This system, along with the formal training of MTU geologists at GeoGraphix in Denver, Colorado and the practical application of the program to both industrial and academic research, has resulted in an active, university-based program that compliments the other visualization efforts in this project.

Visualization of the Pioneer Field at the SVL has progressed through the acquisition of data from Digital Petrophysics, Inc. (DPI) to the application of several software packages, including GeoGraphix, to the Pioneer project. Interpreted log and formation-top data were acquired from DPI and loaded into a GeoGraphix data base and maps of the Miocene unconformity and regional fault traces were produced (Fig. 18). A series of cross sections through Pioneer Anticline were constructed in GeoGraphix (Fig. 19) using log templates generated in QLA2 (see *Well Logs and Well Log Analysis*). The addition of lithologic logs (see *Graphical Display of Lithologic Well Data*) which exploit older data sets and the continued expansion and refinement of the digital GeoGraphix data base will allow for improved, comprehensive 2-D visualization of this field.

ER Mapper, Version 5.0, is being used to facilitate file transfer to and from GeoGraphix. Using this software, aerial photos and satellite imagery can be imported into GeoGraphix where surface maps and digital line data can be overlain and manipulated on these images.

Michigan Technological University Department of Geological Engineering and Sciences 1400 Townsend Drive Houghton, Michigan 49931-1293		
STRUCTURE CONTOUR MAP TOP MIOCENE UNCONFORMITY (FAULT TRACES SHOWN IN PURPLE) PIONEER FIELD - KERN COUNTY, CA DATA PROVIDED BY DPI, BAKERSFIELD, CA		
Drawn By: W. HOUSTON	Scale: 1 : 36,000	
Geology By: S. CHITTICK	Project: PIONEER 100K	Prospect: GLOBAL
Drawn For: D.O.E WORKSHOP	Date: SEPT. 1996	Drawing No.: DOE1.GPF

Scale 1:38000.

N

Figure 18

STRUCTURAL CROSS-SECTION: EQUAL SPACE

Datum = Sea Level Domain = Depth

Scale = 1:24000 Vertical Exaggeration = 4X

Michigan Technological University
Department of Geological Engineering and Sciences
1400 Townsend Drive Houghton, Michigan 49931-1233

STRUCTURAL CROSS SECTION
PIONEER ANTICLINE LIMB
PIONEER FIELD - KERN COUNTY, CA
DATA AND LOGS PROVIDED BY DPI, BAKERSFIELD, CA

Drawn By: W. HOUSTON	Scale: 1 : 24,000
Geology By: W. HOUSTON	Project: PIONEER 100K Prospect: GLOBAL
Drawn For: D.O.E. WORKSHOP	Date: SEPT. 1996 Drawing No: DOE2.GPF

Figure 19

Graphical Display of Lithologic Well Data as a Tool for Database Error Detection and Stratigraphic Interpretation

(W. Everham)

Subsurface mapping and stratigraphic interpretation is greatly facilitated by the use of digital data that can be used to generate graphic displays. Graphic displays of lithologic sample descriptions (LSD) obtained from driller's logs constitute a source of information that can be used for several purposes. Among these are the rapid identification of potential inaccuracies in commercially available subsurface databases, identification of subsurface facies changes, and facilitation of sequence stratigraphic interpretations. Generation of pseudologs that contain depth versus lithology information in Log ASCII Standard (LAS) or Log Binary Standard (LBS) format allows use of log analysis software to display information and correlate wells.

The LSD data used in this study are from Aangstrom Precision Corporation's Michigan Basin Oil and Gas Well database. The database contains information on 51,275 wells; 11,472 of those include LSD data. Prior to use, the LSD data must be converted to digital form. This was accomplished utilizing a FORTRAN program written to extract the depth and dominant lithology from the database and to then output an LAS file containing the well header information and depth versus lithology data. The program assigns a value of one to the dominant lithology for each depth interval and zero to the other possible lithologies. The current version of the program recognizes ten different lithologies: those most frequently occurring in the basin. The LAS file is then converted to an LBS file using GeoGraphix-Schlumberger's QLA 2 Log Interpretation program. QLA 2 is also used to create a template to display the lithology data. Other templates were made to display the lithology data in association with standard well logs, e.g. gamma ray and neutron density (See Fig. 20). The log display templates are used in conjunction with GeoGraphix's *Cross Section* and *WellBase* modules to create the *PseudoLog* lithologic cross-sections. The inclusion of the formation top subsea picks from the database provide a simple, graphic display of the data (See Fig. 21). Examples from the Michigan Basin demonstrate that the display of data in a graphical fashion provides the user with a visual method to compare top subsea picks to log and lithology data. Potentially incorrect top picks can be easily identified using this method, and the database information corrected. Regional cross-sections made using these data define large-scale sediment patterns and permit identification of stratigraphic sequences with a greater degree of confidence.

Figure 21: PseudoLog lithologic cross-section with top subsea picks.

APPENDIX 2

MATLAB 2D AND 3D VISUALIZATION PROGRAMS

MING LUO

J. R. WOOD

MICHIGAN TECHNOLOGICAL UNIVERSITY

DOE CONTRACT NO. DE-AC22-93BC14892

MatLab 3D Visualization
VORP - A New Application of MATLAB in the Geosciences
(M. Luo, J. Wood)

What is VORP ?

VORP is an acronym for *Visualization of Reservoir Properties*. It is a new window application which allows geologists and geophysicists to easily visualize subsurface reservoir parameters in 2 and 3 dimensions and to easily create their own animation pictures showing the spatial distribution of reservoir properties in the subsurface. VORP was written using MATLAB's matrix functions and graphics objects. VORP was developed by Michigan Technological University under this DOE contract.

Why do we use MATLAB to create VORP ?

VORP is written in the MATLAB environment and is a new application of MATLAB in the geosciences. We chose MATLAB as a tool to develop VORP because MATLAB is a technical computing environment for high-performance numeric computation and visualization. Some important advantages taken from MATLAB for this project are summarized below:

1. MATLAB, which stands for *Matrix Laboratory*, represents the-state-of-the-art for matrix computation. To visualize subsurface geological features and reservoir properties in 2 and 3 dimensions, geological databases (data structures) have to be reconstructed into different matrix structures. This difficult job can easily be handled in the MATLAB environment.
2. MATLAB's graphics system provides a variety of sophisticated techniques for presenting and visualizing data. By creating and manipulating MATLAB's low-level graphics objects, visualization applications in geosciences can easily be constructed and used by geologists and geophysicists with only basic computer skills.
3. MATLAB is much less expensive than other graphics software. When the MATLAB executable compiler become available, our new application, VORP, can be run directly in the MS-DOS and Windows environments without relying on the MATLAB window environment itself.
4. MATLAB based graphics applications can be run on different platforms, including SUN/UNIX, MacIntosh, and MS-DOS, without changing a single code. The flexibility is very competitive.

How does the VORP work ?

VORP is a project-oriented graphic user interface which can be used to visualize geological and geophysical data in 2 and 3 dimensions. Users can create their own projects, customized to their own special interests. Currently, VORP must be run in the MATLAB Command Window, although the compiler will be available soon for this project.

At the VORP directory in the MATLAB Command Window, users can start the VORP program by typing: `runvorp`. Then the users can follow the menu-and-button controlled instructions to create a project and to do their visualization studies. An attached flow chart shows how the VORP graphic user interface is modularized and what kinds of functions VORP can offer to users (Figure 22). Users can get on-line help from the working window by clicking the "About" button or on the head of the menu. One of important properties of VORP is that input and output data files are in common text format, which makes geological data preparation, correction, and conversion much easier.

What can be done in VORP ?

Both geological properties and well logging properties can be visualized in the VORP menu windows. In the VORP menu window, users can accomplish the following tasks:

- (1). **Data Processing** --- includes *data filtering*, which keeps all data points properly gridded without any identical data pair; *data girding*, which creates equal-distance 2-D and 3-D data structures (matrices); *load faults* and *add faults*, which integrate faults into the data structure of the reservoir property visualization, when faults are present;
- (2). **2-D Visualization** --- Different types of contour maps can be created and well information can easily be identified from the contour maps. A cross section between any two points can easily be lifted from the contour map and displayed in 2 dimensions and 3 dimensions.
- (3). **3-D Surface Visualization** --- Surface and subsurface maps can be viewed from any viewpoint in 3-D dimensions. Elevations and azimuths can easily be changed. One can also identify individual wells and integrate faults in the 3-D surface map.
- (4). **3-D Slice Visualization** --- Using the *3-D data processing module* to create (in X,Y,Z,V-space) a data structure for a particular reservoir property which one wants to visualize, within a specific depth interval (or multiple layers), the user can create a solid body which shows a real 3-dimensional distribution of the reservoir property in question. A unique feature of VORP is that it lets geologists use the *slicing visual tool* to slice the solid body into segments, in any direction or shape, to investigate a continuous change in reservoir properties at any chosen angle in 3 dimensions.
- (5). **Animation** --- Users can snap any 3-D visualization picture that is created in VORP and save it as a movie. At *on-site shooting*, some important options such as number of frames and shooting speed can be controlled at user discretion. The user can make a

series of movies for a particular project and consequently build up a *project cinema*. In a project cinema, names of all animation pictures are listed in the order that the user prefers. All movies can be replayed by clicking the name of the movie. The speed and number of times that the movie is played can also be easily adjusted by the user.

(6). **Well Log Studies** --- In the VORP window, users also have the opportunity to do some well-log studies, which include:

Log Curve Review allows users to review up to 6 kinds of well log curves at any depth intervals, including: SP log, gamma-ray log, resistivity logs, density log, neutron porosity log, and sonic log.

Cross-Plots allows users to crossplot values from any pair of logs listed above at any chosen depth interval.

Syntheticgram allows users to create a syntheticgram (or "pseudo-seismic cross section"), using either SP logs or gamma-ray logs, along a line that the user draws on a regional map.

Visualization of the Pioneer Field using VORP

3-D visualization of the Pioneer Field can be performed in different styles by utilizing our newly developed VORP graphical tool. So far we have created:

- (1) A 3-D visualization of the structure on the top Miocene, with 9 faults represented (Figure 23, 24). Faults are currently displayed as vertical planes, but will soon be portrayed with true azimuths and dips;
- (2) 3-D visualizations of multi-layer stratigraphy (the top Miocene, Etchegoin, Reef Ridge Shale, Reef Ridge Sand, and Monterey) in the Pioneer Field (Figure 25, 26, 27);
- (3) Several animation pictures showing different 3-D visualizations of the Pioneer Field.

A flow chart showing VORP graphic user interface.

Contour Map of the Pioneer Field

29-Aug-96

Figure 23

29-Aug-96

3-D Visualization of the Top Miocene, Pioneer Field

Figure 24

Figure 25

Figure 26

Figure 27

GeoGraphix Case Study: Kern Front Field

(W. Houston)

The Kern Front Field in Kern County, California is similar to the Pioneer Field in that it contains a large number of relatively old wells, and portions of the field are only represented by old and/or incomplete data bases. It provides an excellent case study of the use of computer visualization in a development geology study, especially in projects where time, manpower, and/or scope are limited.

Between May and August 1996, MTU graduate student W. Houston carried out a reservoir characterization study of a portion of the Kern Front Field (Fig. 28) as part of an internship program developed in cooperation with Santa Fe Energy Resources, Inc., in Bakersfield, California. The following summarizes the computer visualization part of the project which was carried out in GeoGraphix:

Preliminary Reservoir Characterization of SFER Section 23 "FEE", Kern Front Field, T. 28 S., R. 27 E., SW ¼ & SE ¼, Kern County, California

Santa Fe Energy's Kern Front property encompasses approximately 320 acres (the lower half of section 23) about seven miles northwest of Bakersfield, California. This property was first drilled in 1926 and now contains 104 wells, the majority of which were completed prior to 1960. Most geologic interpretations were made in the 1960s. Despite logs and core obtained as recently as 1985, the data base as of May 1996 was loosely consolidated and an updated, comprehensive geologic framework for the property had yet to be compiled. A time frame of three months was established to perform a complete reservoir characterization of the property using computer visualization of existing data.

