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Determining Reservoir Quality by Combined Stratigraphic, Petrographic and Petrophysical Methods as Part of Optimized Recovery Programs: Womack Hill Smackover Field, Clarke and Choctaw Counties, Alabama

Hopkins, Tiffany Lynn And Wayne M. Ahr; Department Of Geology & Geophysics, Texas A&M University, College Station, Tx

INTRODUCTION

Objective of the Study

The objective of this study is to describe depositional and diagenetic characteristics of the Oxfordian (Jurassic) Smackover Formation in the Womack Hill field, Alabama, as part of an integrated reservoir description program. In order to understand the distribution of reservoir units, this study utilized an integrated array of data from core lithological descriptions, borehole logs, core reports, thin section petrography, porosity and permeability measurements on core plugs, and mercury injection capillary pressure (MICP) measurements. These data made it possible to establish reliable measures of reservoir quality by comparing pore geometry with pore type; then determining which pore types correspond with highest porosity-permeability paired values. Pore aperture (throat) median sizes measured by mercury capillary pressures were tested for correspondence with porosity, pore type, permeability, and saturation in order to establish quality rankings for the reservoir units.

From this information, a method was developed to identify best, intermediate, and worst reservoir quality zones. These zones were then put in a stratigraphic context, allowing for a better understanding of the effects of pore categories, original depositional texture, and diagenetic influences on the distributions of the reservoir quality zones. Correlation of this information between wells allows for the three-dimensional mapping of these quality zones, or petrofacies units. The final results are maps predicting areas with optimal recovery potential and/or bypassed pay.

This study attempts to bridge the gap between petrological and petrophysical studies, merging the data into a comprehensive model. This model, instead of mapping facies based solely on lithology, or flow units based only upon permeability, depicts petrofacies, with each petrofacies having distinct porosity, permeability, and capillary pressure ranges. These characteristics are related to specific pore types and diagenetic processes. The resulting combinations are grouped into reservoir quality rock, baffle or poor quality reservoir material, and reservoir seals.

The availability of a large variety of data from the Womack Hill field (Table 1) allows for a unique opportunity to further interpret existing data, use it for additional studies, and ultimately find correlations between various data types (i.e. pore geometry and permeability). The abundance of data allows for an accurate three-dimensional field model to be developed, ultimately enabling the identification of bypassed pay and the development of a procedure that can be used on similar fields in the region (Fig. 1).

Location of the Study Area

Womack Hill field is located in Clarke and Choctaw Counties, Alabama, on the eastern flank of the Mississippi interior salt basin. It is set in the Gilbertown-West Bend Fault System (Mancini, et al., 1990), which is part of a larger peripheral fault trend that extends from Florida to Mexico, delineating the outer edges of the Gulf Coast Basin (Myers, 1975). The field is located on the upthrown (northern) side of a normally faulted, east-west trending anticline. The field is about five miles long and one mile wide (Townsend, 1986).

Production History of Womack Hill Field

The Smackover Formation is the main producing unit in the Womack Hill field. The discovery well at Womack Hill field was drilled in 1970. The field remains under development, which is a principal reason for this study to be undertaken. To date, there have been about 30 productive wells drilled, which have a combined cumulative production of over 30 million barrels of oil or condensate and $15x10^6$ Mcf of gas. Currently twelve wells are producing (Alabama Oil & Gas Board Website). Of the approximately 119 million barrels of estimated oil reserves in the field, about 10-20%, or 12-24 million barrels, can still be recovered using newly developed techniques such as those being provided by this project (Mancini, 2001).

