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CT Assisted Petrography For Understanding Reservoir Heterogeneity in Carbonate Rock of Mumbai High Field

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Summary

Petrographic analysis plays a significant role in understanding the reservoir characteristics and heterogeneity. It includes Thin Section analysis for understanding the pore spaces, Scanning Electron Microscopy (SEM) analysis to identify pore system properties and the types of pore-filling constituents and X-ray Diffraction (XRD) analysis to obtain semi-quantitative mineralogical data.

The studies are carried out on fresh cores of a well in Southern part of Mumbai High Field, an offshore Indian oil field having a multilayered carbonate reservoir. After put on production in 1976, the field has produced about 24% of the initial oil in place (IOIP). Core-Log based data shows large variation in porosity-permeability values in sub-layers of main producing LIII reservoir of the field. Uncertainties observed during drilling of wells and their production behaviour also supports presence of heterogeneity in the reservoir. Therefore, need was felt to carry out CT scan assisted petrography study on fresh cores at this matured stage of the field.

In the present paper, results of this study are discussed. It is observed that macropores in the core samples are more or less interconnected through the matrix, and the mixed-layer illite/smectite is highly dispersed in the matrix. Significant reduction in permeability of core samples after the steady state relative permeability tests has been observed. It appeared that swelling of this type of clay reduced the permeability values of these limestones. Thus the study was found to be useful in understanding the reservoir heterogeneity and in deciding what type of drilling mud is compatible with these clay minerals. Further, rock-fluid compatibility tests are also recommended for completion and stimulation in wells for such limestones.

Introduction

X-ray Computed Tomography (CT) has been widely used in diagnostic medicine to observe internal organs and tissues of human body since 1970's [1-2]. In recent years, CT assisted petrography studies for Reservoir rock description has become increasingly popular in petroleum industry. A detailed description of the microstructure of porous media could be useful to every oil production operation. For the case of multiphase flow through porous media, a knowledge of the distribution of various phases, is of great interest in enhancing the recovery of oil. The shape, size, orientation, and the connectedness of the flow paths play a vital role in the transport of various fluid phases through porous media [3-8].

In order to understand reservoir heterogeneity in a multilayered carbonate reservoir of an Indian Offshore field, CT assisted petrography studies are carried out on fresh cores from a well in the southern part of the field[9]. The reservoir under consideration is heterogeneous, inter-bedded by thin shale bands and argillaceous limestones. The top of this reservoir is easily identifiable on logs due to the presence of a thick over-lying shale. The shallowest litho-stratigraphic reservoir unit is designated as the A1 layer. It has total 11 number of geologcal layers A1, A2I A2II, A2III,

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A2IV, A2V, A2VI, A2VII, B, C and D from top to bottom separated by interbedded shales.

CT Scan, Thin Section Description, Scanning Electron Microscopy, and X-Ray Diffraction Studies

Fresh cores were taken from a vertical well located in the south western part of Mumbai High Field in the interval 1400-1440m. The details of the recovered core are as follows;

CC-1: 1400.00-1413.90m,	Rec.: 64.00%,	9.00m
CC-2: 1413.90-1431.50m,	Rec.:41.77%,	7.31m
CC-3: 1431.50-1440.50m,	Rec.:88.88%,	8.00m

Missing core portions were identified using spectral core gamma ray of the entire core recovered. Sub-layers within the recovered core were identified based on core log gamma ray measurements. The core recovered was in A1, A2I, A2II, A2III, A2IV and A2VII layers of LIII reservoir. The CoreSeal-encased samples were CT scanned 0° and 90° longitudinal and one axial to help identify suitability for further testing and to identify exact trim placement to capture the maximum rock quality and to show heterogeneities within the core. Fig.-1 shows the CT scan photographs of core sample in the interval 1419.53-1419.73m. Density variation in the material present as indicated from darker to lighter colour shows presence of heterogeneity in the core sample.