The initial data base for this characterization consisted of a basemap in the GeoGraphix Exploration System (GES) containing all wells on the property, and 74 digitized logs (52 on the property and 22 on adjacent leases) available in QLA2. Driller's logs, additional paper logs and other data were available from well files. Preliminary lithologic picks were made on cross sections constructed from QLA2 (Log Interpretation Software) logs plotted on templates custom designed to amplify diagnostic log characteristics specific to Kern Front wells.

From picks made on the log cross sections, a GeoGraphix WellBase (Well Data Module) data base was established, becoming the fundamental basis for all subsequent geologic interpretations. Preliminary datum elevation and structure contour maps were created in GeoGraphix and used to identify anomalous data points, which were then corrected in the data base. Lithologic logs were constructed from driller's logs to provide stratigraphic control where electric log data were absent. Throughout the project, lithologic picks were

refined and updated in WellBase. WellBase was also used to archive core data, fluid saturations, production statistics and other data.

Graphical displays were created in GeoGraphix (including well logs and lithologic logs imported from QLA2) including well data maps, structure contour maps, isopach maps and cross sections. The ability to easily update the dynamic database allowed for cross-checking various presentations to provide a measure of quality control (e.g. using a specific cross sections to verify points on a structure contour map). Graphic presentations were continually refined over the course of the project and modified right up until time of presentation.

Presentations generated to exhibit the reservoir characteristics of Santa Fe's Kern Front property included (but were not limited to): Location and well basemaps presenting various data sets; type logs; structure contour maps generated on the tops of specific stratigraphic horizons; structural cross sections; net pay sand isopach maps of stratigraphic intervals; total net pay maps; and schematic well plans both in plan view and in cross section.

Acknowledgments

Michigan Technological University would like to thank Santa Fe Energy Resources, Inc., in Houston, TX, for permission to use the data and results from this study in public demonstrations of computer visualizations.

APPENDIX 3

FINAL REPORT

GEOLOGICAL AND PETROPHYSICAL EVALUATION OF THE PIONEER ANTICLINE AREA, SOUTHERN SAN JOAQUIN VALLEY, CALIFORNIA

PREPARED BY:

DIGITAL PETROPHYSICS

BAKERSFIELD, CA.

W. R. BERRY II

D. M. OLSON

D. J. CRANE

UNDER SUBCONTRACT TO:

MICHIGAN TECHNOLOGICAL UNIVERSITY

DOE CONTRACT NO. DE-AC22-93BC14892

November 26, 1996

Dr. Jim Wood
Michigan Technological University
1400 Townsend Drive
Houghton, Michigan 49931-1295

Dear Jim,

Enclosed are the final deliverables under our subcontract to you for the DOE grant project we have been working on together. I am sending one printed copy of the report, tables, and figures, and also an electronic version of the report text and tables on floppy disk. The figures were created in Petrolog and in Statistica. I know you don't have Petrolog, but you can reproduce Figure 1A in QLA2 if you want to. If you have Statistica I can send you the plot files. One of the figures is a copy of a DOG type log; there was no time to redraft it. In Appendix II, there are references to SEM photos of Opal-A and Opal-Ct. I know Ruth made some images of the Cymric core that would be suitable to put in here, but I don't have copies of her work.

We sent you copies of our hand-drawn maps and cross sections last spring, and those were to be redrafted in GeoGraphix. They should probably be included as attachments to this report also.

All well data was extracted from Petrolog in LIS format, ZIPped, and put on floppy disk. There are a total of 25 disks in this package. I did this to avoid any incompatibility between backup systems, etc. that we might have.

If you have any questions about this, please let me know.

Sincerely,

Deborah M. Olson
Digital Petrophysics, Inc.

**GEOLOGICAL AND PETROPHYSICAL EVALUATION
OF THE PIONEER ANTICLINE AREA
T11N/R22W SBBM**

**PREPARED BY
DIGITAL PETROPHYSICS, INC.**

William R. Berry II
Geologist/Petrophysicist

Deborah M. Olson
Geologist/Petrophysicist

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**UNDER SUBCONTRACT TO
MICHIGAN TECHNOLOGICAL UNIVERSITY**

DOE CONTRACT NO. DE-AC22-93BC14892

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1.0 SUMMARY

This study was performed under subcontract to Michigan Technological University as part of a grant from the Department of Energy to demonstrate computer analysis and visualization techniques for a reservoir description project. The Pioneer Field area, located approximately 10 miles southeast of the town of Maricopa in the San Joaquin Valley, California, was chosen for the example study. This area is located on the plunging nose of an anticline and therefore has considerable structural relief. The project focused on the upper Miocene siliceous shales, but the overlying shaly sands of the Etchegoin Formation were also included in the geological and petrophysical analysis.

The study area was good for demonstration purposes for a variety of reasons. The shaly sand and siliceous reservoirs are typical of the more challenging lithologies present in California, and that are most difficult to characterize and visualize for operators now facing redevelopment or EOR activities to maintain production. The combination of new wells and old E-logs present at Pioneer is quite typical of California's oil fields, and part of the results of this study is a technique for using these data as part of a reservoir evaluation. The area is located on an anticline with high relief and major faults, which is often difficult to visualize from 2-D paper cross sections and maps, so 3-D visualization techniques are quite applicable here.

The diatomaceous reservoirs of the Monterey Formation consist predominantly of siliceous, cherty shales containing various amounts of clay and silt. These reservoirs have high porosities and low permeabilities. The key to production in the Opal-Ct and quartz phases is brittleness and fracture permeability. Most of the siliceous section at Pioneer is in the Opal-Ct to quartz phase, which is at a higher diagenetic grade than its current depth would allow. This indicates that the Miocene was at one time buried deeper than it is now.

The petrophysical and geological analysis that has been performed as part of this study, and that is discussed in this report, resulted in a reservoir description including lithology and porosity for all wells, and water saturation for those wells with adequate logs. Additionally, a methodology is presented for using the wells with porosity logs to calibrate an empirical model for deriving lithology and porosity from the E-log only wells.

2.0 INTRODUCTION

The main objective of the project is to provide the smaller oil field operator with the approach and technology required to undertake an E.O.R. reservoir characterization and evaluation similar to those performed by larger international companies.

The scope of work outlined in the project proposal is categorized into several interactive

and parallel phases.

- . Database Initialization and Management
- . Log Calibration and Analyses
- . Rock Measurement
- . Petrophysical and Geological Modelling

The database management phase provided the vehicle for integrating all available data and interpreted results into the project to enable the process of visualization. This phase involved numerous related tasks including data gathering, digitizing, and construction of an interactive multi-media database. This phase of the project was ongoing and interactive throughout the entire study.

The log calibration and analyses phase involved a detailed review of all of the available log and other well data, and capturing these data digitally for use in the various parts of the project.

The rock measurement work involved the use of various standard and experimental analysis techniques on core and cuttings samples from the project study area to better determine rock properties. The results of the experimental techniques were reviewed and compared to discover whether these methods would have further application in California and elsewhere to measure rock properties.

The petrophysical and geological modelling work included the log analysis, correlation, and mapping work for reservoir description. Preliminary correlations and maps were drawn using unprocessed log data, and were refined later using the results from the log analysis. Physical and chemical properties gathered from laboratory measurements of conventional core and cuttings were also used to develop algorithms which related geological and engineering parameters to log responses. Some core analysis had been performed previous to the commencement of this project, and other tests were done as part of this work. Well log, core and other test data were assembled and stored in QuattroPro and Excel, commercial spreadsheet packages, which allowed for easy access and updating and also for uploading to the project database. Log editing, preparation, and plotting were done at DPI in the Petrolog system from Crocker Data Processing, and the analysis was done in Symbiolog. Preliminary geological correlation and mapping were done at DPI using output from Petrolog. Final rendering of cross sections and maps were drawn at MTU using GeoGraphix.

The tasks completed by DPI included:

- Acquisition of all log, core, and well history data available within the study area
- Digitizing and data capture of well data
- Construction of log database
- Analysis of all wells in study area
- Correlations of formations and markers

This report discusses primarily the work done by DPI on this project. Also included is general information about the geology of the study area and properties of the diatomaceous rocks that are the principal subject of the work.

3.0 REGIONAL GEOLOGY OVERVIEW

The San Joaquin Basin is roughly coincident with the southern portion of the geographic San Joaquin Valley (or Central Valley) of California. It is a downwarped basin with a total thickness of over 35,000 ft of primarily marine sediments ranging in age from late Cretaceous to Recent. The basin is bounded to the east by the Sierra Nevada Mountains, and on the south and west by the San Andreas Fault and associated structures. The northern boundary of the basin is a subsurface rise called the Stockton Arch. The east flank is characterized by gentle dips and primarily normal faulting. The south and west flanks are characterized by steep dips and compressional tectonics.

3.1 TECTONICS

Plate margin tectonics have always dominated the geologic development of western California. Although evidence in the form of remnant metasedimentary bodies exists for Paleozoic continental-platform type deposition in California, the earliest recognizable coherent rock units belong to a subduction-forearc basin complex that formed during Mesozoic time. Most of the "basement" rock west of the San Joaquin Valley consists of a melange of metamorphosed subduction-related rocks called the Franciscan Formation. The basement to the east of the central valley is granitic, comprising the roots of the Mesozoic island arc that bounded the subduction zone. It is not certain where the boundary, and therefore the continental margin, is located beneath the sedimentary cover in the San Joaquin Valley. The oldest recognizable sediments are sand-rich Cretaceous turbidites deposited in the forearc basin. Turbidites and related deep-water deposits dominated the sedimentary section until Pliocene time.

In early Miocene time, the oceanic spreading center that was moving eastward collided with the subduction zone and became a transform fault. This fault or system of faults, collectively called the San Andreas, grew progressively longer as the triple junctions moved northward and southward along the coast. This initiated a regime of oblique compression along the western margin of the basin. This active tectonic system has

been the most significant influence on the structural and stratigraphic development of the basin from mid-Miocene time to the present.

Several sets of en-echelon anticlines have formed along the west and south margins of the basin, all of which contain oil fields. Because of the rapid syn-depositional structural growth, the sedimentary sections are characterized by rapid facies changes and many local and regional unconformities.

3.2 STRATIGRAPHY

The stratigraphy of the San Joaquin Basin is shown in Table 1. This table was modified from Maher, Carter and Lantz (1975), and the reader is directed to this publication for an excellent summary of the geology and stratigraphy of the southern San Joaquin Valley. Formation names used in this table reflect formal U.S.G.S. usage; as would be expected, there are many informal local names used for these units throughout the basin.

The sedimentary section is dominated by the presence of turbidite sands and associated deep-marine shales. Most of the late Miocene-aged shales are diatomaceous, as are parts of the Eocene shales. These rocks are the source for most of California's oil, and under the right conditions also form reservoir rock. Late Miocene diatomaceous (or siliceous) shales are the the subject of this study in the Pioneer Anticline area.

3.2.1 NOTE ON DIATOMACEOUS LITHOLOGIES

Diatoms are part of the marine plankton that make their shells from hydrated amorphous silica (opal). Under certain conditions, their remains can dominate the pelagic sediments. These conditions prevailed throughout most of California's sedimentary basins during most of the Tertiary Period.