The field is located in the updip portion of the Smackover formation where most depositional facies include grainstones, packstones, reefs, and evaporites. The most productive interval in the Smackover at Womack Hill field is the upper part of the formation. The upper Smackover oolitic, peloidal, and oncoidal packstones and grainstones make up the bulk of the reservoirs owing to their inherent depositional porosity and porosity enhancement by diagenetic alteration. There, 3 progressively shallower shallowing-upward carbonate mudstone to grainstone sequences, hereafter termed cycles A, B, and C, characterize the formation. The uppermost sequence (cycle A) grades into Buckner anhydrites, which act as a reservoir seal. In Womack Hill field, the upper Smackover ranges in thickness between 30 and 209 feet, with an average thickness of about 111 feet. Most of the Smackover production in the study areas is at depths of -11,100 to -11,500 feet below present sea level.

METHODS: DATA COLLECTION & ANALYSIS

Table 1. Data From Womack Hill Field.

Data Type	Number Available
Wells in Field	42
Full Diameter Slabbed Core	6 wells
Well Logs	38 wells
Thin Sections	10 wells, 181 individual slides
Core Reports (Porosity, Permeability, and Fluid Saturation Data)	21 wells
Permeability Billets	3 wells, 117 individual pieces
Core Plugs with Helium Porosity and Mercury Injection Capillary Pressure Data	2 wells, 11 individual plugs
Production Reports	28 wells

All data were entered into spreadsheets to facilitate sorting, data retrieval, data correlation, and graphing. Core descriptions focused on depositional textures, fabrics, diagenetic alteration, sedimentary structures, and the presence or absence of accessory minerals and rock types. In thin section, the mineralogy, depositional texture, particle content, diagenetic processes, and porosity types were described. Carbonate minerals were the dominant components of the rocks studied. Calcite was the dominant mineral, but dolomite percentages ranged from several percent to nearly 100% in some areas. Anhydrite was the most prevalent secondary mineral identified, varying from trace amounts to about 20%. Small amounts of siliciclastic silt were also found.

Lithologies included mudstones, wackestones, packstones, grainstones, and occasional boundstones. Both bioclastic and inorganically precipitated particles were common throughout the sections. Biologic components included echinoderm spines and plates, unidentified mollusk shells, ostacode fragments, and microbial formations in the form of oncoids and microbial layers. Varying amounts of peloids and ooids were the primary constituents in grainstones, packstones, wackestones and mudstones.

The most common pore type was interparticle which was often accompanied by dissolution enhanced intraparticle. In rocks with relatively high dolomite percentages, intercrystalline porosities were dominant. These categories also had the highest percent porosities. Moldic and vuggy porosities, created or enhanced by dissolution, were common in finer grained, muddier rocks, accompanied by lower porosity ranges.

From the thin sections studied, it is possible to discern several episodes of diagenesis. Diagenetic processes cement precipitation, several episodes of dolomitization and dissolution. Macro-stylolitization is common throughout the field, showing the compaction and dissolution was occurring on a large scale. Later diagenetic episodes included replacive, pore destructive anhydrite.

Porosity and permeability data were available from core analyses of some wells. A probe permeameter was used to measure both horizontal (k_h) and vertical permeabilities (k_v) from thin section billets to provide additional information. Combining this information with lithologic descriptions, eleven one inch diameter plugs were chosen based on representative porosities, permeabilities, pore types, pore sizes, lithologies, dolomite content, and field locations for high pressure mercury injection capillary pressure (MICP) analysis.

RESULTS

Relationships between porosity, permeability and median pore aperture from MICP Experiments were explored. Permeability strongly correlated with median pore aperture (MPA). Saturations and entry pressures also correlated well with MPA. By graphing these relationships, it is possible to derive equations that allow for the prediction of these parameters throughout the field, wherever permeabilities have been measured. By integrating this information with the geologic descriptions from core and thin sections, it is then possible to define these units on the basis of groups of parameters, rather than a single characteristic. Creating these "petrofacies" then allows for the identification of reservoir, baffle, and seal zones.

Merging these petrofacies with well logs, such as gamma ray; spontaneous potential; shallow, intermediate and deep resistivities; and porosity logs, enable these units to be correlated across the field. Using this method, it is possible to have clear, data rich logs which maps and 3-D models can be based upon.

