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Porosity Characterization Utilizing Petrographic Image Analysis: Implications for Rapid Identification and Ranking of Reservoir Flow Units, Happy Spraberry Field, Garza County, Texas

ABSTRACT

Carbonate reservoirs may be heterogeneous and exhibit lateral and vertical variations in porosity and permeability. New technology and an improved understanding of carbonate reservoirs have led to more detailed reservoir description, flow unit delineation, and flow unit ranking. Petrographic image analysis (PIA), a relatively new method, was used to analyze the carbonate porosity of the reservoir interval at Happy field, Garza County, Texas. The reservoir produces from depths of –4900 to –5100 feet and consists of lower Permian oolitic grainstones and packstones. Associated floatstones, rudstones, and *in situ Tubiphytes* bindstones are also present in the interval.

Reservoir pore characteristics and their corresponding degrees of connectivity ("quality") were determined using standard petrography, PIA, core analyses, and mercury injection capillary pressures. The PIA method enables rapid measurements of pore size, shape, frequency of occurrence, and abundance. Common pore characteristics were used to identify stratigraphic and diagenetically similar intervals, within which four pore facies were observed. Pore facies were defined and ranked as to quality by comparing PIA data with measured porosity, permeability, and, in a limited number of samples, median pore throat diameters. Pore facies exhibiting oomoldic and solution-enhanced interparticle porosity ranked best in quality. Rocks with incomplete molds and dispersed interparticle pores ranked second, rocks with mainly separate molds ranked third, and rudstones, floatstones, and bindstones with dispersed separate vugs and matrix porosity ranked fourth. The PIA technique is a viable and fast alternative to standard petrography. It yields data that compares with petrophysical measurements and, when properly used, is a valuable method for reservoir characterization in heterogeneous carbonate pore systems.

INTRODUCTION

This study tests the applicability of PIA as a tool for identifying reservoir flow units in the carbonate reservoir at Happy Spraberry field. The reservoir interval is interpreted to be lower Leonardian in age and part of the Lower Clear Fork Formation, which is shelf equivalent of the Dean Formation (Handford, 1981; Mazzullo and Reid, 1989). The depositional model for Happy field was interpreted by Hammel (1996) and Roy (1998) and is an oolitic grainstone shoal complex with floatstone and rudstone debris aprons around patches of *in situ Tubiphytes* bindstone buildups. Their interpretation is supported by core descriptions, thin section examination, and wireline log analyses done in this study.

STUDY AREA AND METHODS

Happy field is located in south central Garza County, Texas, on the eastern shelf that flanks the Midland Basin (Fig. 1). Data used in the study include core from five wells, 52 petrographic thin sections, capillary pressure measurements, and wireline log data. Cores were described for sedimentary structures, constituent grains, and depositional fabric

(Layman II, 2002). Thin sections were examined by standard petrographic methods for total porosity, per abundance, pore types, grain constituents, and cements. Wireline logs were used to calculate porosity on reservoir intervals where core analyses were absent. Cross plot porosity from CNL-FDC logs, general log signature, as well as pore facies information were used to correlate subdivisions of the reservoir zones across the field.

Petrographic image analysis of carbonate pores has been used to predict reservoir quality (Anselmetti, 1998; Ehrlich, 1987; Ehrlich, et al., 1991). In this study, pore geometry was measured using PIA and the resulting measurements were related to reservoir quality. Petrographic image analysis was performed on the thin section data set using Image Pro Plus, an image acquisition and analysis software program. Images from thin sections were captured by a Sony DXC-290 digital video camera that relayed the signal to a PC. Ten images per thin section were viewed at 12.5X magnification and analyzed with the software. Porosity was identified and measured for pore size, shape, frequency, abundance, and pore origin. Pores were auto-classified by the software according to geometry and measurement data were culminated into histograms. These “porosity fingerprints” have implications as to reservoir quality and petrophysical characteristics. This method allowed for a much faster and cheaper alternative to reservoir quality assessment and flow unit mapping based on pore data obtained from PIA.