In deep basins that are anoxic at depth, the diatoms accumulate in fine millimeter-scale or thinner layers, and the organic material is preserved. With burial and heat, the amorphous opal (opal-A) of the original diatoms is converted progressively to opal-Ct (opal-cristobalite) and eventually to quartz. There is a commensurate decrease in rock volume and porosity and an increase in brittleness. Original opal-A has a real rock porosity of 60% or more, since there is porosity inside the diatom shells as well as around them. Opal-Ct has porosity ranging from 35%-45%, and quartz phase rocks can have porosity from 0% to about 25%. None of these phases has much primary permeability, although fractures in brittle rock provide abundant secondary permeability. With these ranges of porosity, diatomaceous rocks can have tremendous storage potential, and by using modern methods of well completion and stimulation Monterey-type rocks throughout California are good producers. Diatomaceous rocks are discussed in more detail in Appendix II.

3.3 GEOLOGY OF THE STUDY AREA

The Pioneer anticline is located five miles to the southeast of the town of Maricopa on the southwest margin of the San Joaquin Valley. The east-west trending anticline has surface expression through areas of Sections 26, 27, 28 and 29 in T11N/R23W. Both flanks are steeply dipping and the top is relatively flat, with an east-southeast plunge. Several thrust faults trending sub-parallel to the structural axis have been mapped on the north flank, including one that cuts several wells and causes a repeated section in one of the study wells. Additionally, several cross faults were recognized that probably have an oblique-slip sense of motion.

The local names in use in the study area are noted on Table 1 and shown in the stratigraphic column for the Pioneer Field taken from the DOG (Fig. 1a). Stratigraphically, the deepest wells in the study area are within the Pioneer Field and penetrate several thousand feet of the Temblor Formation. The overlying Monterey, Reef Ridge, and Etchegoin Formations were the study intervals for this project. The San Joaquin and Tulare Formations are present, but were not studied.

The Temblor Formation on this structure consists of a thick (at least several thousand feet) accumulation of sands and interbedded shales with a bedding thickness of ten to fifty feet. The trap for the Pioneer Field and other Temblor accumulations in the area consists of cross faults perpendicular to the anticline that juxtapose interbedded shales against sands, creating a series of thin stacked oil columns distributed over a large interval. Overlying the Temblor sands are a series of clay shales and silty sands that may represent the Gould and Devilwater Shale equivalents. Above this is a section that is about 1500 feet thick in the Pioneer Field area itself that consists of several intervals of siliceous shales interbedded with clay shales representative of the Monterey Formation. Down structure this section thickens and probably picks up some overlying Reef Ridge Formation, although it is difficult to tell the Monterey and Reef Ridge apart without paleontological assistance. The post-Miocene unconformity cuts the Monterey/Reef Ridge section, and it is probably deeply eroded near the structural crest. Overlying the unconformity are silty sands and gray clay shales of the Etchegoin Formation. The Etchegoin greatly thickens downdip. Another unconformity tops the Etchegoin, and this is overlain by the undifferentiated coarse sands and interbedded shales of the San Joaquin and Tulare Formations.

Structural growth has had a profound influence on the stratigraphic section. There is an angular unconformity present at the top of the Reef Ridge Formation, part of the widespread post-Miocene unconformity. Another unconformity is usually mapped at the top of the Etchegoin Formation. Substantial section must be missing across one or both of these discontinuities, since the diatomaceous rocks of the Monterey and Reef Ridge Formations are at a higher diagenetic grade than their present depth of burial would normally allow. This is discussed further in Section 4.2 and Appendix II. As a result of

structural deformation, the oil-bearing siliceous shales of the Monterey and Reef Ridge Formations subcrop beneath younger rocks on the anticline. The oil that is produced throughout this part of the basin from Pliocene rocks is believed to be sourced from these subcropping Miocene shales. Pliocene outcrops to the west of the crest of the structure have been mapped as having oil stain and tar on bedding planes. This oil very likely migrated from the aforementioned subcrops.

3.3.1 EXISTING FIELDS AND PRODUCTION IN THE STUDY AREA

3.3.1.1 PIONEER FIELD

The Pioneer Field itself includes about half a section of productive acreage in Section 32, T11N/R23E. It was discovered in July 1959 and as of the end of 1993 had produced a cumulative of 194,488 bbls. of 37-38° API oil from the Temblor Formation. The reservoir sands are tentatively assigned to the Media/Carneros equivalents. Two wells are still capable of production, of which one is currently on, averaging approximately 7 BOPD with a 16% water cut.

A small amount of Miocene production has been obtained in the Pioneer Field and vicinity, although most of the wells were not formally assigned to the field. In 1980 and 1981, Tenneco drilled six wells on the north flank of the anticline, about two miles northwest of the old Temblor producers. These wells were completed in the Monterey for a low daily rate of flowing, gas-charged heavy oil production. The production was uneconomic and the wells were idled. In 1990, another well was drilled in a different structural position, near the old Temblor wells on the crest of the structure. This well encountered similar conditions to the six Tenneco wells, and is still being produced at low rates.

3.3.1.2 LOS LOBOS FIELD

The Los Lobos Field, located about one mile north of the Pioneer Field, was discovered in 1952. Because of the 70° dips on this flank of the anticline, the wells are distributed in a line one well wide and about two and a half miles long. On the west end, it produces from a turbidite channel sand in the upper Reef Ridge Formation and on the east end from a sand in the overlying Etchegoin Formation. Productive depth ranges from about 6000 ft to nearly 8000 ft over a narrow horizontal range because of the dip. The field is now abandoned.

3.3.1.3 OTHER DRILLING

A number of exploration wells were drilled in the Pioneer area in the 1930's through 1950's, resulting in the discovery of the Pioneer and Los Lobos Fields. More drilling followed during the 1950's and 1960's, but no further discoveries were made. In the 1970's and 1980's, Tenneco (who held nearly all the land in the area) drilled several deep

tests which were quite useful to this project. Many wells have had shows in the Monterey and in some cases were tested. A summary of shows in the more important wells is shown in Table 2.

3.3.2 THE ETCHEGOIN AND REEF RIDGE/MONTEREY IN THE PIONEER AREA

Although the main focus of the project was the siliceous shales of the Reef Ridge/Monterey section, the overlying Etchegoin Formation was included in the analysis. In this area, the upper part of the Etchegoin consists of a gray to gray-green clay shale overlying silty sands interbedded with shales. The section is 100 feet or less in thickness on the crest of the anticline, and thickens down the flanks. Changes in thickness result from a combination of erosional removal from the top and syndepositional growth of the anticline. Etchegoin sands are productive in the eastern part of the Los Lobos Field.

The Reef Ridge/Monterey section includes a channel sand in at the top that is present only in the western part of the Los Lobos Field, where is formed the main producing interval. Elsewhere, the lithology consists of fairly clean diatomaceous rock interbedded with more clay-rich shales.

The major correlations of formation tops were readily visible on the unprocessed logs, and the top Etchegoin, top Miocene, Reef Ridge channel sand, and top Temblor were all identified prior to the availability of the petrophysical results. These tops were needed to assist in parameter selection and zonation of the wells for the log analysis phase of the work. Within the Monterey itself, however, few internal correlations could be recognized. In the past since the siliceous shales are difficult to correlate from raw paper logs, workers have picked the top Miocene unconformity upon which to base all their mapping, although it was well known that the pre-unconformity Miocene structure probably was quite different. If the shales could be correlated internally, structures could be identified that might lead to the discovery of new pools.

In the wells from the Pioneer area, it was possible to identify one correlation in the Miocene from the raw logs: the point labeled "R" on the type log (Fig. 1b). This is the top of an interval where the resistivity is more "spiky" than it is in overlying intervals. This probably indicates an increase in carbonate stringers, one of the typical Miocene lithologies. Above the "R" marker, however, it is difficult to trace correlations on raw logs. The additional correlations shown on the type log were made using the computed results. They show that the intervals of cleaner and shalier siliceous rocks can be traced throughout much of the study area, although their character changes somewhat from well to well. A stratigraphic cross section hung on the top Miocene shows these correlations in an approximate strike view along the north flank of the structure. Fig. 2 uses only raw logs, and Fig. 3 uses the computed logs.

The exercise of correlating the Miocene shows the value of using both the raw logs and

the computed results for geological correlations. It is necessary to perform preliminary correlations on the raw logs, since formation/lithology boundaries are used in the petrophysical parameter selection, but it is important to go back and refine the correlations by using the results from the log analysis.

4.0 METHODS USED IN THIS PROJECT

At the start of this project, a data search revealed that no core material remained in existence for the Monterey section within the study area, although core analysis data from one well and cuttings from another were available. Therefore, to obtain rock material for experimental analysis, the project obtained permission from Unocal Corporation to utilize the core and logs from two wells within the diatomaceous reservoir in the Cymric Field, 25 miles to the northwest.

4.1 CYMRIC ANALOG

Wells in the Cymric field which were completed in the siliceous shales were reviewed in terms of completion technique, production performance, hydrocarbon concentration and reservoir rock quality to determine their suitability for use as an analog for diatomaceous production from the Pioneer Field area.

The Reef Ridge reservoir in the Cymric Wellport pool had produced a cumulative of 961,819 bbls. at 12.6° API oil and 13.38 mmcf gas as of 1993. Current production is 2,653 BOPD, with an average 72.6% water cut. Since discovery in 1957, 151 wells have been drilled to an average well depth of 3500 feet. Fifty-six wells are on production and 55 wells are shut in. This reservoir is somewhat unusual for Monterey-type production in the San Joaquin Valley in that it produces heavy oil from both the Opal-A and Opal-Ct phases. Most production elsewhere is from either the Opal-A or quartz phases, and is generally 20° API or higher. The Cymric Field is a good analog for the Pioneer Field production since the Monterey at Pioneer is also in the Opal-Ct phase and produces heavy oil.

The detailed core analysis and log data from the Cymric cores were used in setting up the analysis model for the Pioneer area. The most extensive Cymric data in Well #418 included a long section of Opal-A phase rock, some Opal-Ct, and the transition between them. The data from the deeper Well #415 included spot cores down to nearly 5000 ft. However, the lithology penetrated by the #415 was more clastic than diatomaceous in the lower intervals and therefore quartz-phase diatomite was not represented in the available core samples. The rocks at Pioneer are primarily in the Opal-Ct to quartz phases, with only a small amount of the section in the lower Opal-A phase range. However, the Cymric data were used to calibrate the Opal-A end of the model.

4.2 LITHOLOGIC AND CORE DATA AVAILABLE

Much of the lithologic data for the project came from the extensive analyses, descriptions, photographs, and personal inspections by team members of the Cymric analog core wells, Unocal #415 and #418. This included thin section and SEM photographs work done at MTU as part of the project. However, although no core material could be located for wells in the Pioneer area, reports on analyses done on the core from Tenneco #62X-30 were available. Additionally, Tenneco performed some detailed analyses on well samples, probably sidewalls, taken from two other wells in the area. Summarized below are the results from the Tenneco special analysis study.

Eight samples of the Antelope Shale taken from various wells in T11N/R23W were examined by Tenneco in 1980. The objective of the examination was to determine the mineralogy and degree of natural fracturing for each well.

The wells were located approximately 1.7 miles apart and were at structurally different depths. Results of the analysis indicated significant lithological differences between each well.

The samples from the Santiago (A) 72-30 well, in which the top Miocene is located at -257 feet subsea, consisted of a diatomaceous siltstone showing very little structure or fabric. Localized concentrations of detrital material included quartz, feldspar, altered rock fragments and detrital clay. Volcanic glass and calcareous microfossils were also identified, with pyrite fillings developed within some of the calcareous microfossils. Siliceous microfossils and glass shards are present in some samples and show no indications of dissolution.

The samples from the Santiago "C" 55-28 well, in which the top Miocene is at -2258 ft subsea, in contrast, was comprised of very finely laminated shale. Pyritized diatoms and other siliceous microfossils were absent or rare. Numerous microfractures dissected some of the samples but were healed by an isotropic fracture filling identified as Opal-A. Some fracture fillings were composed of Opal-Ct. Open microfractures were not observed.

