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**ESTABLISHMENT OF AN OIL AND GAS DATABASE FOR INCREASED
RECOVERY AND CHARACTERIZATION OF OIL AND GAS CARBONATE
RESERVOIR HETEROGENEITY**

Contract No. DE-FG22-89BC14425

**Geological Survey of Alabama
Tuscaloosa, Alabama**

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Objective

The objective of this project is to augment the National Reservoir Database (TORIS database), to increase our understanding of geologic heterogeneities that affect the recoveries of oil and gas from carbonate reservoirs in the State of Alabama, and to identify resources that are producible at moderate cost. This objective will be achieved through detailed geological, geostatistical, and engineering characterization of typical Jurassic Smackover Formation hydrocarbon reservoirs in selected productive fields in the State of Alabama. The results of these studies will be used to develop and test mathematical models for prediction of the effects of reservoir heterogeneities in hydrocarbon production.

Summary of Progress

Work to date has focused on completion of Subtasks 1, 2, and 3 of this project as stated in Annex 1 to the Memorandum of Understanding between the United States Department of Energy (DOE) and the State of Alabama, through the Geological Survey of Alabama (GSA) and attachments to said Annex. Work on Subtask 4 began in this quarter, and substantial additional work has been accomplished on Subtask 2.

Subtask 1

Subtask 1 has been completed and a topical report detailing this subtask has been submitted to DOE. Subtask 1 included the survey and tabulation of available reservoir engineering and geological data relevant to the Smackover reservoir in southwestern Alabama. These data were submitted to DOE via magnetic computer tape in a format compatible with the national reservoir database (TORIS database). Data are being added and/or updated into the database periodically and this will continue throughout the project.

Subtask 2

Subtask 2 comprises the geologic and engineering characterization of Smackover reservoir lithofacies. This has been accomplished through detailed examination and analysis of geophysical well logs, core material, well cuttings, and well-test data from wells penetrating Smackover reservoirs in southwestern Alabama. From these data, parameters relating to reservoir heterogeneity, such as lateral and vertical changes in lithology, porosity, permeability, and diagenetic overprint, have been recognized and used to produce maps, cross sections, graphs, and other graphic representations to aid in interpretation of the geologic parameters that affect these reservoirs. Geological and engineering research pursuant to this subtask has focused on descriptions of core material and petrographic thin sections, and computer entry of pertinent data (including available core analyses), as well as digitization of geophysical well logs. The ultimate goal of this research is a comprehensive characterization of all Smackover fields in the state.

Cores from four Smackover fields (Uriah, Silas, Blacksher, and Zion Chapel fields) have been described this quarter (cores from 23 fields have been described since the start of the project) and graphic summaries of the core descriptions have been integrated with other data to generate reservoir characterizations for these fields. Depositional and diagenetic sequences have been interpreted and summarized for each core. Petrographic thin-section studies have been made on 10 of the 23 fields described, in order to supplement and extend interpretations made from core descriptions. Three hundred fifty-two thin sections have been described (53 this quarter), 299 have been made but not yet described, and 66 have been selected but not yet made. This is a total of 717 thin sections. A comprehensive record, in the form of an annotated file of 35-mm color slides, is being compiled from all thin sections examined. Paragenetic sequences have been reconstructed for most of the 23 fields described. Eighty-nine thin sections have been point counted (63 this quarter) in order to estimate the relative proportions of particle and pore types making up the reservoirs.

Capillary pressure data are being collected on samples taken from selected cores from Smackover fields. These data will supplement the petrographic and geophysical data. To date, 47 capillary pressure analyses have been run on samples from four fields, and 106 other samples have been prepared for analysis. Preliminary capillary-pressure analyses of Smackover reservoir rocks suggest, as expected, that lithologically similar samples yield similar capillary-pressure curves. Samples from North Choctaw Ridge field and Silas field, predominantly oomoldic and pelmoldic dolostone reservoirs with substantial amounts of relict primary interparticle porosity, exhibit leptokurtic unimodal throat-size distributions. This means that nearly all pores are accessed through throats of a very restricted size range. These pore throats appear to result from a combination of (1) incomplete cement coatings on the ooids (now moldic porosity), (2) open primary pores that originally formed a highly permeable network, and (3) interconnection of neighboring particle molds resulting from partial crushing of the rigid cement framework. Further details on the origin and distribution of the all-important pore throats connecting the large moldic pores will be investigated by fluorescence microscopy.

