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Title: **The Carpenteria Reservoir Redevelopment Project**

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The Carpenteria Reservoir Redevelopment Project

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The objective of this project was to develop a simulation-based reservoir management system that could be used to guide the redevelopment of the Carpenteria Offshore Field, which is located just seven miles from Santa Barbara. The system supports geostatistical and geological modeling and reversoir forecasting. Moreover, it is also a shared resource between the field operator, Pacific Operators Offshore, and the mineral owners, the U.S. Depatment of the Interior and the State of California.

1. Background and Research Objectives

The Laboratory's participation was focused on two main goals. The first goal was the development of a simulation-based reservoir management system to facilitate the design and drilling of new extended-reach wells for production from and injection into the State and Federal portions of the field. This management system was intended to help the operator maximize the recovery of the remaining hydrocarbons in individual zones and subzones while minimizing the deleterious effects of the wet sands. The system itself was

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constructed from commercial components available from the oil service sector and delivered by and supported through the national information infrastructure; the methodologies which supported its use were placed in the public domain and documented in the form of web-based tutorials. The Laboratory role was to facilitate the integration of the components of the system with emphasis on web-based access, and to provide "expert" user support to the other members of the project.

The second goal was the development of *distributed* data stores and application interfaces that are compliant with the standards promulgated by the Petrotechnical Open Software Corporation (POSC).

2. Importance to LANL's Science and Technology Base and National R&D Needs

Participation in this project enhanced LANL's strengths in two core competencies: theory, modeling and high performance computing and earth and environmental systems. The effort to integrate stochastic simulation into the fabric of subsurface characterization benefits both the petroleum and environmental components of the latter core competency. The methodologies implemented for this project improved our ability to represent subsurface geology in flow simulation models. The work directed toward the the use of the world wide web to implement a wide area network to support both high performance graphics and computationally-intensive flow simulations benefits the high performance computing tactical goal of the Laboratory. The implementation of distributed databases that conform to the standards promulgated by the Petrotechnical Open Software Corporation has direct future application to the environmental stewardship mission of the Laboratory.

3. Scientific Approach and Accomplishments

The technical approach for this project is outlined in Figure 1. The US Department of the Interior had requested that the operator of the field, POOI, indicate whether it intended to redevelop the field by the end of calendar 1996. At a minimum, the simulation-based system developed in this project was to be used to estimate the probable fluids-in-place to support that decision. This goal was achieved and the operator has indicated that it intends to redevelop the field. Two other important goals were also reached as discussed below.

Full Field Geological Model

A complete geological model of the Carpenteria Field was developed (Figure 2). This model reflects the input from over 175 wells. It consists of over ten million cells representing 57 distinct lithological units. It includes 10 significant faults. The governmental royalty owners (MMS, CSLC) were initially responsible for development of well databases, initial well correlation, and structural mapping. Databases were maintained in commercially available software packages (e.g., Paradox®) and map gridding and contouring of horizon tops was performed using Z-Map®. Three-dimensional visualization of the complexly deformed Hobson fault plane and the multiple structural horizons was accomplished under the guidance of Los Alamos National Laboratory (LANL) using the three-dimensional stratigraphic geocellular modeling software StrataModel® (Landmark) running on SGI (Silicon Graphics) computers. StrataModel permits the computerized display of any gridded three-dimensional data as a colored surface that can be zoomed, scaled, and dynamically viewed from any direction. This sophisticated display capability has many uses including quality control of contoured data (by easy recognition of interference between surfaces), visualization of intersection of surfaces, recognition of thickness changes between multiple surfaces, and visualization of the relationship between fault planes, stratigraphic surfaces, and deviated well traces, among others. To utilize this capability, SGI systems running StrataModel have been installed at MMS in Camarillo, California, and at POOI's offices in Santa Barbara and Ventura, California, in addition to those at LANL.

With the completion of the initial structural mapping, it became necessary to address the question of the numerous small scale faults mapped by prior workers. The firm of R. G. Heck and Associates was engaged by POOI for these studies. Using special log trace files calculated by Coombs and Associates to true stratigraphic thickness, they were able to correlate wells absent the distorting effects of both well deviation and structural dip. The TST traces were displayed in AutoCad-LT™ using simple script files generated in the spreadsheet program Excel®. Panels were prepared showing as many as twenty correlation logs at one time. These panels could be printed, or they could be displayed on a computer monitor where it was possible to alter the scale, position or color of any trace so that highly detailed comparisons between traces could be made. This technique permitted extremely close correlations that clearly revealed small intervals of deletion or repetition of section indicative of faulting. For the first time the operators had a fault interpretation that was based on actual well data. The result was the recognition of a relatively few faults that

subsequently proved to be largely consistent with structural contouring anomalies and with saturation data from well logs.