In summary, the samples from the Santiago "C" wells are very different from those of the Santiago "A" well. The "C" well is more strongly cemented which has resulted in the sealing of any microfractures which could have existed in the "C" well. Similar fractures are open in the "A" well. These naturally-occurring fractures are high-angle and indicative of compression. The fractures are closely-spaced and numerous and are the main conduit for hydrocarbon production. In contrast, the "C" well exhibits significantly less fracturing. High angle compression fractures are present, but more widely spaced. However, the rocks in the "C" well are at a more advanced stage of diagenesis and are more brittle, so continued tectonic movements are likely to continue fracturing the rock.

The samples were subjected to both acid exposure and simulated steam injection tests. Samples from the Santiago "C" well were very resistant to acid attack and remained intact, while the "A" well samples experienced various degrees of mechanical degradation.

The simulated steam injection tests had no effect upon the Santiago "C" samples and showed no signs of hydrocarbon displacement. Santiago "A" samples, however were broken down by steam injection with the maximum breakdown occurring in samples at depths between 1377 and 1394 feet. It was concluded that the degree of breakdown is directly related to the volume of smectite in the fine size fraction.

Potential reservoir problems were identified as a result of the laboratory tests and are summarized as follows:

1. The changes in mechanical strength of the Antelope shale is a direct result of variations in silica cementation. Santiago "A" 72-30 has low strength and will have low embedment pressure. Packing of induced fractures will present difficulties. The strength of the shale in the Santiago "C" 55-28 well will be high, as will the embedment pressure.
2. Acid sensitivity in the "A" well suggests potential for damage due to the secondary precipitation of iron compounds.
3. Fresh water sensitivity will be a major problem in Santiago "A" due to smectite clay. Steam injection tests demonstrate a large degree of disaggregation. The properties of the Antelope shale in the "C" well will be unaffected.

The lithology of the siliceous intervals in both wells is typical of the diatomite in this area, with clay content varying from 10% to 30%.

4.3 ANALYSIS APPROACH FOR THIS STUDY

DPI has established a procedure for performing petrophysical field studies that was used to organize and guide the work on this project. This procedure is discussed below.

A modern petrophysical field study that is properly performed has very significant implications for reservoir management. Although advances in tool design and the development of new analysis techniques have improved our ability to assess reservoir potential, the most important aspect of a modern field study is an integrated analytical approach.

The elements of an integrated analysis are:

- Development of a predictive model for the entire field (field function)
- Preparation of a standard dataset for uniform processing
- Model parameter selection based on reservoir geology
- Engineering and production data incorporated where known
- Use of a detailed plan for all studies that is adapted to specific project needs

DPI has used an integrated analytical approach for the Pioneer Anticline study. The elements are further discussed in Appendix I.

4.3.1 OVERVIEW OF DPI PROJECT TASKS

The primary purpose of this study was to perform a reservoir description to be used as an example in demonstrating the use of PC-based evaluation and visualization software. As part of this effort, DPI developed a petrophysical model that would be predictive of water saturation, porosity, shale, and clay volume in the Pioneer area. DPI also performed stratigraphic correlations and structural mapping to provide a basis for computerized visualizations of the structure and stratigraphy.

Well data were acquired and digitized. Since no core material was available from the Pioneer area, the project secured the release of extensive core material and analysis data from two wells in the Opal-A/Opal-Ct heavy oil reservoir in the Cymric Field. These cores provided samples for laboratory analyses at MTU and also calibration data for the Pioneer analysis model.

At DPI, the well data were edited, depth shifted where applicable, and standard environmental corrections were applied. Log normalization was done, then a foot-by-foot computerized analysis was run on all project wells that included a significant section of Etchegoin and Reef Ridge/Monterey Formations. For the wells that had modern resistivity and porosity logs (full log suites), it was possible to use standard petrophysical models to derive values of lithology, porosity, and saturation. Many project wells had only old electrical logs, however, and it is not possible to apply standard models to these wells. Based on the analytical results in the full suite wells, DPI developed an empirical model to derive lithology and porosity for these wells. It is not possible to compute a resistivity-based water saturation value from an electric log, since the old deep-reading curve is strongly asymmetrical in its response and standard machine processing is invalid. The complex thin bedded nature of most resistivity anomalies made R_t derivation using "old E-log" technology impractical. Therefore, no saturation calculation was performed for these wells.

These data were used to test various computer software packages for their usefulness in a small-company setting to perform reservoir description with PC-based tools. Most of the software testing was done by MTU staff using data generated by DPI and by MTU.

4.3.2 PETROPHYSICAL MODEL: DUAL WATER

Conventional interpretation models have not proven reliable for quantifying porosity, water saturation, and clay volumes in most San Joaquin Valley oil fields. Classical models such as Simandoux, Dispersed Clay, Laminated Clay, or Indonesian have yielded erroneous results in similar reservoirs due both to inadequacies of the models and improper parameter selection. The Dual Water model, while theoretically sound, can also yield erroneous results if parameters are improperly selected.

The model used in this study is unique and proprietary to DPI in that published equations have been applied in software written by DPI and in other systems that are commercially available. The model is based upon interpretation models generally accepted throughout the industry. The sequence of interpretation steps within the model is crucial to an accurate computation. Improper sequencing of otherwise correct equations will result in error where measurements require both shale and hydrocarbon corrections. Clay volume is first computed from each desired indicator. The minimum, median, or average clay volume is then determined as desired. Clay-corrected porosity is computed and iterated for hydrocarbon corrections. The hydrocarbon saturation of the invaded zone is computed on each iteration. Water saturation is then computed either by a quadratic form of the equation or by using an iterative method where 'n' is not equal to 2.0. The formation factor porosity exponent 'm' in the saturation equation is not a constant in the Pioneer area model, but is a variable as a function of lithology.

The model is discussed further in Appendix I.

4.3.3 WORK SEQUENCE

The work sequence followed in this project conforms to the Field Study Management template prepared by DPI. The only exceptions to the guidelines occurred when certain project-specific technical issues required further investigation outside the scope of the general Field Study outline. The main segments of the sequence are:

- Database preparation and editing
- Environmental corrections
- Normalization
- Log correlation
- Parameter selection
- Verification of analysis and sensitivity runs
- Identification of analysis problems
- Final analysis
- Verification of correlations with analytical results
- Zone summations

- Mapping of zone tops and properties from the zone summations
- Final report

4.3.4 DATABASE PREPARATION AND EDITING

The database construction consists of: locating well data, creating tracking spreadsheets for each well, digitizing paper logs, editing data, depth shift and verification, environmental corrections, and normalization. The database was prepared for both the petrophysical analysis and for the geological interpretation.

4.3.4.1 DATABASE CONSTRUCTION

Pre-existing digital data were not available on any wells, therefore the paper logs were digitized. The curves were edited to remove invalid data, and then depth shifted where necessary. Header data and drilling zone information were also entered for each well.

Standardized curve nomenclature was used throughout the database preparation phase to ensure the maximum efficiency of batch processing later. A lexicon of curve names is included in Table 3: It is important, however, to retain the actual name of resistivity curves so that the type of tool can always be identified. A second set of resistivity curves was created in each well that consisted of copies of the original curves with uniform names for use with cross section programs.

4.3.4.2 ENVIRONMENTAL CORRECTIONS

The appropriate chartbook corrections were applied to the induction, gamma ray, neutron, and density logs. No similar corrections exist for old electric logs.

4.3.4.3 NORMALIZATION

Normalization was made difficult in this study by the large area, the structural and lithologic changes, and the scatter of the well data. A full discussion of normalization procedures is provided in Appendix III, Section A.III.1.4.

4.3.5 PARAMETER SELECTION

Parameter selection was challenging for this project due to the need to develop a useful model both for full-suite wells and for E-log only wells. Parameter selection proceeded in three stages: calculation of clay volume, calculation of porosity, and calculation of water

saturation. The parameter selection process is discussed briefly in the following sections and in Appendix IV.

4.3.5.1 CALCULATION OF CLAY VOLUME

Volume of clay was computed by applying a non-linear transform to the baseline-shifted SP curve. For a few wells with poor SP's, clay was computed from the shallow resistivity curve. Very little quantitative data were available to calibrate the clay transform, so it was set up principally by the interpretation of descriptive data from core and mudlogs, local knowledge, and geological expertise. Details of this procedure are discussed in Appendix IV, Section A.IV.1.1.

4.3.5.2 CALCULATION OF POROSITY

On full-suite wells, total and effective porosity were computed from the neutron-density crossplot after application of an iterative light-hydrocarbon correction. The model was calibrated to whole core porosity and verified with available sidewall core data. All core porosities are assumed to represent values close or equal to total porosity, since the samples were analyzed using the Dean-Stark procedure. No data were available to correct the measured laboratory data for the effects of overburden, so whole core porosities tend to be somewhat higher than computed values. For the E-log only wells, an empirical depth function was developed for total porosity based on the computed values from the full-suite wells. Effective porosity was then computed as a function of total porosity and clay volume.

Total porosity is computed from the crossplot by projecting the data points onto the matrix line along a certain slope, defined by a line between the matrix point and the dry clay point.

Details of the porosity model calibration are presented in Appendix IV, Section A.IV.1.2.

4.3.5.3 CALCULATION OF WATER SATURATION

After establishing good V_{clay} and porosity transforms, calculation of water saturation was performed. Some core analysis and mudlog data were available to assist in model calibration. Water saturation results are only available for full-suite wells, since the old lateral logs in E-log only wells are invalid for the calculation of a foot-by-foot water saturation. Methods exist for hand calculating the correction for the lateral logs to true resistivity as an average over an interval, if the bed is thick enough to allow the tool to read properly, but in the siliceous shales the bedding is far too thin for these tools to be valid. Other methods exist for deconvolving these curves based on tool response physics, but

any of these resistivity-log corrections were beyond the scope of this project and were not done. Water saturation was determined using the relationship:

$$S_w^n = \frac{(C_t * F_o) - (S_{wb} * (C_{cw} C_w)) * S_w^{n-1}}{C_w}$$

where:

Fo = Dual Water formation factor

Ct = 1/Rt = true formation conductivity

Cw = 1/Rw = formation water conductivity

Ccw = clay bound water conductivity

Swb = fractional portion of total porosity saturated with clay bound water

This is the published form of the Dual Water equation as presented in the Schlumberger literature.

The calculation of water saturation is discussed further in Appendix IV, Section A.IV.1.3.

5.0 RESULTS OF THE STUDY

This project was not typical of most reservoir descriptions in that the results were not intended to be used for any economic purpose within the context of the project itself. The main result of DPI's portion of this study is the digital log database, the analysis, the geological correlations, and the methodology for actually performing the work. Some observations and conclusions can be drawn from the study, however, and they are discussed below.

5.1 OBSERVATIONS AND CONCLUSIONS

A model has been developed to allow the use of old E-logs and other wells lacking porosity data in an integrated reservoir description project for diatomaceous reservoirs. Such a model must be calibrated to each individual field and reservoir by including all available modern log and rock properties data. It is also important to note that the E-log only model depends heavily on a geologically-based rule set. The geologist/log analyst is performing an interpretation that must come from personal knowledge of the area when he/she sets up an old E-log for processing, so it is best if the petrophysics is done by the project geologist. If this is not possible, the petrophysicist should at least work very closely with the geologist when performing this kind of field study.

Nearly all basins in this country have a large number of old E-log wells, even if they also

have many newer wells with porosity logs. The E-logs are always used by the geologist for correlation, and are often ignored by the petrophysicist in performing log analysis. The approach used in this study can serve as a guidepost for the integration of the old log data into the quantitative reservoir description.