Point counting of more than 80 thin sections from 10 Smackover fields, as well as examination of cores and thin sections from a total of 23 Smackover fields, has revealed that Smackover pore systems in Alabama are dominated by only a few pore types. Particle moldic pores (primarily oomolds and pelmolds), including secondary intraparticle pores (partial molds), and intercrystalline pores in dolostones, account for 85 percent of all porosity in Smackover carbonate reservoirs examined to date in Alabama. Interparticle pores, fractures, vugs, and fenestral pores are locally common, but only interparticle and fracture pores materially enhance reservoir permeability. Particle molds dominate reservoirs that are not fully dolomitized or in which dolomitization was fabric selective. More highly altered reservoirs strongly affected by nonselective dolomitization are dominated by intercrystalline pores. Although these two "end-member" reservoir types can be defined, intermediates are common, and most intermediate reservoirs more closely resemble intercrystalline reservoirs. The pore systems of intermediate reservoirs consist of "isolated" moldic pores, or clusters of secondary intraparticle pores within former particles, connected by networks of intercrystalline pores that lie between dolomite crystals in dolomitized calcium-carbonate cements. Consequently, the intercrystalline pore systems are the conduits through which the hydrocarbons in the isolated molds must drain. Because the characteristics of a conduit control the rate at which a storage space can fill or empty, these intermediate reservoirs tend to behave like intercrystalline reservoirs.

Subtask 3

Subtask 3 includes the geologic modeling of reservoir heterogeneities for Smackover reservoirs. This research was completed before this quarter began.

Subtask 3 also requires that GSA host an annual public conference targeted at Alabama oil and gas operators for the purpose of transferring data and results of the project. The first of these conferences was held September 18-19, 1990, at the University of Alabama in Tuscaloosa, Alabama. The second technology transfer conference is planned for sometime in the coming year (precise date and location not yet decided).

Detailed topical reports of the results of Subtasks 1, 2, and 3 have been completed.

Subtask 4

Subtask 4 includes the development of reservoir exploitation methodologies for strategic infill drilling, based on the results of subtasks 2 and 3, for typical Smackover reservoirs. These strategies are to be verified by geostatistical modeling. The Smackover field to be examined as part of Subtask 4 is Churchula field. The three components of this study are (1) geological and petrophysical reservoir characterization of the Churchula reservoir, (2) geologic flow modeling, and (3) geostatistical modeling of Churchula field.

Geological and Petrophysical Reservoir Characterization

In order to elucidate the spatial variation of, and controls on, reservoir characteristics within Churchula field, 12 general maps and 14 cross sections have been constructed for Churchula field. These maps provide information on the 3-D configuration of the Smackover reservoir, general variation in porosity and permeability within the field, and factors (depositional and structural) that control reservoir quality and distribution.

The cross sections were hung on a stratigraphic datum (top of Buckner Anhydrite Member). For each well on the cross sections, Smackover lithologies (dolomite vs. limestone), distribution of reservoir within the Smackover, and porosity and permeability values are indicated. These cross sections suggest that Churchula field may contain a highly compartmentalized reservoir and that the porosity lenses in the reservoir have irregular shapes.

In addition to the cross sections, a series of "slice maps" were prepared to depict variation in porosity and permeability within the field. These maps are isopach maps of the 5-foot average porosity and permeability at selected structural and stratigraphic horizons within the field. A series of 13 maps were generated for porosity and for permeability on both structural and stratigraphic datums. These maps indicate that the Churchula reservoir is very complex.

