RESEARCH ON IMPROVED AND ENHANCED OIL RECOVERY IN ILLINOIS THROUGH RESERVOIR CHARACTERIZATION

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OBJECTIVE

This project will provide information that can maximize hydrocarbon production, minimize formation damage and stimulate new production in Illinois. Such information includes definition of hydrocarbon resources, characterization of hydrocarbon reservoirs, and the implementation of methods that will improve hydrocarbon extractive technology. Increased understanding of reservoir heterogeneities that affect oil recovery can aid in identifying producible resources. The transfer of technology to industry and the general public is a significant component of the program.

The project is designed to examine selected subsurface oil reservoirs in Illinois. Scientists use advanced scientific techniques to gain a better understanding of reservoir components and behavior and address ways of potentially increasing the amount of recoverable oil. Initial production rates for wells in the Illinois Basin commonly decline quite rapidly and as much as 60 percent of the oil in place can be unrecoverable using standard operating procedures.

Heterogeneities (geological differences in reservoir make-up) affect a reservoir's capability to release fluids. By-passed mobile and immobile oil remain in the reservoir. To learn how to get more of the oil out of reservoirs, the ISGS is studying the nature of reservoir rock heterogeneities and their control on the distribution and production of by-passed, mobile oil.

SUMMARY OF TECHNICAL PROGRESS

Mapping, Cross Sections, Subsurface Depo-Systems (Task 2)

Bartelso Field

The Bartelso Field study: "Reservoir Heterogeneity and Potential for Improved Oil Recovery within the Cypress Formation at Bartelso Field, Clinton County, Illinois is being prepared for printing.

Boyd Field

The Boyd Field study is being rewritten after initial peer review.

Dale Consolidated Field

Sandstone bars in the Aux Vases Formation at southwest Dale Consolidated Field constitute structurally modified stratigraphic traps. Sandstone bars are "shingled", separated by shale beds less than three feet thick. Petrographic analyses reveal a distinct upper zone of higher permeability within the reservoir interval. This zone will be preferentially depleted during primary production and will be the most efficiently swept during waterflooding. In the study area, the maximum regional stress axis (σ_1) trends roughly east/west. In McCreery and McCullum Units, hydraulic fracturing techniques

created fracture networks oriented sub-parallel to σ_1 . These fracture networks connect east/west offset wells and lead to inefficient sweeping of mobile oil in interwell areas. Volumetric calculations suggest that a substantial amount of by-passed mobile oil remains within the reservoir.

An integrated geologic and engineering study of the McCreery and McCullum Units in the Dale Consolidated Field has been completed. The scope of this study included data gathering, analyses, interpretations and integration into a reservoir simulator for the evaluation of the reservoir behavior and prediction of future performances.

Available data were gathered from well logs, core analyses, producing rock, hydrocarbon fluids, drilling, completion and production histories from scout tickets, literature and the operator.

The pressure-volume-temperature properties of the oil and gas from these reservoirs were analyzed in the ISGS PVT laboratory. Petrographic, SEM and XRD work showed mineral contents and relationships. Maps of isopach, tops, porosity and permeability etc. were generated and used as input into the reservoir simulator. The operator provided information on the field production history which was also input into the simulator.

The simulation model was used to simulate the historical depletion of the units and to compare the potential effects of various water-injection-well placement options and hydraulic fracturing effects on waterflood oil recoveries.

A final report is almost complete.

Energy Field

Research for the Energy field study has been completed and the manuscript is in peer review. Energy Field, located in Williamson County, Illinois was discovered in 1968. The trapping mechanism is stratigraphic, with structural position affecting oil/water production ratios from the sandstone bar facies of the Aux Vases Formation (Valmeyeran) at about 2400 feet. Twenty-two oil wells, seventeen dry holes and one injection well have been drilled in the field; the field is still being developed.