The Miocene diatomaceous section analyzed in this project is widespread throughout the southwestern San Joaquin Valley. The reservoir description work resulting from this effort will have application to a much larger area that is prospective for oil production. With the recent increase in oil price and level of effort in California, these results may have a significant impact on future activities in this part of the basin.

There were anomalies in the water saturation results that suggest water resistivity variations exist within the study area that could not be identified with the data available. This should not be surprising, since the Monterey was probably deeply flushed with meteoric water during exposure at the end of Miocene time. Also, it is well known that diagenesis of feldspathic sands in the San Joaquin Valley has a significant effect on the chemistry of connate waters. Either or both of these processes could have large and unpredictable effects on water resistivity within the reservoir.

5.2 OUTPUT DATA INCLUDED WITH THE REPORT

The output product of this study delivered to MTU by DPI consists of several kinds of digital data and this written report. These deliverables are discussed below.

5.2.1 FINAL REPORT

The final report consists of a brief summary of each analysis step and issue involved in the study, followed by a full discussion included in the Appendices. Appendix V contains all figures and illustrations to which the text refers.

5.2.2 FINAL DATABASE

The final database for this project area consists of raw curves, depth shifted, and environmentally corrected curves, and a number of computed curves. The computed curves fall into two families: final model outputs and intermediate process curves used as model inputs. These are tabulated and defined in Table 3.

Other digital data delivered include a spreadsheet of well information and correlations by well. Previously DPI has delivered a set of hand-drawn cross sections and maps to MTU for use in setting up computerized displays in GeoGraphix and other systems.

6.0 DISCLAIMER

All interpretations are opinions based on inferences from electrical or other measurements made by third parties and we cannot, and do not, except in the case of willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses directly or indirectly incurred or sustained by anyone resulting from any interpretations made by any of our officers, agents, or employees. These interpretations are also subject to our general terms and conditions as set out in the current Digital Petrophysics, Inc. price schedule, which are incorporated at this point as though set forth at length.

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APPENDIX I

Background Information

A.I.1.0 ANALYSIS APPROACH

The integration of all available reservoir information, viewed from a strong geological/production engineering standpoint, combined with modern and theoretically sound petrophysical analysis techniques is the overall philosophy of field study management that guides DPI's approach to projects such as the Pioneer area study. The basic goal of the analysis is the development of a field function: a petrophysical model that can be used to derive a consistent set of computed parameters for every well. If the field function is properly calibrated and if the database is consistent, it can then be used to interpret other wells in the project area that are determined to be similar.

Every effort is made to construct a consistent database for the project, using uniform curve nomenclature, the same preprocessing procedures such as depth shifting and environmental corrections, and careful normalization to adjust tool responses. These steps are all described in detail in this report in the various sections included in Database Preparation, Section 2.2.2, and Appendix III. The key wells from this database, usually core wells, are used for calibration of the model, and parameter selection is performed and verified on them. This phase of the project is very time-consuming, but the model analysis can be quickly extended to the rest of the field wells when the database is consistent, thus saving a great deal of time on the processing of the entire project.

No field study database contains definitive information for all necessary reservoir parameters required by a petrophysical model. Most of these are derived from laboratory analyses on core material. These analyses must be graded on the basis of the procedure used, sample quality, and overall validity of the data. Most of the model parameters are based on the geological characteristics of the reservoir, such as mineralogy, grain size, sorting, and stratigraphy. DPI utilizes geologist/petrophysicists experienced in oilfield production operations for selecting model parameters. Even where excellent core data exist, the ultimate model calibration must rely heavily on the experience of the analyst, based not only in previous petrophysical work but in a background of sedimentary and reservoir geology. The clay and porosity transforms in particular are judged by how well they fit the known mineralogy, depositional environment, and diagenetic history of the sediments.

It is also very important, whenever possible, to incorporate local expertise on the

geology and reservoir conditions from staff personnel who are most familiar with the field. In the case of this project, DPI staff had already worked in the area and had a good knowledge of the reservoir.

DPI has developed a set of detailed guidelines for field study management. All the necessary steps for execution of a field study are listed in their proper order. However, the system is flexible and can accommodate additions and changes in project direction and scope as technical issues are identified that alter the original plan. Without the guidelines, steps could easily be forgotten, performed incorrectly, or out of sequence when events occur that disrupt project flow.

Nearly all field studies include several elements that are almost research in nature, and often result in new ways of viewing the reservoir. These are explained fully in DPI's final report, along with a detailed record of all procedures, events, and results from the study. The product of this is an interdisciplinary tool that contains raw data, petrophysical computed parameters, and an interpretation of the analyzed data.

A.I.1.1 PETROPHYSICAL MODEL

A.I.1.1.1 CHOICE OF MODEL

Classic approaches to shaly sand analysis such as SARABAND's laminated-dispersed logic (Poupon et al., 1970) are unstable under a variety of conditions including very low porosity gas sands, feldspathic sand and silt sequences, and heavily cemented sands. Without logging tools that recognize thin beds, such as raw dipmeter or various micro resistivity measurements, it is not possible to distinguish between laminated and dispersed shales. Therefore, a dispersed-shale model was chosen for this study. Of these, the Dual Water and Waxman-Smits models are preferred because they are theoretically sound. Insufficient information was available to calibrate the Waxman-Smits model properly, so the Dual Water model was used in this study.

A.I.1.1.2 POROSITY MODEL

Porosity was determined from the neutron-density crossplot method for shaly sands for all the wells with porosity logs. A matrix density curve was computed and used instead of a fixed point in this crossplot calculation, since the matrix endpoint varies in diatomaceous rocks from less than 2.0 g/cc up to more than 2.75 g/cc, depending on the degree of diagenesis, clay content, and dolomitization. Hydrocarbon corrections were applied on an iterative basis to the density and neutron data for computation of total and effective porosity. The correction is computed by iteration until the porosity change is within a certain tolerance (or until a certain number of iterations have been done). The overall

correction applied was that for a low-gravity API oil, which results in very little correction. In diatomaceous rocks, neutron-density crossover does not necessarily indicate gas, but is merely a function of lithology in Opal-A and Opal-Ct.

The calculation of the hydrocarbon correction was complicated by the absence of an R_{xo} measurement in most of the wells. Therefore, S_{xo} was computed from R_t using a quadratic solution of the Dual Water equation and an exponent as follows:

$$S_{xo} = S_w^x$$

A.I.1.1.3 SATURATION MODEL

Where ' n '=2, the Dual Water model can be solved quadratically. Where ' n ' $\neq$ 2, the solution is iterative. The model repeats the iteration until the solution converges within an acceptable user-defined limit, or until a set number of iterations has been performed.

The choice of electrical properties for the saturation model was quite a complex and involved procedure due to the unusual nature of the reservoir, the small amount of useful core data, and the problems to be solved. The porosity exponent " m " and the saturation exponent " n " that were used in the model were both variable functions of computed lithology. Also, the R_w value was difficult to identify, and it is likely that there are some water resistivity variations that could not be identified with the available data. Calibration procedures are discussed in detail in Appendix IV, Section AIV.2.2.4.3.

APPENDIX II

Characteristics of Diatomaceous Rocks

A.II.1.0 MONTEREY SHALE FACIES AND PRODUCTION CHARACTERISTICS

The characteristics and evolution of the siliceous shale facies of the Miocene Monterey formations are complex and have caused consternation among many operators since they were first found to be productive. The Monterey can be found productive at any depth. However the characteristics of the reservoirs vary dramatically with depth and clay content. A clear understanding of the depositional and diagenetic process involved in the formation of these reservoirs is necessary in order to appreciate the potential of the biogenic shale reservoirs at Pioneer Anticline and elsewhere in the San Joaquin Valley.

A.II.1.1 FORMATION OF A DIATOMACEOUS RESERVOIR

Diatoms are marine planktonic plants that form their shells from hydrated amorphous silica, or Opal-A. At the time of deposition, the hydrated amorphous silica is composed of one molecule of SiO_2 bound with a number of H_2O molecules. Under certain conditions diatoms dominate the plankton in open-sea areas and, where clastic input is minor, deposits of nearly pure diatomite can be formed admixed with a small amounts of silt and clay. The combination of normal intragranular porosity and the void space inside the hollow diatom shells can yield a bulk porosity of up to 75% in unaltered (Opal-A phase) diatomite. However, due to clastic contamination and compaction at even shallow depth, the porosity is normally in the 55%-65% range. The grain size is very small and the permeability is low, usually less than 1 millidarcy. Figure A.II-1 shows a scanning electron microscope (SEM) photograph of pristine Opal-A diatom frustules. The rock is rigid but friable. With the high matrix porosity, reservoir fluid storage potential is very large.

Under moderate heat and pressure, the unstable amorphous opal (Opal-A) of the diatom tests begins to convert to a microcrystalline form of quartz called Opal-Ct (Cristobalite). Through compaction and morphological changes related to the formation of Cristobalite, most of the diatom tests lose their intricate structure and take on the appearance of watered down corn flakes. Thus, most of the individual diatoms are no longer distinctly recognizable as fossils. There is a consequent large loss of rock volume and porosity, although a typical Opal-Ct still has a porosity of 40%-45%, high by conventional standards. Such rocks have significant matrix reservoir storage. Fig. A.II-2 shows an SEM photograph of Opal-CT.

With greater heat and pressure, the Opal-Ct converts to quartz, resulting in an additional loss of rock volume and porosity. With enough heat and pressure, very clean diatomites end up as glassy chert with no matrix porosity. Under the right tectonic conditions, the glassy chert can be extensively fractured, thus providing a very high permeability reservoir. Such reservoirs may have little or no matrix storage but can have exceptionally high fracture porosities. Quartz phase rocks with admixed clastics retain some matrix porosity, and consequently have potential matrix storage for hydrocarbons. Intermediate stages of diagenesis yield a rock with moderate to low (15% to 20%) porosity which is very brittle and readily fractured. The term porcelanite is generally applied to quartz phase diatomite having low to moderate amounts of clay and moderate porosity.

Below the Opal-Ct phase window, the rock alters gradually to quartz phase, generally over a long interval. At Lost Hills and South Belridge, the quartz transition in the clean facies starts around 4,000 feet subsurface. Remnant Opal-Ct may be present in some places as deep as 5,500 feet, but the majority of the rock having low clay content is in the quartz phase by 5,000 feet. In some more tectonically active structures, prior depth of burial and subsequent erosion have brought Ct and quartz facies to shallower depths or to outcrop. If the diatomite was relatively pure, its quartz-phase equivalent endpoint is glassy chert. However, the transition from porous quartz phase clean diatomite to glassy chert can be over many thousands of feet, depending upon temperature and pressure. In the San Joaquin Valley, there is very little glassy chert but there are vast volumes of brittle porcelanite that was originally diatomaceous shale having low to moderate clay volume. The shale usually has streaks of pure porous quartz or chert, and often retains matrix porosity to relatively great depths. Quartz-phase rock retains both micro- and macro-fractures much better than Opal-Ct phase rock.

Recent developments around the San Joaquin Valley and better understanding of existing production from Monterey-type reservoirs indicate that the quartz-phase reservoirs can be excellent producers under certain circumstances. The rock must be clean enough to be brittle and must be subject to significant tectonic stress to propagate extensive macro fractures. Abundant additional reserves are possible where the rock retained sufficient matrix porosity and/or micro fractures to store hydrocarbons.

Production from the Monterey in coastal oil fields is often from fractured glassy chert having little or no matrix storage. However, fracturing in these reservoirs is so intense that the fracture storage is much higher than that found in most San Joaquin Valley deposits.

