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Diagenetic studies on the Reservoir Rocks of Nannilam and Bhuvanagiri formations of Kanjirangudi Field of Ramnad Sub-Basin

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Abstract

Basic petrophysical and Mercury Injection Capillary Pressure (MICP) studies were carried out on reservoir cores of Bhuvanagiri and Nannilam formations of Kanjirangudi field with the aim to evaluate the extent of diagenesis in both the formations. Pore throat distribution was experimentally determined by MICP method and the same was utilized to evaluate extent of diagenesis. The present study evidently depicts that the diagenesis involves smectitic clay and Calcium carbonate cementation causing alteration of pore distribution. The reduction of larger pore throats were ascribed to the process of diagenesis. The gradual increase in diagenesis corresponds to incremental displacement pressure and irreducible saturation. Characterization of reservoir facies have been done on the basis of k/ϕ ratio and extent of diagenesis is associated with gradual decrease in k/ϕ ratio.

Introduction

Reservoir sands of Bhuvanagiri and Nannilam formations of Kanjirangudi field are believed to be adversely affected due to clay diagenesis destroying primary porosity and altering the original pore type and geometry of the pores. The factors contributing to diagenesis are temperature, pressure and age. Increasing temperatures increase the solubility of many different minerals which get increasingly dissolved in pore waters with time. The main effect of pressure is compaction, causing loss of porosity. However, the presence of smectite clay and calcium carbonate cementation, evidently indicates another course of diagenesis.

Present study aims at evaluation of extent of diagenesis process through studies on pore distribution through Mercury Injection Capillary Pressure on core samples. Variation of the same across the two formations, have been utilized to indicate the extent of diagenesis. Further the process of diagenesis alters porosity/ permeability ratio whose variation have also been employed as indicator of diagenesis in the present study.

Experimental

The core plugs were cut from the core segments of different cores from the Kanjirangudi wells of Cauvery basin, using the core cutting machine. These core plugs were thoroughly washed with water and dried in the oven at 80 – 90^{0}C. Then plugs were soxhlated using toluene for completion of 4 cycles and are dried in the hot air oven for 4 hours. These core plugs were then preserved in desiccators. The length and diameter of these cylindrical core plugs were measured using the Vernier Caliper to determine their bulk volume. The weights of the dry plugs were also measured to determine their grain density.

The porosity of the core plugs was determined using Helium Porosimeter and the permeability was determined by using Gasperm permeameter. Porosity calculations are based on Boyle's Law. Permeability of plugs were determined using steady state principle in which nitrogen gas is flown across the core plugs under constant (steady) pressure difference. Mercury injection capillary pressure curve was generated by injecting mercury into the pores of the rock samples (cuttings and plugs) at incrementally higher pressure. Displacement pressure (P_d) was determined from the injection pressure at which mercury starts intruding into the pores. Irreducible wetting phase saturation (Sw_{irr}) is determined from the saturation value below which the Sw cannot be reduced despite increase in pressure. Pore throat sorting values (PTS) is determined from the square root of the ratio of the 3rd quartile pressure to 1st quartile pressure.

Results & Discussion

The porosity distribution of Nannilam Formation ranges from 8% to 42% (Table 1). However most frequent porosity range is 30%-35% (Fig 1(a)). The Permeability distribution ranges from 0.02 - 336mD (Table 1) and highest permeability range is 50-250mD (Fig 1(b)). The porosity distribution of Bhuvanagiri Formation lies from 14% to 28% (Table 2) and most frequent porosity range is 20%-25% (Fig 2(a)). The Permeability value ranges from 0.08 – 9.3 mD (Table 2) and most frequent permeability range is 1-9mD (Fig 2(b)). From the k and ϕ values distribution, Bhuvanagiri Formation appears to be more diagenised than Nannilam Formation.