STRATIGRAPHY AND LITHOLOGY

The carbonate interval at Happy field is interpreted as Lower Clear Fork Formation (lower Leonardian). This is time-equivalent to the basinal Dean sandstone (Montgomery, 1998). Primary production is from a grainstone shoal complex with associated lithofacies (Fig. 2). The shoal is composed of well sorted, medium grained oolitic grainstones and packstones and it averages about 20 feet in thickness. Lithoclastic rudstones and floatstones containing fragmented and whole mollusks, crinoids, and fenestrate bryozoans are common as fringe deposits around the small skeletal buildups. The buildups are composed mainly of encrusting organisms and *Tubiphytes*-rich bindstone that grew mainly in the central part of the field between two larger grainstone bodies (Ahr and Hammel, 1999).

RESULTS

The types of data obtained from PIA studies include pore size, shape, frequency, and abundance (total porosity). In addition, pores in each sample were classified according to their geological origin. Total porosity from PIA was compared to porosity values obtained from standard petrographic methods, log calculations, and core analyses. The comparisons showed that the accuracy of PIA estimates of porosity are comparable to the other methods. Porosity histograms were constructed from the pore data to rapidly assess all pore characteristics (Fig. 3). Samples were then correlated to determine trends and patterns in the pore data that defined pore facies of the reservoir.

Pore facies are combinations of pore data that have predictable reservoir potential and petrophysical characteristics. Four pore facies were identified in the reservoir and associated carbonate section at Happy Spraberry field. These pore facies serve as the basis for the quality classification scheme. The highest quality or “best” pore facies occur in the oolitic/skeletal grainstones that typically exhibit 15-25% porosity and 12-25 millidarcies (md) of permeability. This pore facies consists mainly of moldic and solution-enhanced intergranular pores that were produced by diagenetic leaching of grains and interstitial cement. Intermediate quality pore facies typically exhibits porosity ranging from 15-25% and 5-12 md of permeability. Rock types consist of moderately cemented skeletal grainstones and packstones in which the dominant pore types are incomplete moldic and solution-enhanced intergranular. The pore facies with the lowest reservoir quality is comprised of two subfacies. The higher quality subfacies includes isolated molds in highly cemented oolitic skeletal grainstones where leaching only effected metastable grains. Scattered other grains underwent micritization, stabilization, and neomorphism. As a result, pores are often isolated, disconnected, and may be classified as separate vugs (Lucia, 1983). Porosity histograms of this pore facies typically show the influence of large (greater than 10,000 microns^2), separate molds, and less than 20% of any other pore type or size. Porosity averages 10-14%, but may be as high as 25%. Permeability is typically less than 5 md. The overall lowest quality pore facies is present in silty, skeletal packstones, siliciclastic siltstones, and rudstones. Typically, porosity is less than 10% and permeability is less than 10 md. This rock type has abundant quartz silt that is locally more porous and permeable than its surrounding carbonate rocks. Large, blocky vugs are also typical in this pore facies. Table 1 is a summary and ranking of the pore facies and associated pore data of each one.

CONCLUSIONS

Happy Spraberry field produces from heterogeneous, shallow-shelf carbonates where lateral and vertical variations in porosity and permeability are common. Porosity is predominantly a diagenetic overprint on depositional texture (grain-moldic in oolitic grainstones). Utilizing PIA as a method for characterizing carbonate reservoirs is a relatively new procedure. Data on pore characteristics is obtained much faster than standard petrographic methods. Image analysis data were interpreted to identify 4 distinctive pore facies which, in turn, are predictors of rock type, petrophysical properties, and production characteristics.

Image analysis was proven to be a good substitute for more time-consuming methods for determining porosity and provided results with accuracy comparable to results obtained from core analyses, wireline log calculations, and standard petrographic methods. The highest quality reservoir rocks occur in oolitic grainstones and packstone where large (greater than 10,000 microns^2) moldic pores dominate. Also, the highest combined values of porosity and permeability were associated with the presence of large, solution-enhanced intergranular pores in addition to the moldic pores (oomoldic and skelmoldic). We interpret that storage capacity existed in the moldic pores and that solution-enhanced porosity provided connectivity. Pore size data obtained from petrographic image analysis is a useful predictor of median pore throat size, which would otherwise only be available by performing expensive mercury injection capillary pressure tests. Pitfalls of petrographic image analysis include choosing a magnification that gives appropriate and accurate images of porosity, quality control on preparation of thin-section samples, and consistent sampling of thin sections.