The transition between diagenetic phases is gradational and is partially dependent on clay content. The Opal-A/Opal-Ct transition in low clay environments usually occurs between depths of 1700 - 2500 ft. The presence of clays retards the Opal-A to Ct conversion, so in a section with interbedded clastics the transition could be stretched over an even longer interval. The Opal-Ct/quartz transition is more variable in depth and can extend as a mixed facies over several thousand feet. However, for clean diatomite (low clay), the

transition occurs between 4,000 and 5,000 feet along the west side of the San Joaquin Valley.

Diatomaceous rocks become more brittle as they reach higher diagenetic grade, culminating in pure quartz cherts that shatter like glass. Brittleness and susceptibility to fracturing decrease with increasing clay content. When these diagenetically embrittled rocks are deformed in the young, tectonically active structures common on the west side of the San Joaquin Valley they fracture readily. Therefore, fracture permeability is common and greatly enhances the productive capacity of the rocks. Fracture stimulation in wells is often used in these reservoirs to facilitate the interconnection of the existing microfracture network and access the large matrix and micro-fracture storage capacity.

A.II.1.2 ANALOGOUS SILICEOUS SHALE RESERVOIRS IN THE SOUTHWESTERN SAN JOAQUIN BASIN

Nearly all reservoirs of upper to middle Miocene age in the Southwestern San Joaquin Valley are either turbidites or biogenic siliceous shale. They are found in formations commonly referred to as the Reef Ridge, the McClure/Antelope Shale, and the McDonald Shale. There is economic production from the siliceous shale facies of one or more of these formations in fields such as Lost Hills, North and South Belridge, and Buena Vista Hills. Some of the reservoir characteristics of these formations are summarized below.

A.II.1.2.1 REEF RIDGE FORMATION

The Reef Ridge (Miocene) consists of moderate to very clayey diatomaceous shales. In the crestal portion of the Lost Hills and South Belridge fields, the Reef Ridge is in the Opal-A phase and responds well to fracture stimulation. Further down the structure, the transition to Opal-Ct results in lower productivity in the clay rich zones. However, in some intervals having lower clay content, the Opal-Ct responds with good production rates of oil and associated gas.

A.II.1.2.2 MCCLURE/ANTELOPE SHALE FORMATION

The McClure (Antelope) Shale (Miocene) is similar in nature to the Reef Ridge. Deposition in the vicinity of the Lost Hills and South Belridge fields during Reef Ridge and McClure times was dominated by diatom blooms during periods of varying clastic influx. Diatom bloom cycles which were contemporaneous with periods of low clastic influx resulted in relatively clean diatomites. Late in the McClure times, diatom deposition was high and clay influx was low, thus yielding several hundred feet of fairly clean diatomite with low clay and silt content. At Lost Hills, this clean interval is the Cahn Zone which has been the subject of considerable development. The occurrence of limestone or dolomite lenses is more common in the McClure than in the Reef Ridge.

A.II.1.2.2.1 CAHN ZONE OF THE MCCLURE/ANTELOPE SHALE FORMATION AT LOST HILLS

DPI classifies the Cahn Zone as being the low clay diatom rich interval which is easily correlated on neutron-density porosity logs over the entire Lost Hills structure. This zone has a very low clay content and represents a period of locally intense diatom deposition with very low clastic influx. The Lost Hills Cahn Zone has similar characteristics to the clean intervals at Pioneer. The Opal-A/Opal-CT and the Opal-CT/quartz phase boundaries in Lost Hills have subsea depth windows of 1,800 to 2,300 feet and 4,300 to 5,000 feet respectively. At Southeast Lost Hills there is strong evidence that individual well production is a function of the thickness of the clean facies and the degree of natural fracturing.

A.II.1.2.2.2 MCDONALD SHALE RESERVOIRS AT LOST HILLS

The McDonald Shale is productive on the southeast plunge of the Lost Hills anticline. The clean diatomite facies in the McDonald may be clayier than the clean facies in the Cahn zone above. Also, the McDonald contains a great number of limestone or locally dolomitic layers ranging in thickness from a few inches to a few feet. These layers may be locally fractured and contribute to production.

A.II.1.3 FRACTURING

The more prolific biogenic shale reservoirs of the Monterey produce from a system of natural micro and macro fractures which drain the primary pore system. The macro fractures are tectonically induced. The micro fractures can be derived from both tectonic and diagenetic causes. Micro fractures, and to a lesser extent macro fractures, can be healed or closed off by precipitation of cementing agents or by plastic deformation of the matrix.

A.II.1.3.1 MICRO FRACTURING

Micro fractures can be derived from both tectonic and diagenetic processes. The diagenetic transformation of Opal-A to Opal-Ct and finally to quartz creates a material balance problem. The transition from Opal-A to Opal-Ct results in several changes to the rock. Opal-A ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) gives off most of its structural water resulting in an increase of matrix density from as low as 1.8 g/cc to a range of 2.5 to 2.65 for Opal-Ct. At the same time, matrix porosity is reduced from about 60% to about 45%. This results in a net reduction of total rock volume (inclusive of pore space). This results in a net expulsion of large amounts of water. As these biogenic facies are nearly always encased in clastic-dominated clay-rich shale sequences, complete expulsion of the water with increasing depth of burial is not always accomplished. Thus, microscopic discontinuities in the seemingly "welded" Opal-Ct are held open or "wedged" by hydraulic pressure. Thus,

microfractures are created and preserved by the diagenetic phase transformation. Most Opal-Ct intervals tend to be overpressured, regardless of their structural setting. The trapped fluids have preserved the micro fractures and are the cause of the overpressure.

In cleaner Opal-Ct zones, the rock is more rigid than in the clayer intervals. Higher concentrations of clay cause the Opal-Ct facies to deform plastically when exposed to moderate tectonic stress. When exposed to severe tectonic stress, the clayey Opal-Ct will exhibit both micro and macro fracturing, but readily heals. Cleaner Opal-Ct will exhibit failure (fracturing) at lower stress. However, even fractures in the cleaner Opal-Ct facies will heal with time if hydraulic wedging is insufficient to hold the fractures open.

With the transition from Opal-Ct to quartz, there is a further decrease in rock volume due to a reduction in porosity from 45% to less than 30% and a simultaneous further increase in matrix density due to the final expulsion of any residual structural water. Again, the rock must expel water or sustain a further increase in internal pore pressure. The net effect is that much of the micro fracturing which originated with the first diagenic phase change and any subsequent stress induced micro fracturing can be further preserved by the hydraulic wedging. Most quartz phase biogenic shales in the subsurface are overpressured regardless of their relationship to structure.

A.II.1.3.2 MACRO FRACTURING

Most of the natural macro fracturing that is encountered in the diatomaceous shales is tectonically induced. Because most of the west side major structural features such as the Lost Hills anticline, Belridge, Pioneer, and others are young and growing structures, any structural cause of fracturing that is present can be thought of as an ongoing process. The same or similar structural mechanisms govern growth of most of the major structures paralleling the San Andreas Fault. This type of continued deformation implies that the structures are still growing and would favor the preservation of existing fractures and propagation of new ones.

A.II.1.4 PRODUCTIVE POTENTIAL OF BIOGENIC SILICEOUS SHALE RESERVOIRS

Wells drilled into a naturally fractured biogenic siliceous shale reservoir in the quartz phase should have about the same productive potential as such reservoirs as the ASZ (Antelope Shale Zone) at Buena Vista Hills. Wells drilled into biogenic siliceous shale reservoirs lacking an extensive natural macro fracture system will have about the same productive potential as the Cahn zone at southeast Lost Hills. Other fractured shale analogs also exist and are further discussed in this report. These pools, both in the San Joaquin Valley and on the coast, have produced very large quantities of hydrocarbons at very high rates.

A.II.1.4.1 FRACTURE STIMULATED PRODUCTION AT LOST HILLS

There is abundant production from diatomaceous rocks in the Lost Hills Field. In the absence of extensive natural macro fractures, the biogenic siliceous shale reservoirs may produce only a few barrels of oil and a few MCF of gas per day. However, massive (250,000 to 500,000 # frac sand) hydraulic fracture stimulation results in very high initial production rates and cumulative production ranging from 100,000 bbl to 400,000 bbls per well. Fracture stimulated production at Lost Hills has been obtained from wells completed in both the Opal-Ct and quartz phase facies. There are many high volume producing wells in the quartz-phase Cahn Zone in the Southeast Lost Hills pool.

Opal-A reservoirs in the Etchegoin and Reef Ridge are produced through fracture stimulation by several operators along the anticlinal axis a few miles south of the structural culmination. These reservoirs have moderate to high oil saturations. Naturally fractured "Cahn chert" has been produced for many years by Chevron through slotted liner completions in the central portion of the field. In 1913 Chevron drilled a well into a naturally fractured interval of the Cahn Zone. The well produced at least into the 1950's with a gas/oil ratio of about 1500 SCF/Bbl and a water cut which increased from 50% to about 90%. Between 1949 and 1952 an additional 26 wells were put on production.

The next significant drilling program occurred between 1977 and 1982 when the number of Cahn completions jumped from 36 to 259. This drilling boom was a result of what was considered a major new pool discovery, the southeast Lost Hills field extension. The production consists of light oil and significant gas from somewhat naturally fractured siliceous shales in Opal-Ct and quartz phase. Commercial production rates were achieved by large-scale hydraulic fracture stimulation. The best wells in this pool had IP's of as much as 600 barrels of 40-degree oil per day, with gas and water. The completions usually consist of a multi-stage frac over an interval of 500 to 1,000 feet. Each frac stage is about 200 feet. The most successful frac jobs put away over 250,000 pounds of frac sand. The pool has had a history typical of a naturally fractured reservoir with good matrix storage capability: the decline rates were very high initially, but soon flattened to production of around 200 BOPD for the best wells and 50-100 BOPD for lesser wells. After the initial decline, most of these wells exhibit a decline rate of less than about 5%. The deepest wells on the southeast plunge are on 10 acre spacings. Originally the reservoir was somewhat overpressured and the IP rates declined both with the decrease in reservoir pressure. Later wells which were drilled in marginal positions to the main pool showed lower IP's as well.

Chevron and Mobil, as well as other operators, are currently active in Lost Hills, at a time when they have severely curtailed their activities in most other fields in the San Joaquin Valley. They are clearly seeing a good return from investment in light-oil producing Opal-Ct and quartz-phase diatomaceous shales in central and southeast Lost Hills.

Commercial rates of production have been obtained from wells drilled to nearly 9,000 feet in the siliceous shales of the Southeast Lost Hills pool. These wells required massive hydraulic fracture stimulation to achieve good results. Most of these wells are located on the broad and less intensely deformed southwestern flank of the southeast plunge of the structure and do not appear to have naturally existing large scale natural fractures. The greater success rate of the wells in this area is due to the thicker net clean facies in the Cahn zone and the McDonald cherts.

The most successful frac completions tend to be in the cleanest portions of the Cahn Zone and McDonald cherts. Wells with thicker intervals of clean diatomite tend to produce at higher rates and have flatter declines. Several operators are evaluating plans to drill horizontal wells in the southeast portion of the field.

A.II.1.4.2 PRODUCTION ANALOGS IN OTHER FIELDS

During the early 1950's the Antelope Shale Zone Unit at Buena Vista Hills was developed on 40 acre spacing. These wells encountered 200 feet of naturally fractured siliceous shales at depths of 5,000 to 6,000 feet. During the flush production of the ASZU unit, these wells produced 200 bbls per day oil plus significant gas. During the flush production at Buena Vista Hills, there were no attempts at fracture stimulation.