For Nannilam Formation, Displacement pressure (P_d) varies from 0.14 to 4.70 atm (Table 3) while for Bhuvanagiri Formation, it varies from 0.39 to 1.98 atm (Table 4). Low value of P_d indicates favourable and higher values unfavourable reservoir characteristics. Irreducible saturation (Sw_{irr}) values for Nannilam Formation vary from 0.037 to 0.947 (Table 3) with most frequent Sw_{irr} range of 0.4-0.5 (Fig 7) For Bhuvanagiri Formation, Sw_{irr} ranges from 0.206 to 0.781 (Table 4) with most frequent Sw_{irr} range of 0.5-0.8 (Fig 8). The Sw_{irr} values for Bhuvanagiri formation are relatively higher than Nannilam Formation corroborating to the poorer petrophysical properties of Bhuvanagiri Formation.

On the basis of ϕ and k cross plot, Nannilam Formation exhibit three types of reservoir rock facies. (Fig 3)

Type 1: k/ϕ = 0.5-5
Type 2: k/ϕ = 5-50
Type 3: k/ϕ = 50-500

On the basis of porosity and permeability values, Bhuvanagiri Formation exhibit two types of reservoir rock facies. (Fig 4)

Type 1: k/ϕ = 0.5-5
Type 2: k/ϕ = 5-50

The attributes of different reservoir facies are concurred by capillary pressure and pore throat distribution curves for Nannilam (Fig 5) and Bhuvanagiri (Fig 6) formations. The obliteration of porosity and permeability is ascribed to presence of smectite clay and calcium carbonate cementation which is ascertained from SEM analysis of the core samples. (Fig 9)

Conclusion

The present study on diagenesis connotes that Nannilam Formation exhibits better reservoir characteristics than that of Bhuvanagiri Formation. The basic petrophysical study reveals that the porosity and permeability values in Nannilam Formation are higher and vary in wider range than that for Bhuvanagiri Formation. Based on k/ϕ ratio, three reservoir facies have been identified for Nannilam Formation having different extent of diagenesis. Similarly, for Bhuvanagiri Formation, two reservoir facies are identified showing relatively higher degree of diagenesis than that in Nannilam Formation and MICP studies also corroborates the same. Low k/ϕ ratio signifies higher extent of diagenesis whereas high k/ϕ ratio represents less diagenesis. Transition from high to low k/ϕ ratio indicates progress of diagenesis. k/ϕ value distribution evidently indicates higher extent of diagenesis in Bhuvanagiri Formation than that in Nannilam Formation.

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Tables & Figures

Table 1: Basic petrophysical data for Nannilam Formation

Sample No.	Well No.	Core No.	Depth (m)	Grain Density (g/cc)	Porosity (%)	Permeability (mD)
1	A	CC-1	2171.58	2.71	34.08	335.96
2	A	CC-1	2171.58	2.70	37.96	304.24
3	A	CC-1	2172.35	2.68	31.97	215.09
4	A	CC-1	2172.35	2.72	35.57	301.96
5	A	CC-1	2173.25	2.70	30.45	101.06
6	A	CC-1	2173.25	2.70	30.99	92.89
7	A	CC-1	2174.15	2.69	31.72	187.19
8	A	CC-1	2174.15	2.70	31.41	199.32
9	A	CC-1	2176.48	2.70	19.18	1.95
10	A	CC-1	2176.48	2.70	20.58	2.38
11	B	CC-1	1946.26	2.70	21.78	2.08
12	B	CC-1	1946.26	2.71	23.81	1.73
13	B	CC-1	1947.34	2.65	8.10	0.03
14	B	CC-1	1947.34	2.63	8.43	0.02
15	B	CC-1	1948.11	2.73	24.99	11.40
16	B	CC-1	1948.11	2.74	25.84	13.43