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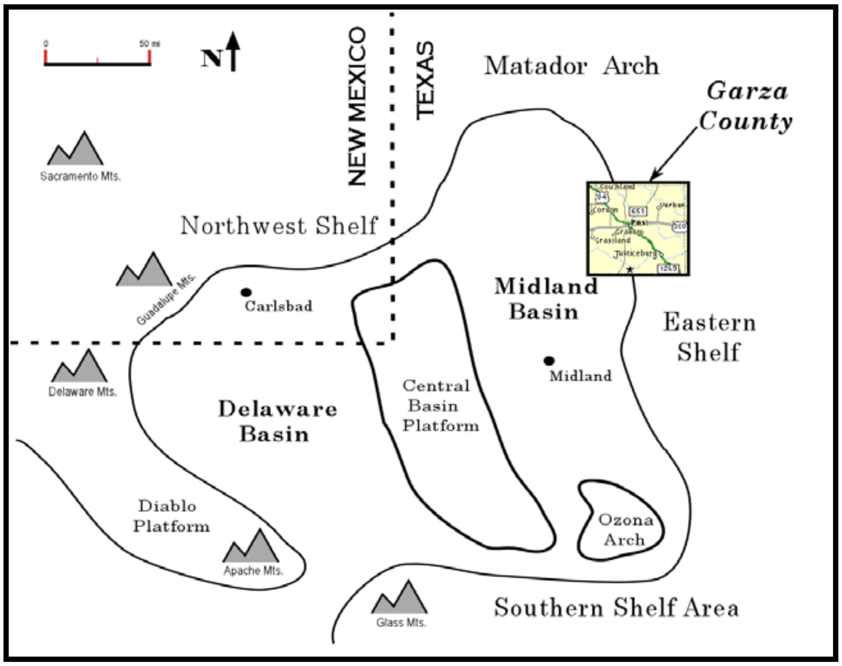

Figure 1. Location of study area and physiographic map of the Permian Basin. Garza County is located on the central Eastern Shelf of the Midland Basin. Happy Spraberry field (star) is located in south-central Garza County. Modified from Handford, 1981.