In addition to digital log traces, Coombs and Associates prepared an extensive suite of log attributes for each of the more than two hundred wells in the field using LogCalc® by Scientific Software Intercomp running on a DEC MicroVAX computer. These attributes included porosity, permeability, bulk shale volume, water saturation, among others, on a per foot basis. These values were then summed or averaged by zone for each well to produce files of net and effective porosity and permeability, true thickness, bulk shale volume, water and oil saturation, hydrocarbon pore volume, etc. In order to quality check these calculations, and to get a feel for their geologic significance, contour maps of each attribute were prepared for each zone using Golden Software's Surfer® program. Several hundred individual maps were prepared and examined. Lithologically associated attributes, such as porosity, true thickness, and shale volume, indicated that the paleoenvironment of the Carpinteria Field consisted of the toe of a south facing paleoslope during deposition of the lowest units, followed by a slope environment characterized by more channelized sedimentation. The attributes calculated by Coombs are now being used as inputs to StrataModel's geocellular modeling feature from which, with LANL's assistance, reservoir and fluid volumes of the original reservoir were calculated.

Reservoir Simulation Model

A reservoir simulation model of the field was constructed. This model was based on the geological model described above. The simulation team is in the process of validating this model against existing field production data.

The Laboratory acted as the facilitator for the activities described above. Specific tasks that the Laboratory supported were:

- scoping of the statistical coherency of the data that supports the geological model,
- implementation of a shared computing environment between the project's participants, and
- development of a simulation-based reservoir management tool.

Publications

1. Kendall, R., and E. Whitney, R. Webster, A. Sgro, J. Kindel, "*Advanced Reservoir Management for Independent Oil & Gas Producers*," SPEJ, submitted (LAUR-96-2195).

2. Kendall, R., and E. Whitney, R. Webster, A. Sgro, J. Kindel, "*Improved Oil Recovery for Independent Oil & Gas Producers*," SPEJ, submitted (LAUR-96-335).

3. Kendall, R., E. Whitney, R. Paul, S. Coombs, M. Voskanian, I. Ershaghi, "*A Simulation-Based Reservoir Management Program*," SPEJ, submitted (LAUR-96-594).