17	B	CC-1	1949.39	2.74	22.86	5.40
18	B	CC-1	1949.39	2.73	24.18	4.70
19	D	CC-2	1984.03	2.70	26.57	24.08
20	D	CC-2	1984.03	2.71	27.70	42.40
21	D	CC-2	1985.25	2.68	30.21	117.41
22	D	CC-2	1985.25	2.68	30.14	94.28
23	D	CC-2	1987.01	2.69	34.28	197.14
24	D	CC-2	1987.01	2.67	41.49	322.78
25	D	CC-2	1987.63	2.71	31.20	113.97
26	D	CC-2	1987.63	2.71	33.11	139.75
27	D	CC-2	1988.65	2.69	29.24	89.79
28	D	CC-2	1988.65	2.69	31.43	95.61
29	D	CC-2	1989.64	2.69	22.50	4.62
30	D	CC-2	1989.64	2.71	23.89	8.47
31	D	CC-2	1991.62	2.68	24.03	18.97
32	D	CC-2	1991.62	2.69	24.21	5.61
33	D	CC-2	1991.82	2.70	25.73	3.81
34	D	CC-2	1991.82	2.75	26.54	4.60
35	E	CC-1	2036.36	2.69	26.07	172.32
36	E	CC-1	2036.36	2.70	29.34	208.72
37	E	CC-1	2037.28	2.72	12.42	0.16
38	E	CC-1	2037.87	2.71	28.47	36.0
39	E	CC-1	2037.87	2.71	29.89	33.90
40	E	CC-1	2038.17	2.69	24.78	22.66
41	E	CC-1	2038.17	2.70	27.92	39.89
42	E	CC-1	2038.71	2.70	25.35	16.99
43	E	CC-1	2038.71	2.70	27.21	26.15
44	E	CC-1	2039.54	2.70	26.54	24.44
45	E	CC-1	2039.54	2.71	28.34	11.85
46	E	CC-1	2040.88	2.71	26.62	11.70
47	E	CC-1	2040.88	2.72	25.99	8.97
48	E	CC-1	2041.70	2.69	25.61	113.95
49	E	CC-1	2041.70	2.71	27.86	117.90
50	E	CC-1	2042.88	2.68	27.72	108.69
51	E	CC-1	2042.88	2.70	26.99	102.92
52	E	CC-1	2043.80	2.67	24.21	100.54
53	E	CC-1	2043.80	2.68	25.64	90.083
54	E	CC-1	2045.77	2.69	27.75	176.15
55	E	CC-1	2045.77	2.72	28.24	178.65

Table 2: Basic petrophysical data for Bhuvanagiri Formation

Sample No.	Well No.	Core No.	Depth (m)	Grain Density (g/cc)	Porosity (%)	Permeability (mD)
1	A	CC-2	2340.42	2.59	18.02	0.12
2	A	CC-2	2340.42	2.60	19.89	0.13
3	A	CC-2	2341.37	2.63	20.01	0.11
4	A	CC-2	2341.37	2.65	21.22	0.08
5	C	CC-2	2165.53	2.63	20.48	4.05
6	C	CC-2	2165.53	2.68	27.93	5.28
7	C	CC-2	2166.60	2.65	20.70	7.52
8	C	CC-2	2166.60	2.66	24.84	9.32
9	C	CC-2	2167.15	2.71	17.20	1.30
10	C	CC-2	2167.15	2.72	20.27	1.82

11	C	CC-2	2168.60	2.62	19.16	3.53
12	C	CC-2	2168.60	2.63	19.85	3.07
13	C	CC-2	2169.42	2.69	20.79	3.83
14	C	CC-2	2169.42	2.69	21.54	2.73
15	C	CC-2	2170.85	2.72	18.98	0.75
16	C	CC-2	2170.85	2.71	20.10	0.53
17	C	CC-2	2171.15	2.73	19.87	0.81
18	C	CC-2	2171.15	2.73	20.67	0.95
19	D	CC-3	2189.20	2.72	21.18	0.75
20	D	CC-3	2189.20	2.73	19.11	0.82
21	D	CC-3	2190.15	2.71	15.12	2.41
22	D	CC-3	2190.15	2.71	15.87	2.36
23	D	CC-3	2197.47	2.69	19.01	1.33
24	D	CC-3	2197.47	2.71	20.89	2.58
25	D	CC-3	2192.19	2.68	21.50	3.08
26	D	CC-3	2192.19	2.68	22.00	4.04
27	D	CC-3	2194.80	2.68	13.99	0.63
28	D	CC-3	2194.80	2.68	16.42	0.55
29	D	CC-3	2195.52	2.72	14.57	0.55
30	D	CC-3	2195.52	2.72	14.55	0.45
31	D	CC-3	2196.65	2.69	15.54	1.38
32	D	CC-3	2196.65	2.71	16.03	1.30
33	D	CC-3	2197.33	2.69	17.60	2.79
34	D	CC-3	2197.33	2.70	17.03	3.05