The economically important siliciclastic zone ranges from 6 to 35 feet thick and consists primarily of sandstones and shales. Within this zone, four reservoir sandstones have developed in two sets of distinct bars. Both sets of bars have lower and upper reservoirs which range up to 24 and 10 feet thick, respectively. The sandstones can pinch out in the distance of one location (660 feet) and grade laterally and vertically into encapsulating shales, calcareous shales and calcareous sandstones. The upper sandstones also grade into limestone.

The reservoir facies consists of fine- and very-fine grained sandstones cemented by clay, quartz overgrowths and calcite. The lower sandstones were deposited during a

marine regression and are interpreted as marine tidal ridges/bars based on multiple occurrence, morphology, petrography and sedimentary structures visible in core. The upper sandstones are interpreted as winnowed crestal sandstones deposited during a marine transgression. This interpretation is based on repeated areal association of upper and lower bars, ichnofauna, associated shallow facies and differences in petrology of the bars. Differential compaction of sediments over the lower bars allowed the winnowing and shoaling of the upper bar sandstones. The lower and upper sandstones are separated by a thin, impermeable interval of algally bound calcareous sandstones, shale and biocalcarenitic quartzose sandstones interpreted as intertidal mudflat deposits based on core examination and areal distribution. The periodicity of tidal ridge deposits may be a useful exploration strategy to locate similar reservoirs.

The primary drive mechanism at Energy Field is solution gas. The oil/water contact is -1,923 feet in the southern bar complex and -1,974 feet in the northern bar complex. The different oil/water contacts and initial pressure data indicate that the bar complexes are not in communication.

The original oil in place is calculated to be 4,004,000 BBL. A recovery efficiency of 20.9% of OOIP has been calculated for the field. Remaining mobile oil in place, recoverable through primary and selective secondary recoverable efforts, is estimated at 552,000 BBL.

A preliminary study shows that mud cleaning acid (MCA), commonly used in completion of Aux Vases wells, mobilizes ions which may form precipitates damage reservoir quality. Core flow experiments using MCA and core from this field record a drop in effective permeability when approximately 3 pore volumes of MCA are flushed through the core.

Data gathering, geologic modeling (with the Stratamodel) and transfer to the VIP simulator (through the GeoLink) has been completed. A PVT analysis was done on oil and gas from a virgin Energy well (Burr Oak #3) and the data is being used in this work. Single well (cross-sectional) simulation is used to generate the pseudo-relative permeability/saturation data needed in this work. The full-field reservoir simulation is presently in progress.

Lawrence Field

A study of the Cypress reservoir in Lawrence Field, Lawrence County, Illinois, is in progress.

Mattoon Field

Intraformational analysis (Phase 2) of the Cypress Formation is in progress. The Mattoon Field basemap has been corrected and the database has been expanded from

440 to 633 logs. Intraformational structure maps (Glen Dean through Rosiclare) have been completed. Database corrections applicable to existing cross-sections and maps are in progress. Four horizons have been defined in the Cypress, with structure, isopach and lithofacies maps in progress.

Oakdale and Markham N. Fields

Mapping is in progress.

Richview Field

Richview Field is in the final phase of the study, with volumetric calculations, final map interpretations and initial manuscript preparations in progress.

Richview Field has produced over 3.2 million barrels of Cypress oil from 86 wells on 800 acres to date. Although some production is attributed to an upper stray sandstone that immediately underlies the Barlow Limestone, the majority of the oil has been produced from the upper 20 feet or less of a sandstone, the top of which is 10 to 30 feet below the base of the stray sand horizon. This sandstone varies in thickness from 20 to 50 feet and displays a very clean, blocky SP log character. Thickness increases occur as incremental, blocky sands, 10 to 20 feet thick, indicating a stacking of genetic depositional units. Log indications show thin, laterally traceable shales separate these sand units.

The northeast, southwest trending field appears to be largely stratigraphically controlled. The sandstones change facies to shale rapidly away from the field. Structurally the field lies in a saddle between Irvington Field to the north and Ashley Field to the south. Richview Field lies immediately west of and on the uplifted limb of the Du Quoin monocline.