We have made a tentative interpretation of the distribution of reservoir-grade rock within Churchula field. We have developed an initial model that defines individual reservoir compartments. Efforts during the remainder of the project will concentrate on testing and refining this model. The reservoir-distribution model will be tested against more detailed lithologic data now being collected from Churchula field as described below. The model will be revised as needed to incorporate the new lithologic data. In addition, interpretations that are now being made of drainage areas for individual wells and of interconnectedness of well pairs will be compared with the model and necessary modifications made. The ultimate goal will be to accurately define the 3-D geometry and other characteristics of the reservoir that makes up Churchula field and to identify the geologic factors that control this geometry.

Four Churchula cores were described in detail this quarter and three detailed core logs have been produced. One hundred fourteen thin sections have been made.

Three of the four Churchula cores described contain the upper part of the Norphlet Formation. High- and low-angle cross-laminae interpreted to be eolian dune and interdune deposits and structureless sandstone suggesting partial marine reworking occur at the top of the Norphlet in these cores. This indicates that transgressing Smackover seas only partially reworked Norphlet dunes. The resulting uneven topography may have influenced the distribution of Smackover depositional facies.

The lowest Smackover facies is an algal boundstone. This facies varies in thickness from 2 feet in the north central part of the field to 20 feet in the southernmost part of the field. Intertidal flat laminated algal boundstone with a predominantly muddy matrix grades upward into mottled algal boundstone with a peloid oncoid packstone-grainstone matrix in the southern part of the field. In the northern part of the field thin algal boundstone is overlain by lower energy peloid oncoid wackestone, probably deposited in deeper water than equivalent rocks to the south. In the central part of the field, the algal boundstone is overlain by shoal to shoal-margin deposits. These dramatic facies variations indicate (1) significant topographic variation in early Smackover time, possibly influenced by Norphlet dune-interdune paleotopography, and (2) that the Churchula reservoir is heterogeneous both vertically and laterally.

Smackover rocks in Churchula field show an overall stratigraphic progression (although there is considerable geographic variation) from predominantly grainy strata to muddy strata in the middle Smackover and back to grainier strata in the upper Smackover, forming a transgressive-regressive cycle. Even though all of the lower Smackover and most of the upper Smackover was thoroughly dolomitized, the best porosity commonly occurs in grain-supported strata. The most common pore types are particle-moldic and intercrystalline, with less secondary intraparticle and

minor vuggy porosity. Dolomite in reservoir lithofacies is predominantly medium to coarsely crystalline. Where a significant amount of calcium carbonate occurs, porosity is commonly poor.

Geologic Flow Modeling

The purpose of this project is to evaluate the effects of reservoir heterogeneity and reservoir continuity on the production performance of Churchula field. Engineering analysis forms a part of the overall study of Churchula field aimed at developing a program for enhanced recovery by means of strategic infill drilling and injection. To accomplish the immediate goal of evaluating the effects of reservoir heterogeneity and reservoir continuity on production performance of Churchula field, a program of data acquisition and reservoir-engineering analysis was undertaken. These data will be used as input to a suite of reservoir-engineering analyses. The primary method of reservoir-engineering analysis will be the application of a black-oil simulator. Initial qualitative analysis of the data indicates that the reservoir is heterogeneous but appears to be continuous throughout the field with at least one exception. Simulation studies will begin during the next quarter and more definitive information on reservoir dynamics should be available.

Fluid composition in Churchula field is complex, including gas, condensate, and oil. For long-term management, a compositional simulator would be favored over a black-oil simulator. However, evaluation of the long-term behavior of the reservoir is not a primary goal of this study. Rather, an analysis of the continuity and heterogeneity of the reservoir is the objective. The black-oil simulator can be used with sufficient accuracy to achieve this objective. This is because the reservoir-fluid pressure does not drop below the dew-point pressure and therefore the reservoir behaves as a single-phase system. As long as the reservoir fluid is single phase, a black-oil simulator can be adjusted to provide comparable results to those that could be derived from the more complex and computationally more intensive compositional simulation.