Table 3: MICP Parameters for Nannilam Formation

Plug No.	Well No.	Core No.	Depth (m)	Displacement pressure (P_d)	Pore throat Sorting	Sw_{irr}
1	A	CC-1	2171.58	0.81	2.89	0.406
2	A	CC-1	2172.35	1.40	1.89	0.369
3	A	CC-1	2173.25	0.94	2.50	0.144
4	A	CC-1	2174.15	1.29	2.50	0.647
5	A	CC-1	2176.48	0.60	2.58	0.795
6	B	CC-1	1946.26	0.14	1.00	0.923
7	B	CC-1	1947.34	0.19	1.00	0.947
8	B	CC-1	1948.11	1.06	2.98	0.426
9	B	CC-1	1949.39	2.91	2.74	0.310
10	D	CC-2	1984.03	0.82	2.39	0.448
11	D	CC-2	1985.25	1.65	1.87	0.289
12	D	CC-2	1987.01	1.73	1.90	0.208
13	D	CC-2	1987.63	0.77	3.16	0.493
14	D	CC-2	1988.65	4.70	2.93	0.155
15	D	CC-2	1989.64	1.56	2.00	0.366
16	D	CC-2	1991.82	1.39	2.00	0.486
17	E	CC-1	2036.36	1.78	2.00	0.184
18	E	CC-1	2037.28	2.00	3.16	0.617
19	E	CC-1	2037.87	1.23	2.45	0.372
20	E	CC-1	2038.17	1.53	2.36	0.311
21	E	CC-1	2038.71	0.89	2.74	0.467
22	E	CC-1	2039.54	1.12	3.00	0.388
23	E	CC-1	2040.88	1.04	2.39	0.385
24	E	CC-1	2041.70	1.45	2.39	0.320
25	E	CC-1	2042.88	1.08	2.37	0.342

26	E	CC-1	2043.80	0.69	3.16	0.264
27	E	CC-1	2045.77	1.57	2.45	0.037

Table 4: MICP Parameters for Bhuvanagiri Formation

Plug No.	Well No.	Core No.	Depth (m)	Displacement pressure (P_d)	Pore throat Sorting	Sw_{irr}
1	A	CC-2	2340.42	0.64	1.71	0.551
2	A	CC-2	2341.37	0.65	1.58	0.518
3	C	CC-2	2165.53	0.39	2.74	0.747
4	C	CC-2	2166.60	0.67	2.12	0.621
5	C	CC-2	2168.60	0.60	1.83	0.709
6	C	CC-2	2170.85	0.63	1.63	0.781
7	C	CC-2	2171.15	0.56	1.73	0.752
8	D	CC-3	2190.15	1.08	2.11	0.268
9	D	CC-3	2197.47	0.62	4.47	0.327
10	D	CC-3	2192.19	0.77	2.83	0.357
11	D	CC-3	2194.80	1.40	1.55	0.418
12	D	CC-3	2195.52	1.04	1.53	0.498
13	D	CC-3	2196.65	1.98	1.63	0.437
14	D	CC-3	2197.33	1.26	2.79	0.206