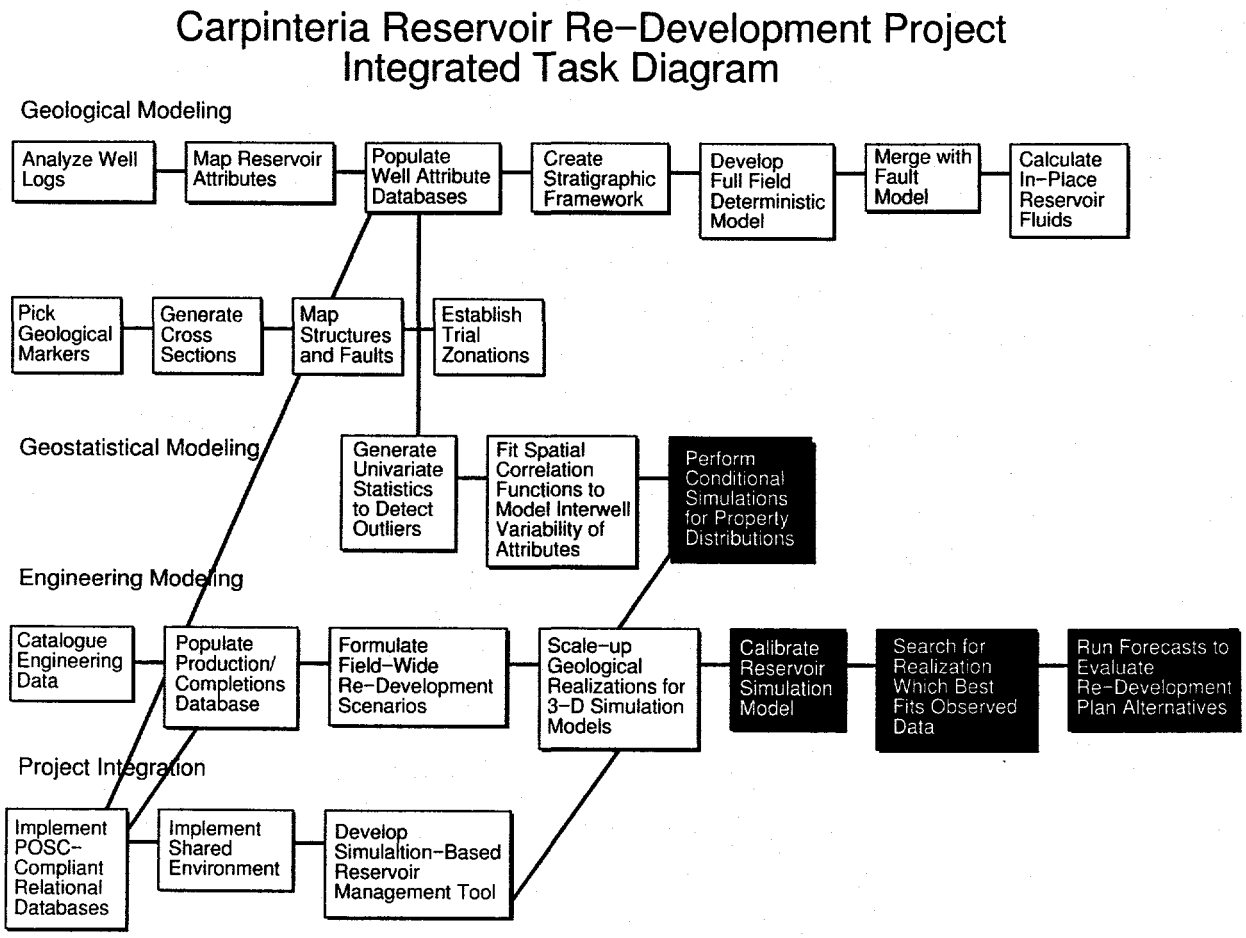

Figure 1. Completed project tasks for the Carpinteria Reservoir Redevelopment Project.

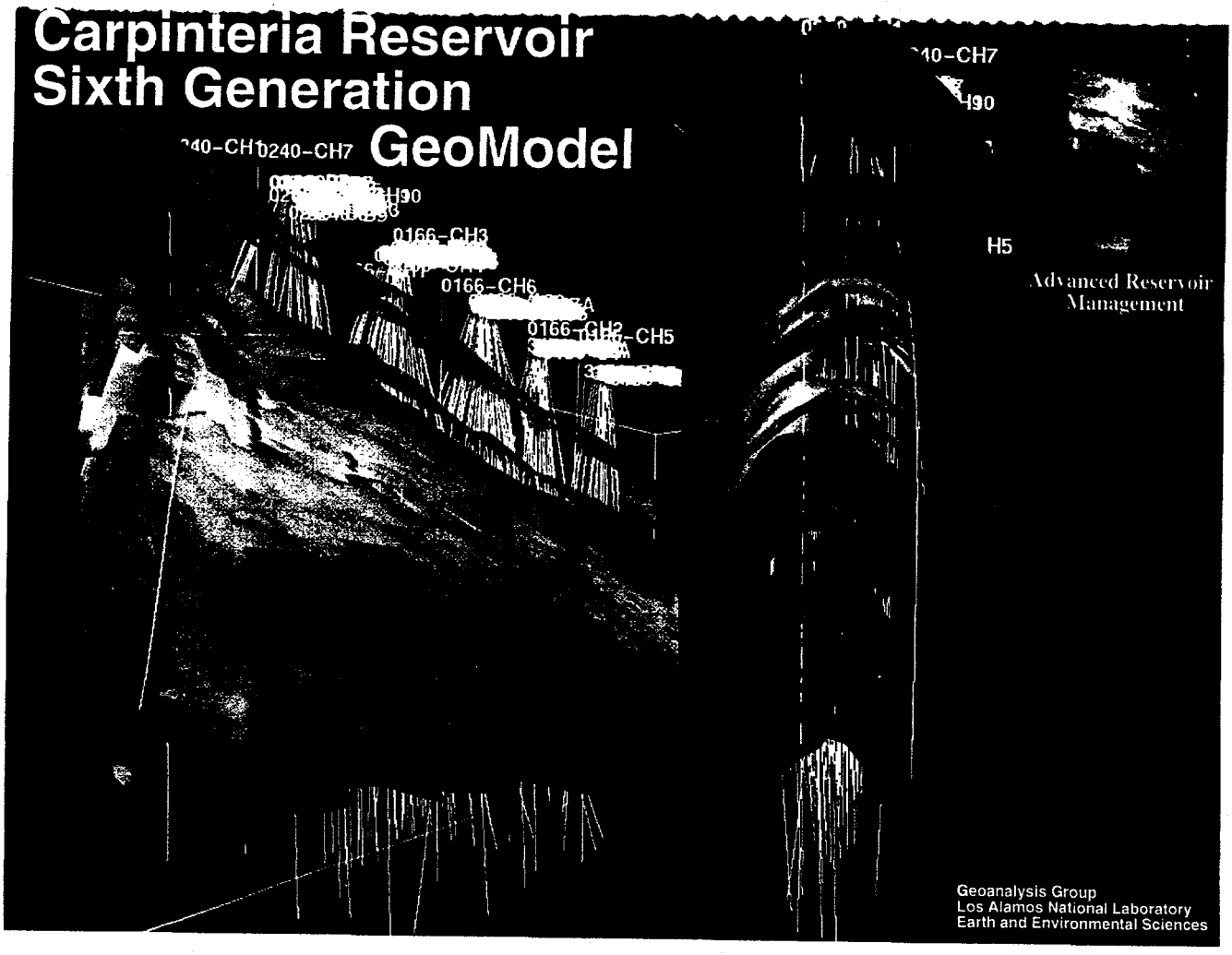

Figure 2. Major horizons of the Carpinteria offshore field as displayed by Stratamodel.