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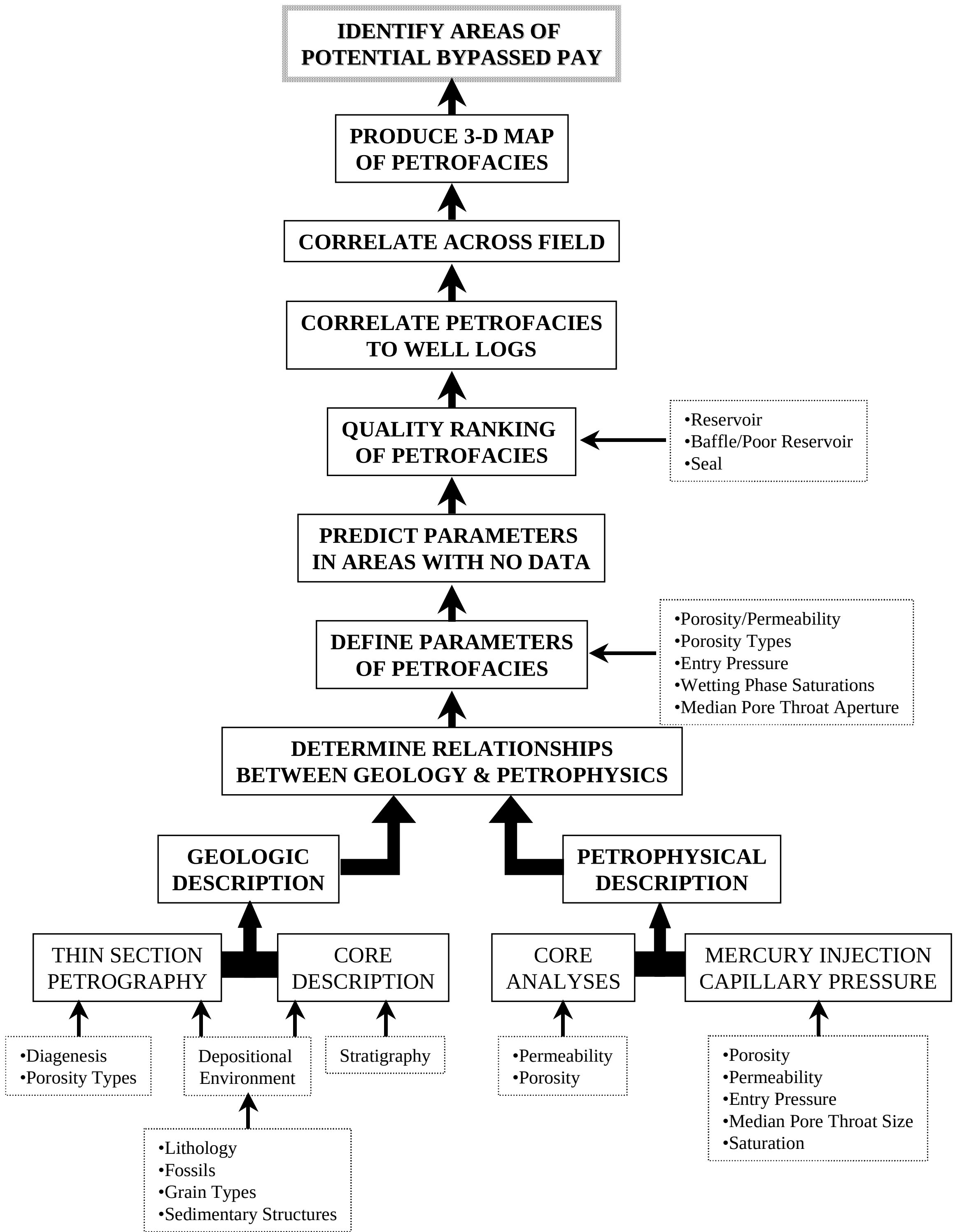

Figure 1. Flow chart showing how various data were obtained and integrated and the subsequent steps used to identify, predict, and map petrofacies.