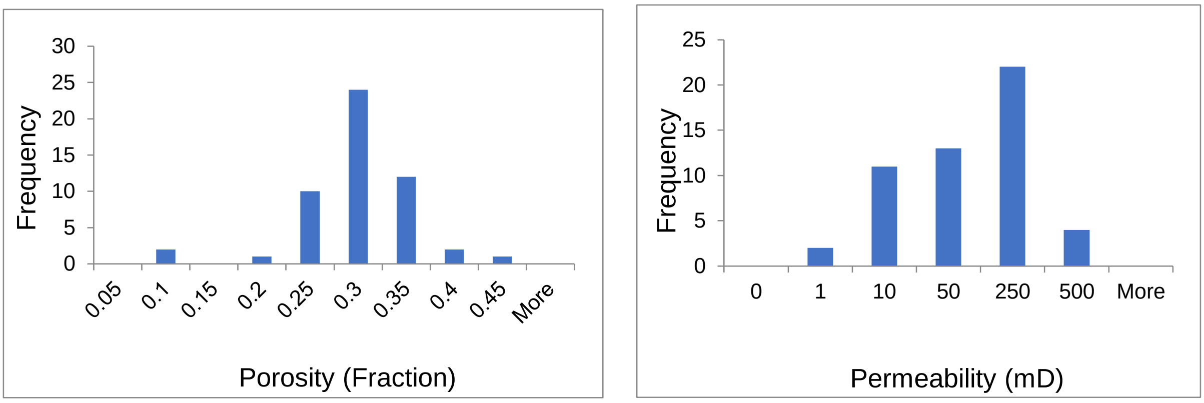
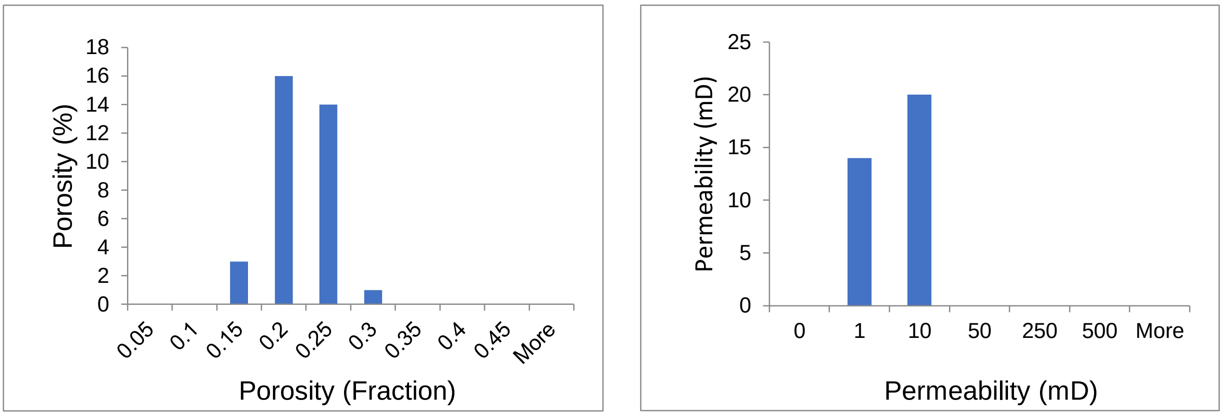


Fig 1(a): Porosity distribution **Fig 1(b): Permeability distribution**

Fig 1: Porosity and Permeability distribution for Nannilam Formation



tion **Fig 2(b): Permeability**

Fig 2: Porosity and Permeability distribution for Bhuvanagiri Formation

Fig 3: k-ϕ cross plot for Nannilam

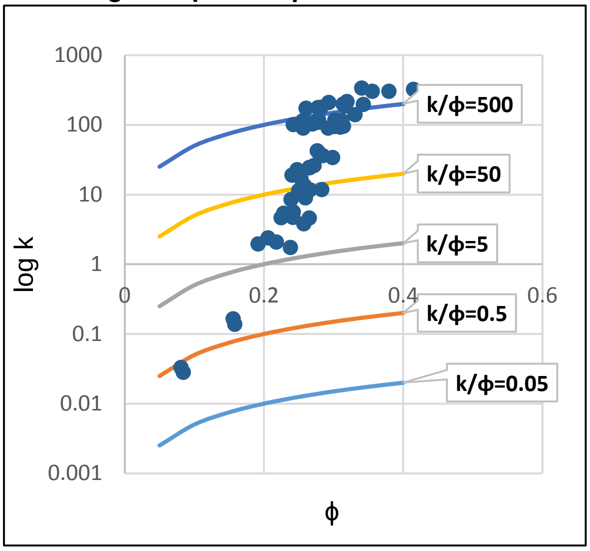
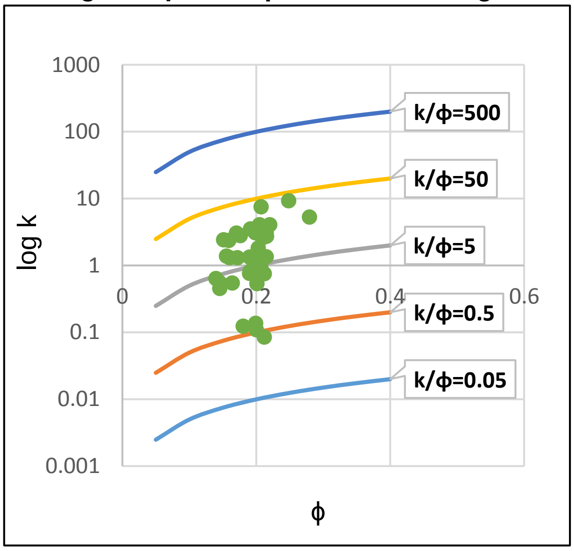