Stewardson Field

The manuscript "Reservoir characterization of the Mississippian Aux Vases Formation at Stewardson Field in southeastern Shelby County, Illinois," has been submitted to publications and graphics. Tasks completed as of this date: analysis of geophysical logs; development of interval isopach maps; structure maps on both the Ste. Genevieve and Beech Creek Formations; cross sections derived from the logs; petrographic analysis of well cuttings and core biscuits; geochemical analysis of oil and brines; clay analysis; volumetrics and the determination of depositional environments and the diagenetic sequence.

Storms Field

A study of the Cypress and Aux Vases sandstone reservoirs at Storms Field in White County, Illinois has begun. Well data, formation tops and isopach intervals for over 400

wells in the field have been collected and entered into a computerized data base. Preliminary cross sections, structure maps, isopach maps and pay map have been prepared.

Tamaroa Field

The Tamaroa Field study is at the editing and drafting stage. Reservoir compartmentalization and pressure maintenance control cumulative production and ultimate recovery efficiency. Maximum production is obtained by draining and pressure maintaining, separate, correlative sandstones from a vertically stacked, multilateral marine bar setting. Both marginal and very successful production programs are apparent within the multiple oil reservoirs of Tamaroa and Tamaroa South field. Recovery of 40 to 60 thousand barrels of oil per well from 10 acre spacing and less than 10 feet of reservoir thickness are typical where pressure is maintained within distinct, correlative sandstone bodies. Recovery efficiency for the more effectively managed reservoirs is 43 percent.

Xenia East Field

The pool study of the Cypress reservoir at Xenia East Field is in peer review.

Zeigler Field

The first draft of the Zeigler Field is in peer review. Reservoir heterogeneities have been linked to facies and diagenesis. Reservoir pressure data confirm compartmentalization.

A cross-sectional simulation consisting of six wells was accomplished and used to demonstrate the effect of compartmentalization and water injection rates on reservoir depletion and oil recoveries.

Outcrop Studies (Task 2)

The four exposed faces have been photographed and assembled into a montage. Overlays are being constructed which will show the petrophysical data and geologic interpretations. Data collection for the I-57 project has been completed. This entailed 60 measured sections and over 1,000 permeability measurements, along with the gamma ray logging and two core plugs for each section.

Oil and Gas Development Maps (Tasks 2,5)

Development of a computer generated series of maps to replace the older ISGS series of hand-drawn oil and gas development maps is continuing. Xenia, Fairfield, Centralia,

Carlyle, Mt. Vernon, Carbondale, Pinckneyville, Mattoon, Shelbyville, Du Quoin Roaches and McLeansboro maps are now complete.

Engineering Lab (Task 3)

An integrated geological modeling and reservoir engineering simulation study on the Zeigler field, Franklin County has been carried out during the report period. First, a geological model was constructed with Stratamodel software using log and core data obtained from 78 wells. Inter-well attributes such as porosity, permeability and water saturation as calculated using the various interpolation methods were then directly transferred to a reservoir simulation model (VIP). History matching of oil and water production as well as pressure history was then performed for the thirty years production period. The capability of direct data transfer from the geoLogical model to the engineering model has greatly facilitated the several modifications of the geological model needed to successfully match the production history. Evaluation of the strength and weakness of the various interpolation techniques has also become possible with this integrated approach.

SEM/EDX (Task 4)

Several samples were prepared using the critical point drying method to ensure that diagenetic clays coating grains, lining pores and bridging pores were left in as natural a state as possible. This technique is most critical when fibrous illite is present. No discernable differences were observed in samples prepared using the critical point drying technique versus those prepared using air drying. Only two trace examples of fibrous illite were found in all critically point dried samples.