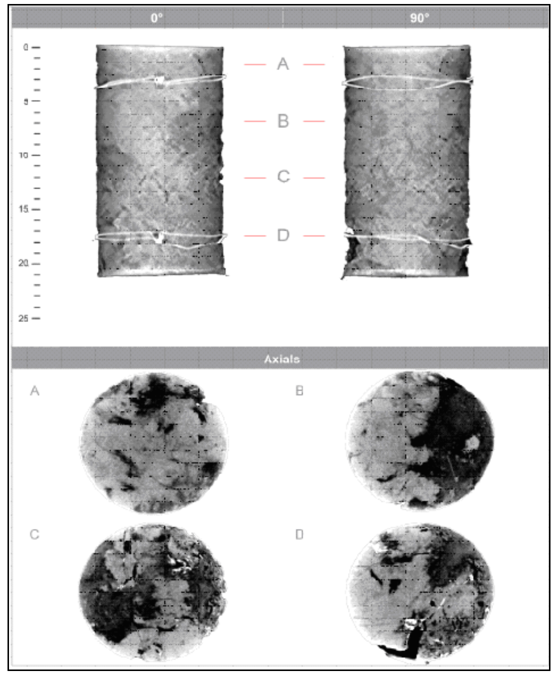


Fig.1 CT Scan Photograph of a Core Sample

Details of the samples studied for Thin section, SEM and XRD analysis are given in the Table -1. In order to study the presence of vertical heterogeneity, core samples are taken from different sub-layers of LIII reservoir of the well covering the depth interval from 1405 to 1437 m.

Depth (m)	Layer	Porosity (%)	Permeability, (md)	Lithology
1405.44	A1	27.53	7.20	Limestone
1414.07	A2-I	17.77	8.49	Limestone
1417.33	A2-II	26.19	3.60	Dolomitic limestone
1419.01	A2-III	35.70	65.50	Dolomitic limestone
1437.11	A2-VII	23.69	1.09	Dolomitic limestone

Table-1: Details of Core samples and their lithology

Discussion of Results

Thin Section and SEM Analysis

The five analyzed samples are all limestones, which are further classified according to the abundance of dolomite contents (Table-1). Dolomitic limestones contain >10% dolomite, whereas limestones contain <10% dolomite. These samples consist of two packstones and three wackestones according to Dunham's classification. Packstones are grain-supported in texture; matrix is the major pore-filling constituent. Wackestone is texturally mud-supported (i.e., matrix-supported), with allochem grains scattered throughout the matrix. In addition, stylolites are present in one sample, and defined by the concentration of detrital clays and other insolubles (Fig.2A).

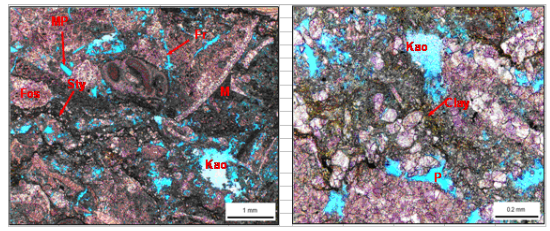
Matrix is the most abundant pore-filling constituent in the packstones, and it is also the predominant constituent in the wackestones. Thin section and SEM analyses reveal that the matrix consists of both micrite and detrital clays. Based on XRD analysis, the total clay contents in these limestones range from 6% to 14%; the clay minerals include mixed-layer illite/smectite, illite, kaolinite and chlorite.

Fe-dolomite (ferroan dolomite) and dolomite are the most common diagenetic minerals in these samples and mainly replace matrix (Fig.2B). Trace to minor amounts of authigenic pyrite (Fig.2C) and kaolinite (Fig.2D) also occur in these limestones.

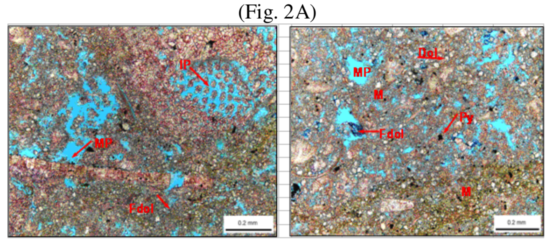
Pore System Characteristics

According to thin section and SEM analyses, visible pores are generally moderate to common in these limestones. These visible pores are dominantly moldic and intragranular; they are derived from the partial to complete dissolution of fossil fragments. Thin section and SEM analyses reveal that these macropores (moldic and intragranular) are more or less interconnected through the pore system of the matrix. Overall, these macropores are poorly to moderately interconnected.

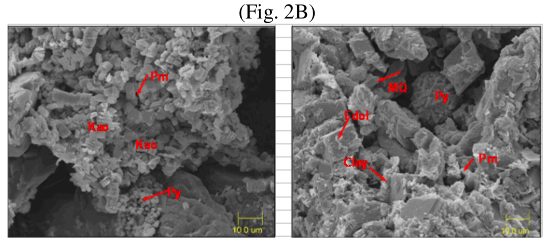
Core analysis data show that the measured porosity varies from 17.77 to 35.70%, which are generally higher than visible porosity. The discrepancy between the visible porosity and core analysis porosity is attributed to microporosity, which is estimated to be moderate to common. The measured permeability ranges from 3.60 to 65.5 md. The overall reservoir quality of these samples is probably fair to good for oil.