Fig 4: k-ϕ cross plot for Bhuvanagiri



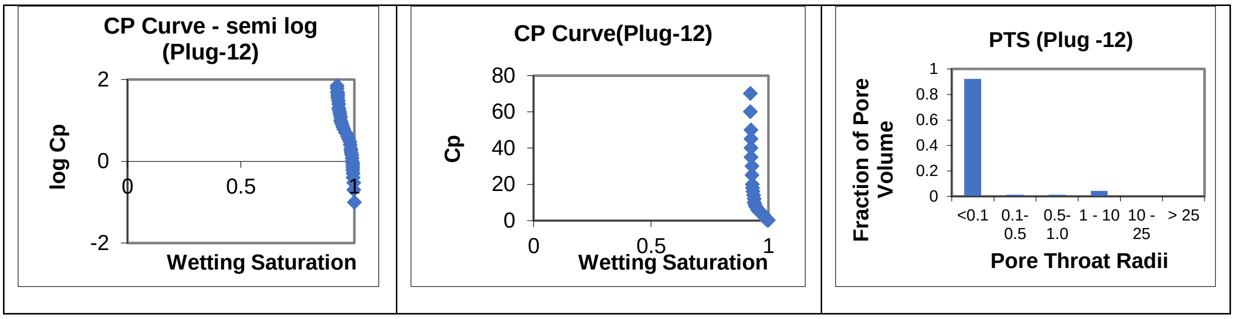


Fig 5 (a): Type 1

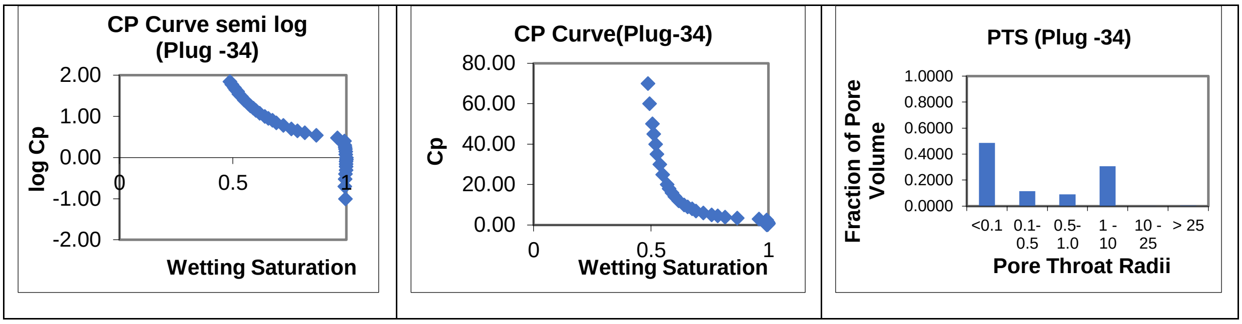


Fig 5(b): Type 2

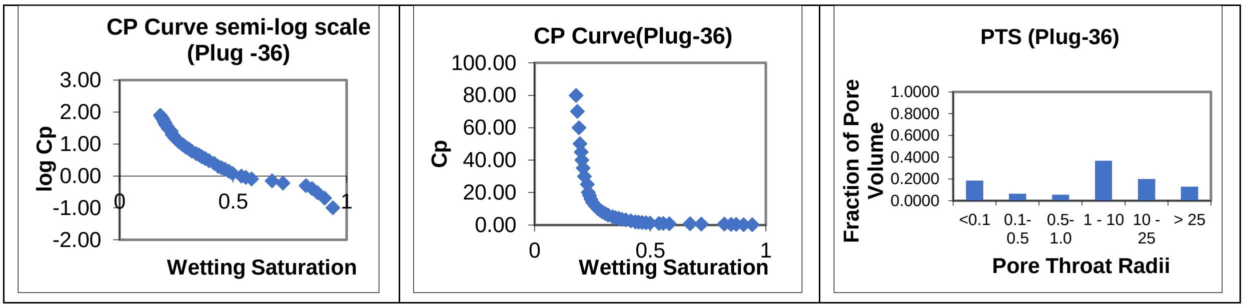


Fig 5(c): Type 3