SEM/EDX analysis of reservoir samples subjected to core flow with MCA has been completed. These analyses show that calcite dissolution is the most widespread change observed. Physical morphology of diagenetic clay minerals appear to be unaffected, however there are several distinct elemental variations found between clay minerals exposed to MCA versus those untreated. MCA treated clay minerals generally contain Mg, Al, Si, Cl, Ca Fe and K, depending on the MCA used, while untreated clay minerals contain Mg, Al, Si, Fe and, occasionally, minor amounts of K. It is believed that the Ca found in treated clay minerals is an artifact of (CaCO₃) calcite dissolution throughout sample and Cl and K may be residues of from H Cl hydrochloric acid and KCl potassium chloride used in MCA fluids.

Clay Minerals (Task 10)

The mineralogy of the clay-sized fraction of reservoirs of the Aux Vases and Cypress Formations has been surveyed. On the basis of 111 samples, from 8 Aux Vases reservoirs, relatively Mg-rich chlorite dominates the clay-sized fraction. All samples contain small amounts of illite and an illite-rich illite/smectite. Four samples contain

detectable amounts of kaolinite. Illite dominates the clay-sized fraction of shales associated with the Aux Vases Sandstone. Forty-nine samples from three Cypress Sandstone reservoirs, contain subequal amounts of Fe-rich chlorite and kaolinite. The clay mineral suites in both reservoirs appear to be primarily diagenetic rather than detrital. Statistical comparison of characteristics of the clay minerals in these two reservoirs clearly distinguishes one from the other. Similar comparisons show promise for distinguishing one field from another. Chlorites in samples from both formations are apparently unusual; the odd-ordered basal reflections on X-ray diffraction tracings from oriented aggregates are broader than the even-ordered reflections, the result of the interlayering of small (probably <20 percent) amounts of berthierine- or serpentine-line 7 A layers. That coatings of chlorite inhibit the development of quartz overgrowths in sandstones has been recognized in general (Heald, 1965, Pittman and Lumsden, 1968; and McBride, 1989). We are searching for questions that will determine whether or not the type of mixed-layered 7 A/chlorite in these samples is a more effective inhibitor of overgrowths than non-mixed-layered chlorite. Additional efforts are being focused on the effects of stimulation and enhanced recover treatments on the clay minerals in these reservoirs.

Geochemistry of Formation Fluids for Reservoir Characterization and Enhanced Oil Recovery (Task 10)

Geochemical data on about 300 brine samples from Aux Vases and Cypress formations were obtained from previous ISGS publications and the DOE database. These data were then processed and incorporated into our computerized database. Formation water resistivities for the samples were computed from total dissolved solid (TDS) content using formulas that we recently developed for the Aux Vases and Cypress formations. The computed resistivity values for the above 300 samples, in addition to about 100 actual measurements made in the field, were mapped. Other geochemical parameters that have implications for oil production (i.e, TDS, SO_4^- , Ba^{++} , Mg^{++} , Ca^{++} , Fe^{++} and Fe^{+++} etc.) are being mapped and statistically evaluated for a publication.

We have succeeded in solving technical problems previously encountered in adopting geochemical modeling codes to our computers. Tests of three codes (Solmineq88, Eq3/Eq6, UICU-Geochemist's Workbench) selected for the geochemical modeling task have been successfully completed. During the next two or three reporting periods, these codes will be used for predicting (1) paleochemical reactions that influence porosity and permeability, and (2) changes in reservoir properties in response to the injection of improved oil recovery fluids.

Technology Transfer (Task 12)

At the invitation of DOE, four members of the project team presented the project design and results to Mr. James Randolph, Assistant Secretary, Fossil Energy and several

members of his staff in Washington, DC on March 12. Further conversations with DOE program staff in Germantown were held in the afternoon.

Four members of the research team exhibited at the Annual Illinois Oil and Gas Association meeting on March 13. Engineering and geologic characterization and modeling, computerized development maps, and demonstrated database access were demonstrated.

Two team members presented a talk on "Optimizing Reservoir Management" to the local SPE chapter.

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