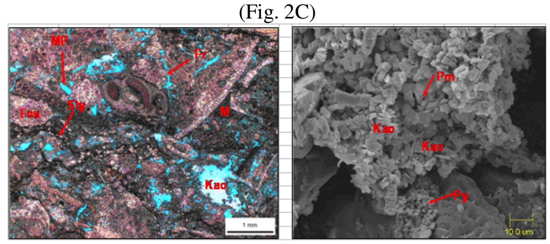
(Fig. 2A)



(Fig. 2B)



(Fig. 2C)



(Fig. 2D)

Fig.2A, 2B, 2C and 2D- Thin Section and SEM photographs of Core Samples

XRD Analysis

Results of X-ray diffraction analysis performed on both bulk and clay fractions of five samples are shown in Table 2A&B. It is observed that Calcite (60-80% by weight), Fe-dolomite/dolomite (4-23% by weight) and clays (6-14% by weight) are the predominant minerals; plagioclase and pyrite are much less common. X-ray diffraction analysis reveals that the clay minerals include mixed-layer illite/smectite, illite, kaolinite and chlorite. Calcite totals reported by XRD include fossil fragments and micrite in the matrix. Fe-dolomite/dolomite totals reported by XRD are mostly very finely crystalline, replacing the micritic and detrital clay matrix. The clay minerals (mixed-layer illite/smectite, illite, kaolinite and chlorite) recorded by XRD are dominantly detrital clays and intermixed with micritic matrix; authigenic kaolinite locally occurs in trace to minor quantities and fills moldic pores. Pyrite detected by XRD is authigenic and has framboidal morphology. Quartz and plagioclase reported by XRD occur as clay- to silt-sized grains and are mixed with detrital clay matrix; authigenic quartz is very rare in these limestones. Overall, XRD data are in general agreement with thin section and SEM observations.

Depth (meters):	Layer:	Whole Rock Mineralogy (Weight %)								
		Quartz	K-Feldspar	Plagioclase	Calcite	Fe Dolomite /	Siderite	Gypsum	Pyrite	Total Clay
1405.44	A1	3	0	1	80	10	0	0	Tr	6
1414.07	A2-1	4	0	1	76	4	0	0	1	14
1417.33	A2-2	6	0	1	60	21	0	0	1	11
1419.01	A2-3	5	0	1	66	21	0	0	1	6
1437.11	A2-7	3	0	1	63	23	0	0	1	9

Table-2A

Depth (meters):	Layer:	Relative Clay Abundance (Normalized to 100%)				
		Illite / Smectite *	Illite & Mica	Kaolinite	Chlorite	%Smect. in I/S *
1405.44	A1	21	41	18	20	40-50
1414.07	A2-1	38	12	28	22	40-50
1417.33	A2-2	35	22	26	17	40-50
1419.01	A2-3	31	20	26	23	40-50
1437.11	A2-7	40	25	21	14	40-50

Table-2B

Table-2A&B: Results of XRD analysis on core samples

Potential Formation Damage

Minor amounts of mixed-layer illite/smectite (40-50% smectite layers) occur in all the limestones; mixed-layer illite/smectite is prone to swelling if exposed to fresh water and/or undersaturated brine (i.e., relative to the formation brine). It should be noted that the macropores (moldic and intragranular) in these limestones are more or less interconnected through the matrix, and the mixed-layer illite/smectite is highly dispersed in the matrix; therefore, the swelling of mixed-layer illite/smectite may significantly reduce the permeability values of these limestones.

Significant reduction in permeability of plugs considered for Steady State (SS) Relative Permeability test was observed after the test. The test was carried out on wettability restored core samples at net confining pressure of 1500 psi and 66^{0}F. The samples were saturated with synthetic brine of 23000 ppm NaCl and tagged isopar mineral oil. Sample wise Pre and Post details are given in Table-3. The reduction in permeability varied from 34 to 91% whereas reduction in porosity varied from 4 to 26%. Pre and post SS test Poro-Perm relationship is shown in Fig.-3. it is seen that regression coefficient also reduced significantly from 0.95 to 0.60. This may be mainly due to the swelling of mixed-layer illite/smectite present in the core plugs.