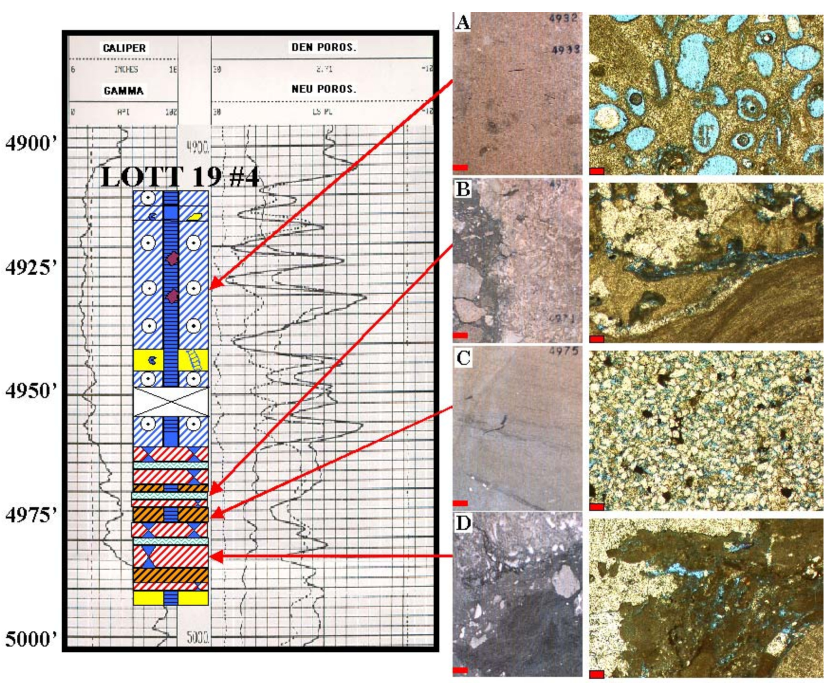

Figure 2. Lott 19 #4 well log with core photographs and photomicrographs of reservoir interval at Happy Spraberry field. The productive interval (A) consists of oolitic grainstones and packstones with well-developed skel- and oomoldic porosity which approach 1 cm. B is lithoclastic rudstone with *in situ Tubiphytes* bindstone in the right portion of the core photograph. Large bryozoan fragments and replacive anhydrite are visible in the photomicrograph. C is a quartz siltstone with primary intergranular porosity. D is matrix-dominated lithoclastic floatstone with large, complete fossils present. Scalebar: Core photographs = 1 cm, photomicrographs = 100 microns.

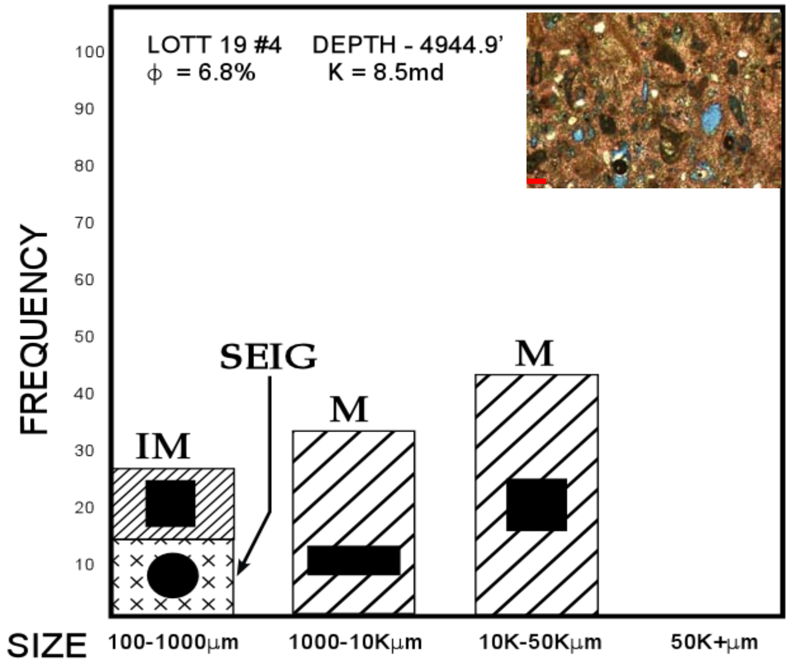

Figure 3. Histogram of pore data from sample Lott 19 #4, 4944.9'. A photomicrograph of the sample is located at top right. Scalebar = 100 microns. Size is plotted on the x-axis, frequency on the y-axis, and shape per pore bin is also shown. Pore type is denoted by abbreviation; M = moldic, IM = incomplete moldic, and SEIG = solution enhanced intergranular.

QUALITY		SIZE (μm^2)	SHAPE	TYPE	FREQUENCY	ϕ(%)	K(md)
HIGH		>10K	Elongate	M,IM	75-90%	15-25%	12-25md
		100-50K	Elliptical	SEIG	10-25%		
INTER.		1K-50K	Elongate	M	60-90%	15-25%	5-12md
		<1K, >50K	Blocky	IM			
		100-1K	Elliptical	SEIG	10-40%		
LOW	A	>10K	Elliptical	M	80-90%	10-20%	0-10md
		100-1K	Elongate	SEIG,IM,MAT	10-20%		
	B	100-1K	Circular	MAT	85+%	0-10%	0-10md
		1K-10K	Elongate	SEIG			
		10K-50K	Blocky	Vuggy	10%		

Table 1. Summation of pore data obtained from PIA. The four pore facies served as the classification system for reservoir quality. Shown are pore size, shape, origin, frequency, and expected porosity and permeability values for each facies. Data was used to construct flow unit stratigraphy based on pore measurements from PIA.