A.II.1.5 HIGH WATER CUTS COMMON IN BIOGENIC SILICEOUS SHALE RESERVOIRS

The combination of the diagenetic processes and the high surface area to volume ratios associated with the matrix porosity in any of the three diagenetic phases results in high water cuts in most Monterey completions. Reservoirs having light oil and higher gas oil ratios may actually have gravity segregation as a function of pore geometry. Gas and lighter oils may have entered pore systems having pore throats too small to pass higher viscosity crudes. Many core descriptions refer to dark staining (suggesting heavier oil) near fracture planes but lighter oil and brighter fluorescence in the less fractured matrix. Thus, it is possible that the lighter ends have penetrated into the portion of the rock having the smaller pore throats. These micro porous systems have higher surface to volume ratios, and thus will have higher water saturation. When the reservoir pressure is lowered, the gas expands and displaces significant volumes of water from the micro pore system. It is not uncommon to have immediate 50% water cuts in intervals far from the oil water contact.

APPENDIX III

Database Preparation

A.III.1.0 DATABASE PREPARATION AND EDITING

The sequence of steps in the preparation of the database is critical to the timely and efficient analysis of the data. The following sections describe the sequence and methods employed in the preparation of the database.

A.III.1.1 DATA LOADING

All log data were digitized from paper prints for this project. They were loaded to the Petrolog program on the computer and made available for further processing. Header data off the logs were also loaded to Petrolog. Well information was entered to a spreadsheet for use by the geologists and log analysts on the project.

A.III.1.2 DEPTH SHIFTING

All depth shifting was performed interactively. Only the wells with core and porosity logs required depth shifting. In all cases, the shallow resistivity curve was taken to be tool zero. Porosity logs were shifted using standard methods. Core data were shifted by comparing the linear-interpolated core porosities to a preliminary computed log-derived porosity. After depth shifting, the core porosity can better be used to calibrate the analysis.

The question is sometimes asked why the core data are linear interpolated before depth shifting. When depth shifting, the analyst uses visual comparison to determine a target depth for a given part of an input curve, so a depth pair is generated. The depth shift algorithms used in most analysis programs are of the "rubber band" type; they use successive depth pairs to compute a positive or negative shift for each depth point and then move it to the nearest database increment (commonly one/half foot). Point data, such as input core data, are usually moved by these methods into the spaces between depth increments and are lost. A linear-interpolated set of core data solves this problem since data are not lost from a continuous curve.

A.III.1.3 ENVIRONMENTAL CORRECTIONS

Environmental corrections must be applied prior to the normalization step and must be considered for each curve. The chart-book corrections appropriate to the service company were made as required. Gamma ray, density, neutron, and induction curves were all corrected according to the chartbook algorithms included in the Petrolog program. The SP curves were baseline shifted to produce a curve called SBL.

A.III.1.4 NORMALIZATION

Normalization becomes an issue in petrophysical studies whenever more than one well is to be evaluated. The goal of a normalization procedure is to calibrate all the log responses to a single standard. An absolute standard such as a dolomite or massive salt is preferred, but in the absence of this a relative standard is chosen that is representative of what a majority of the logs already read; the database is therefore calibrated to itself. Variations in tool readings are the result of calibration error, differences between service companies, variations in tool design or (especially in the last ten years) differences in software processing applied to the raw tool data. Real spatial variations also exist, especially in complex geological environments, and the normalization process must take these into account and avoid editing them out of the dataset.

The dataset for this project was only partially normalized in terms of the procedures described below because the full-suite wells were scattered over several sections and the differences in diagenetic grade in the siliceous shales masked the effect of miscalibrated logs. In particular, the gamma ray curves showed such variation that it was unclear how to normalize them. They were not used in computation of clay volume. However, the theory and procedures of normalization are discussed here since this project will also be used as a guide to work elsewhere.

A.III.1.4.1 NORMALIZATION DEFINED

The term 'normalization' as found in the literature has several meanings in log analysis. In this report, 'normalization' is used in the context of a field study where a statistically valid number of wells in the study area are compared to identify those variations in log response that can be attributed to log calibration errors. The logs are corrected, or normalized, by applying the appropriate shift to each curve as calculated from the normalization process. If multiple logging runs are present, it is necessary to normalize each run, but a single normalization applies to an entire logging run regardless of how many zones are included. Analysis parameters that are determined from calibration to known data points, such as coreholes, can then be applied with confidence to the entire project. Therefore, areal variations in reservoir properties that are seen in the results can be attributed to real-world differences and not to spurious log errors.

To perform a valid normalization, the log data must first be verified, edited, depth shifted, and environmentally corrected. These tasks have been described elsewhere in this report. Geological correlation should also be done prior to normalization, so that the same stratigraphic interval can be selected in each well for comparison.

As in the Pioneer area, most field studies in California sand/shale sequences have no lithologies with a known and consistent log response (such as carbonates or salt), so all normalizations must be performed as relative shifts to a locally defined standard. A local standard is usually established by examining all the wells in the study and identifying the log response of a majority of the wells sampled. It is important to use a stratigraphic interval that includes both sands and shales so that both ends of the log response spectrum are represented.

The standard is not an absolute value, however, since log response is also influenced by geological variation and changes in fluid saturations within the reservoir and over time. A mapping approach to the normalization problem for the porosity logs is recommended and described in this report. DPI has performed statistical research as part of previous projects (not a part of the current project) to test the usefulness of various statistical techniques in evaluating the logs for normalization. DPI has also tested the effects of using various stratigraphic intervals and examining only selected lithologies within an interval. The recommended normalization procedures reflect the results of this research and also of the many field studies DPI has performed throughout the world. These procedures are discussed below under the sections for specific curves.

A.III.1.4.2 GR METHODOLOGY

Histograms of GR values were made over the selected stratigraphic interval and compared. A group of wells were chosen to be the standards whose histograms were very similar and the other wells were compared to these. For most wells logged by the same company, the range of gamma ray response was similar and the only normalization required was a simple shift of several units. Wells logged by different companies usually require larger shifts, and sometimes a range expansion. This does not mean that the logs are bad or wrong, only that the tool design is different. Normalization takes care of this difference in response between companies so that the same analysis parameters can be used throughout the study. Wells that require a range expansion can usually be normalized by applying an equation of the form $y=mx+b$ (straight line).

The gamma ray curve responds to changes in the amount of radioactive elements in the formation and borehole. The type of clays in the mud system and their inherent radioactivity varies from well to well. Variations in mud radioactivity will shift the histogram to the left or right when compared to other wells. Variations in the formation lithology will cause relative changes in the shapes of the histograms, with shaly intervals having more high gamma ray and sandy intervals having more low gamma ray. In most cases, it is not

necessary to account for possible geological variations that could affect the gamma ray response and the logs can be shifted to a median value. The normalized gamma ray can then be used to compute a clay volume to investigate the effects of clay on the responses of the porosity and induction curves.

A.III.1.4.3 POROSITY NORMALIZATION

Ideally, an interval barren of hydrocarbons should be used for porosity log normalization, since gas and light oil can severely affect the response of the density and neutron curves. If this is not possible, then the potential effects of hydrocarbons must be kept in mind when comparing logs from different parts of the structure and from different dates. The date is important since hydrocarbon composition and saturation change during reservoir depletion due to pressure changes, waterflooding, gas cap expansion, and other causes.

In many field studies, there is a dominant logging company. If this is the case, the standards should be chosen from this company's logs only, and one should expect to shift the logs from other companies to these standards. As for the gamma rays, differences between logging companies do not mean that one company is better than another, only that the tool calibration standards are not the same. The normalization and parameter selection procedure can and do compensate for any differences between logging company.

A.III.1.4.3.1 DENSITY METHODOLOGY

Histograms of the density curve were made over the selected interval and compared. Initially, the correct log response was unknown. Most wells had similar widths to their ranges, but the distributions were shifted laterally from one another. Some of these shifts were likely calibration errors, but most were variations in porosity. Therefore, the logs cannot simply be shifted laterally to match the standard since true geologic variations will therefore be shifted out. To address this problem, the data were mapped.

The simplest kind of map, one of the means of the distributions, is somewhat misleading, since the mean will be different in two wells that have the same log response if one has more sand than the other (Fig. A.III-1). A better method is for the analyst to identify the most common density curve pattern in the dataset, then compare the histograms to the type by hand and determine a shift from the standard, which is then mapped. This is done by overlaying all the histograms and finding a group whose members match. Histograms are judged to match if the leading and trailing edges have the same numeric values (the range is the same) and if the overall shape is similar. Changes in sand/shale ratio can affect the relative size of modes at the ends of the histogram, which can radically shift the mean value, but an experienced analyst can readily recognize a matching histogram from a shifted one.

Typically, a group of wells are identified whose histograms matched. These wells are used as the standards to which others were compared. A +/- shift was then determined for each well as compared to the standard. These shifts were then mapped to look for non-systematic variations over the area of interest.

If the reservoir had an initial gas cap, one would expect to see light density and low neutron values on top of the structure, grading down the flanks to heavier density and higher neutron. If reservoir fluids had changed through time, one would see trends based on drilling dates. There may be other trends related to geological variation and are supported by several wells. Such trends as these are not tool error and should be left alone. Instead, wells that stand out as anomalous within these trends should be inspected and shifted to fit the trend. Note that an effort to shift all the density logs to a common standard would erroneously eliminate these real porosity changes.

A.III.1.4.3.2 NEUTRON METHODOLOGY

As for the density and gamma ray, histograms of the neutron curve from each well were made over the selected interval and compared. Even more than the density curve, the neutron is heavily affected by hydrocarbons and by changes in sand/shale ratios, so a simple comparison of histograms and a linear shift to the standard will be invalid since real lateral changes in the reservoir will be eliminated. Again, as for the density, the neutron data must be mapped.

The simple map on the mean of the neutron histograms shows more information about geology than it does tool response. In fact, such a map typically shows a combination of areal geological changes (shaling trends) and increasing gas effects (lower neutron) in later wells.

A.III.1.4.4 INDUCTION METHODOLOGY

In field studies in clastic reservoirs, normalization of the induction logs is frequently ignored because there are seldom lithologies in clastic sequences with known absolute resistivity values (such as anhydrite, salt, or non-porous carbonates). However, some of the anomalous saturation data obtained from analysis of certain field wells may be due to induction log calibration problems. Therefore, DPI recommends that the deep induction curves be included for normalization. Since the curves are originally recorded in conductivity, all induction curves were converted back to conductivity for normalization.

For perspective, the standard tool error for an induction log is +/- 5 mmhos. At 10 ohmm, this equals +/- 0.5 ohm, which in a sand with 18% - 20% porosity can equal approximately +/- 1.5% in saturation units. If the log has an error of as much as 25 mmhos, the equivalent saturation error will be approximately +/- 5% in saturation units. At higher resistivities, the effects of these errors is magnified. For example, in a 100 ohm sand, a

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log with a +25 mmho error would only read 28.6 ohms.

The deep induction curves within the hydrocarbon-bearing zone are far too much affected by the oil to perform any meaningful normalization, so it is especially important to select a barren interval. Ideally, a shale section should be chosen, since the errors in conductivity range will be most obvious in low resistivity intervals and any hydrocarbons present will have minimal effect.

APPENDIX IV

Parameter Selection

A.IV.1.0 PARAMETER SELECTION

Discussed in this section are the detailed procedures involved in parameter selection for the Pioneer Anticline project.

A.IV.1.1 CALCULATION OF VCLAY

Gamma ray, SP, and neutron-density crossplot are usually the best available clay indicators in a typical shaly-sand sequence. However, all of these measurements include contributions from both clays and from other reservoir conditions whose effects are difficult or impossible to quantify. Also, a large number of the wells in this project had only E-logs and therefore only SP and resistivity curves available.

The gamma ray curves showed a huge variation in range both vertically within wells and between wells, and this is attributed more to changes in radioactive mineral content than to lithology changes. The gamma ray could be used for clay volume calculation in most wells, but many zones would have to be established by the analyst based on arbitrary decisions about changes in the gamma ray response. Since these curves were variable and were not available on the E-log only wells, the clay volume in all wells was computed with the baseline-shifted SP curve.