Sample Depth	Grain density		Permeability		Porosity	
	Pre test	Post test	Pre test	Post test	Pre test	Post test
(m)	(g/cc)	(g/cc)	(md)	(md)	(%)	(%)
1405.44	2.721	2.723	7.20	2.78	27.5	24.2
1406.29	2.718	2.723	8.96	3.26	27.7	25.2
1406.62	2.717	2.731	5.75	3.78	27.5	26.5
1407.88	2.752	2.747	7.17	2.33	27.5	26.0
1415.83	2.711	2.712	67.8	14.2	36.3	29.9
1415.96	2.709	2.713	98.9	8.84	39.1	28.8
1418.85	2.700	2.725	34.5	4.70	36.5	30.1
1419.01	2.711	2.723	65.5	6.04	35.7	27.0

Table-3: Pre and Post Steady State Test Porosity and Permeability Data

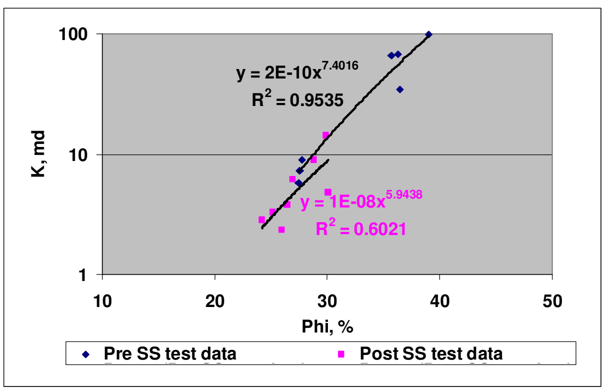


Fig.3: Effect on Permeability pre and Post Steady State Relative Permeability Test

Oil-based drilling mud is compatible with these clay minerals. Based on the above results, it is recommended to carry out rock-fluid compatibility tests for completion and stimulation with 4-6% KCl or 1%CaCl2.

Conclusions

1. Prior screening of core using CT scan helped in selection of cores samples for petrographic study. CT scan photographs showed presence of material of varied density.

2. Large variation in porosity and permeability values observed from core samples indicated presence of heterogeneity in the reservoir.

3. In reservoir rock, macropores (moldic and intragranular) are more or less interconnected through the matrix, and the mixed-layer illite/smectite is highly dispersed in the matrix.

4. Presence of mixed-layer illite/ smectite is prone to swelling if exposed to fresh water and/or undersaturated brine (i.e., relative to the formation brine) and significantly reduces the permeability values of the reservoir rock. This effect of reduction in permeability has been observed during measurement of permeability Pre and Post Steady State Relative permeability test.

5. It is recommended to use oil-based drilling mud as it is compatible with the clay minerals present in the reservoir rock.

6. In order to minimize the reduction in rock permeability, completion and stimulation with 4-6% KCl or 1% CaCl2 are recommended after confirmation from the rock-fluid compatibility tests.

References

1. Computed tomography for rock – porosity determination and fluid flow visualisation, E.M. Withjack, SPE 16951.

2. Computer tomography as a core analysis tool: applications and artifact reduction techniques, Hunt et.al.,SPE 16952.

3. Reynolds, R.C., Jr., 1980, Interstratified clay minerals: in Brindley, G.W. and Brown, G. eds., Crystal structures of clay minerals and their X-Ray identification: Mineral Society of London, p. 249-303.

4. Reynolds, R.C., 1985, Principles and techniques of quantitative analysis of clay minerals by X-Ray diffraction methods: Short Course Notes, The Clay School, Denver, pp. 36.

5. Sordon, J., 1980, Precise identification of illite/smectite interstratifications by X-Ray powder diffraction: Clays and Clay Minerals, V.28, p. 401-411.

6. Sordon, J., 1984, X-Ray powder diffraction identification of illitic materials: Clays and Clay Minerals, V. 32, p. 337-349.

7. Schreiner, W.N. And Jenkins, R., 1983, Profile fitting for qualitative analysis in X-ray powder diffractometry: In Automated Powder Diffractometry, Norelco Reporter Special Issue 30, p. 66-69.

8. Wilson, M.D. and Pittman, E.D., 1977, Authigenic clays in sandstones: recognition and influence of reservoir properties and paleoenvironmental analysis: Journal of Sedimentary Petrology, V. 47, p. 3 - 31.

9. Advance Core Analysis Report of Well RS-11-7, Core Laboratories, USA, 2008.

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