Geostatistical Modeling

During this quarter the geostatistics group refined and continued development of the hierarchical simulation algorithm, described in the last quarterly report. Further two-well tests of this algorithm have been run on the Cray computer. In addition, parametrization of spatial correlation of permeability values in Churchula field was completed.

Significant progress has been made in the development of the hierarchical fractal simulation program. The motivation of this approach is that a hierarchical approach requires significantly less computer time and memory than alternate methods, and therefore permits the simulation of larger systems. Our recent simulations contain 64×66 (4,224) cells and are larger than would be possible using conventional methods (or at least represent the upper limit of such methods). The present version of our simulation algorithm has the virtue of reproducing the input well data exactly, while estimating values for the vertical two-dimensional panel between the two wells. The present limitation on the size of the model system is set by the amount of memory available on the computer. In January there will be a more than twofold upgrade of the Cray, which will permit simulation of a system roughly four times larger ($128 \times 128 = 16,384$ cells); this will be undeniably larger than anything that can be done with other methods. Being able to handle systems of this size is significant, for it makes possible for the first time meaningful 3-D simulations (e.g., $32 \times 32 \times 16$ cell matrices).

The following tasks are contemplated for the remainder of the project period: (a) completion of geostatistical modeling, (b) indicator kriging (involving conversion of continuous permeability data to two-state variables using various reservoir cutoffs), and (c) further development of the simulation algorithm and its application to the whole of Churchula field.

In any discussion of the impact of reservoir heterogeneity or fluid movement within the formation, the issue of scale is a vital consideration. The data for reservoir description are commonly derived from cores and logs which examine relatively small quantities of rock. Thus,

there exists a fundamental problem in scaling up the detailed reservoir description data to something representative of typical reservoir model grid block sizes. Conditional simulation is a geostatistical technique which can be used to generate outcomes of a spatial random function, such as permeability. The generation of equiprobable maps with a given spatial structure is termed stochastic simulation. We will perform conditional stochastic indicator simulations using core-derived permeability data. The future plan is to apply our hierarchical algorithm to simulation of porosity and permeability distributions of selected cross sections bounded by two wells. After simulating some cross sections, we will produce contour plots of the variation of various quantities over our cross sections, such as the probability of having a porosity in excess of 9 or 12 %.

Significant Accomplishments

Significant accomplishments include completion of Subtasks 1, 2, and 3, and completion of comprehensive topical reports of the results of these subtasks. In addition, significant progress toward development of detailed predictive geostatistical and geologic reservoir models for the Smackover reservoir at Churchville field is near completion.

Significance to EOR Research Plan

The results of Subtasks 1 and 2 research provides us with the basic data necessary to gain an understanding of the Smackover reservoirs in southwestern Alabama. The results of Subtask 3 allows us to place reservoirs into a hierarchical ranking scheme of reservoir heterogeneity, which gives a relative means by which to rate reservoirs in terms of those most likely to contain unswept or uncontacted mobile oil and, therefore, be likely candidates for infill drilling or EOR.

Progress in geostatistical and geologic reservoir modeling is significant to the EOR research plan because these models will provide stochastic and deterministic predictions, respectively, of reservoir geometry, compartmentalization, and fluid-flow pathways. These data are important to the design of EOR methodologies and to the infill drilling strategy within a field.

NORTH CHOCTAW RIDGE FIELD **CORE LOG WITH PERMEABILITY VS. DEPTH CURVE**

Permit No. 1878

Figure 1. Variation in permeability values for three lithofacies distinguished by lithology and by pore types, North Choctaw Ridge Field, Choctaw Co., Alabama. Lithofacies 1 is dominated by intercrystalline pores, lithofacies 3 by moldic pores, and lithofacies 2 is characterized by a combination of these two pore types plus interparticle pores.

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