The SP deflection is a function of clay content, clay type, and the difference in ionic potential between the mud and the formation fluids. The presence of hydrocarbons can suppress the SP deflection. R_w is suspected to vary unpredictably in this field. Apparent variations in clay content based on the SP using traditional analysis techniques are therefore partially due to changes in other factors. In this study, the effects of these other factors is minimized by the analytical approach.

First, the analyst carefully baseline-shifted the SP using geological knowledge and the resistivity curve to aid in interpreting lithologies. Then, the curve responses of all SP's in the study were normalized by range expansion or contraction to a common deflection magnitude. However, the variations in SP deflection from R_w changes and other non-clay effects are still present in the curve. DPI has introduced the concept of the clean SP baseline, analogous to the shale baseline. The analyst carefully creates a curve that joins SP peaks he/she believes to be clean, and the values of this curve are used

instead of a constant in the non-linear SP equation. To some extent the analyst is interpreting when setting the SP baseline, and it must be emphasized that the SP-clean curve is also an interpretation: the geologist/analyst is making a quantitative interpretation of clay volume based on his/her best assessment of the lithology of the rocks as shown by the logs and by local knowledge.

In some wells, the SP was a bad curve, and the resultant clay volume was not valid. For these wells, clay volume was computed from the shallow-reading resistivity curve.

A non-linear transform was used to compute the clay volume from both the SP and resistivity wherever they were used. This kind of transform takes into account the fact that the diagenetic clays in the sands are of a different type and character from the detrital clays in the adjacent shales. The generic transform takes the shape shown in Fig. A.IV-1; the specific shape is dependent on the parameters selected for local conditions.

A.IV.1.2 CALCULATION OF POROSITY

Standard crossplot techniques were used to compute porosity from the density-neutron logs for all full-suite wells. However, a curve was used for the matrix density value instead of a constant to account for the radical changes in rock density that occur in diatomaceous sequences.

Whole core porosity data from the Cymric wells and from the Tenneco 62X-30 well within the study area were used to calibrate the porosity model. Assuming that the porosities from Dean-Stark analysis represent total porosity, the data were used to set up this part of the crossplot porosity model.

For the E-log only wells, an empirical model of porosity was developed based on these full-suite wells. It was noted that the porosity in the siliceous shales decreased with depth in a predictable way, as would be expected from what is known about phase changes and compaction in these rocks. Therefore, an empirical function relating porosity to depth was developed and applied to the E-log only wells. Since a clay volume had been computed for each one, it was possible to derive an effective porosity from the computed total porosity.

A.IV.1.3 CALCULATION OF WATER SATURATION

No information was available from the field for electrical properties (Archie 'm' and 'n'). The actual values used were determined by sensitivity analysis. Both parameters varied as a function of lithology, and were lower in clean rocks than in shales. However, the apparent changes in water resistivity throughout the study area could not be quantified and caused the water saturation calculations to be doubtful in many wells. For the E-log only

wells, saturation could not be computed at all due to the lack of a suitable resistivity curve.

Little water resistivity data are available for the study area. Chemical analyses indicate somewhat variable but moderate resistivities. The R_w value used in the study was consistent with a water of about 25,000 ppm, typical for the upper Miocene in California, but in many wells the resultant water saturation is very low. Without further information about the reservoir fluids, the analysts hesitated to increase R_w until a saturation value that was deemed more reasonable was computed, since DPI does not recommend that the analyst make arbitrary decisions about parameters without field data or sound geological reasoning to support them. Therefore, the saturation data as calculated are left in the database for a later researcher to improve upon.

TABLE 1
San Joaquin Valley Stratigraphy
Official U.S.G.S. Stratigraphic Nomenclature

FORMATION Proper Name	PIONEER ANTICLINE Local Name (if different)	THICKNESS
Pleistocene/Pliocene		
Tulare Formation		600-2200
Pliocene		
San Joaquin Formation		1200-2100
Etchegoin Formation		1700-3500
Carman Sandstone Member	Los Lobos Sands, Gusher, Calitroleum	900-2000
Tupman Shale Member		750-2000
Middle and Late Miocene		
Reef Ridge Shale		200-1150
Monterey Shale		2100-4100
Antelope Shale Member (informal)		1800-3300
McDonald Shale (informal)		80-600
Gould and Devilwater Shale Members	Hazleton Shale?	100-655
Oligocene and early Miocene		
Temblor Formation		2900-4100
Media Shale Member	Pioneer Sands	150-560
Carneros Sandstone Member		0-950
Santos Shale Member		1340-3090
Wygol Sandstone Member		450
Cymric Shale Member		300
Oligocene		
Wagonwheel Formation		250-700
Eocene		
Kreyenhagen Formation		2300-2900+
Welcome Shale Member		900-1950+
Point of Rocks Sandstone Member		400-2000+
Gredal Shale Member		Not penetrated at Elk Hills

Table after Maher, Carter, and Lantz(1975) in their U.S.G.S. Professional
 Paper on Elk Hills: formation thicknesses are for Elk Hills and vicinity

TABLE 2
SUMMARY OF HYDROCARBON SHOWS
T11N/R23W SBBM

WELL	SECTION	CORE	SWS	MUDLOG	TEST
JERGENS 5	4				X
STEVENSON 1	6	6427-33, 7452-68			
MC FARLAND 1	7		X		
RAS 523	10		X		X PROD
353X	11	X	X		
LEUTHOLTZ 45-14	14	X6521-40,6873-91,7024-39	6635		
W. MINERALS 10	16	X	X		
HAVENSTRITE 1	17		X		
HAVENSTRITE 7	17	NO HISTORY			
MARICOPA 1	18	NO HISTORY			
G.P. 54X-20	20		X		
G.P. 52X-20	20		X	X	
G.P. 41X-20	20		X		
VISALIA MARICOPA 1	20	X			
WOODWARP 4	21	x 1952-62			
SANTIAGO CREEK C7	21	?			
WOODWARD 35	22				X
ARCO USL 1	22	NO HISTORY			
W. MINERALS 4	22	?			
W. MINERALS 6	22	?			
W. MINERALS 8	22	BLEW OUT @ 1737 ft. OIL & GAS			
RIPLEY 1	25	X 541-44			
RIPLEY TRUST 3	25		X491-3003		
RIPLEY 41	25	X 2840-50			
RIPLEY 44	25		?		
SANTIAGO 1	25		?		/
W. MINERALS 37	25	X			
W. MINERALS 8	25				X265-
1 MW 1	23	X 1140-1075			
1 MW 2	23		X		
SHELL USL 1	23	X828-1082			
WEST MINERALS 12	26			X	
WEST MINERALS 11	35			X243-318	
SW 31-12	35	X 2327			
1MW-27	23	X 1346-1446			

TABLE 3
CURVE LEXICON FOR LOG DATABASE

CURVE	DESCRIPTION
AM10	10" short normal
AM16	16" short normal
AO10	10' lateral
AO19	19' lateral
AZIM	Azimuth from deviation survey
BVES	Bulk volume water effective from E-log only model
BVTS	Bulk volume water total from E-log only model
BVWE	Bulk volume water effective from full-suite model
BWWT	Bulk volume water total from full-suite model
C1R	C1 gas curve from mud log
C2R	C2 gas curve from mudlog
C3R	C3 gas curve from mudlog
C4R	C4 gas curve from mudlog
CALS	Depth shifted caliper
DEVI	Hole deviation from survey
DISC	Discriminator, for bad hole
DRHS	Depth shifted delta-rho
DTS	Depth shifted sonic
EAST	Easting from directional survey
F	Formation factor
GRC	Corrected Gamma-Ray
GRDL	Gamma ray from DIL
GRS	Depth shifted GR
GRSS	Depth shifted GR from sonic
ILD	Deep induction
ILDC	Corrected deep induction
ILM	Medium induction
ILMC	Corrected medium induction
KSCI	Sidewall permeability
KWCI	Whole core permeability input
KWCL	Linear interpolated core permeability
KWCS	Depth shifted core permeability
LL8C	Laterolog-8
LL8U	Unaveraged laterolog-8
LTHE	Lithology flag for e-log only model
LTHF	Lithology flag for full-suite model
MCRV	Porosity exponent for Etchegoin
MM	Porosity exponent for Miocene
NORT	Northing from directional survey
NPHC	Corrected neutron porosity
NPHS	Shifted neutron porosity
OFFS	Total offset from directional survey
OSCI	Sidewall oil saturation
OWCI	Whole core oil saturation input
OWCL	Linear interpolated core oil
OWCS	Depth shifted core oil

TABLE 3
CURVE LEXICON FOR LOG DATABASE

CURVE	DESCRIPTION
PHES	Effective porosity from E-log only model
PHFG	Flag curve for porosity model
PHIE	Effective porosity from full-suite model
PHIT	Total porosity from full suite model
PHMX	Matrix density for E-log only model
PHTS	Total porosity from E-log only model
PHZC	Depth function total porosity
PSCI	Sidewall core porosity
PWCI	Whole core porosity
PWCL	Linear interpolated core porosity
PWCS	Depth shifted core porosity
RD	Deep resistivity
RHOH	Hydrocarbon density
RM	Medium resistivity
RMAT	Matrix density for full-suite model
RO	Resistivity of rock at 100% water saturation
ROBC	Corrected bulk density
ROBS	Depth shifted bulk density
ROMX	Matrix density
ROS	Ro from E-log only model
RS	Shallow resistivity
SBL	Baseline shifted SP
SCLN	Clean SP line
SFLU	Unaveraged shallow focused log
SP	Spontaneous potential
SPN	Normalized baseline shifted SP
STUS	Unlimited total water saturation, E-log only model
SWE	Effective water saturation, full-suite model
SWES	Effective water saturation, E-log only model
SWT	Total water saturation, full-suite model
SWTS	Total water saturation, E-log only model
SWTU	Unlimited total water saturation, full-suite model
SXOE	Effective water saturation of the flushed zone, full-suite model
SXTU	Unlimited total water saturation, flushed zone, full-suite model
TVD	True vertical depth, deviation survey
VCDS	Dry clay volume, E-log only model
VCLD	Dry clay volume, full-suite model
VCLW	Wet clay volume, full-suite model
VCLY	Final clay volume from SP, E-log only model
VCWS	Wet clay volume, E-log only model
VSHL	Shale volume, full-suite model
VSHS	Shale volume, E-log only model
WSCl	Sidewall water saturation input
WWCI	Whole core water saturation input
WWCL	Linear interpolated core water saturation
WWCS	Depth shifted core water saturation

APPENDIX V

FIGURES

FIG. A.II-1. SEM Photograph of Opal-A.

FIG. A.II-2. SEM Photograph of Opal-CT.

Sand/Shale Ratio Histogram Example

Non-Linear Clay Transform Example

FIG. A.IV-1

KCL 44375

LITHOLOGIES

Clayston

Water

Shales

Sand Stone

Hydrocarbon

Diatomaceous

VCLDDW	SP	SFLU	DEPTH FT	SWT DW	PHITDW
0	-80 NU 20	0 OHMM 20	1:1200	0	.50 0
VCLUDW	SGR	ILD		SWE DW	PHIEDW
0	0 GAPI 150	0 OHMM 20		1	.50 0
USHLDW		ILM			
0		0 OHMM 20			
PHIEDW					
1					
BWEDW					
1					
TIME					
0					

FIG.
1A

2800

3000

3200

VCLDDW		SP		SFLU	
0	1	-80	MU 20	0	OHMM 20
0	1		SGR	0	ILO
0	1	0	GAPI 150	0	OHMM 20
0	1			0	ILM
0	1			0	OHMM 20
1	0				
1	0				
0	1				

SWT DW		PHITDW	
1	0	.50	0
1	0	.50	0