Fig 5: Capillary pressure and pore throat distribution curves for Nannilam Formation

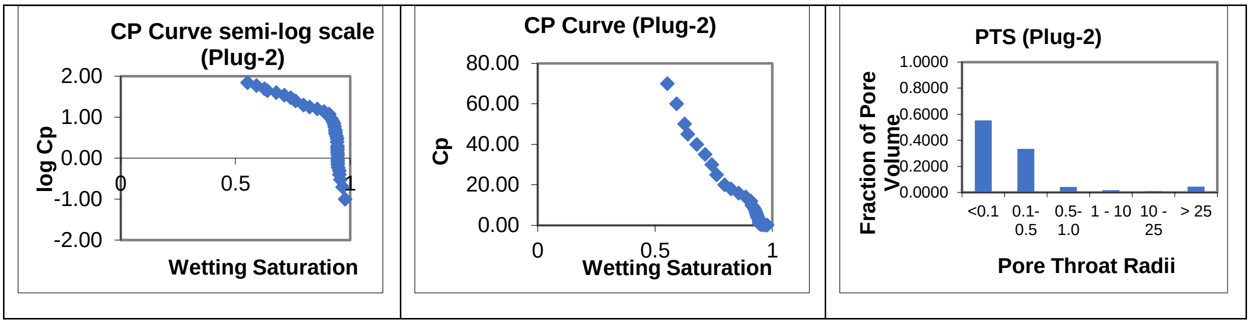


Fig 6(a): Type 1

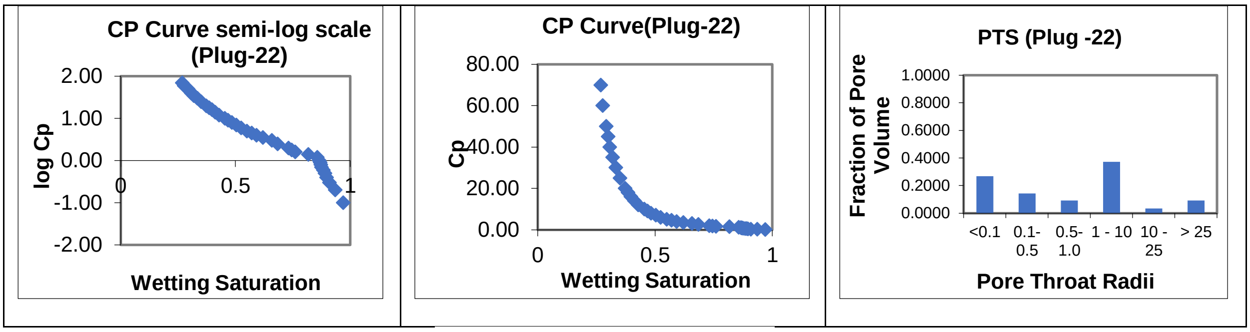


Fig 6(b): Type 2

Fig 6: Capillary pressure and pore throat distribution curves for Bhuvanagiri Formation

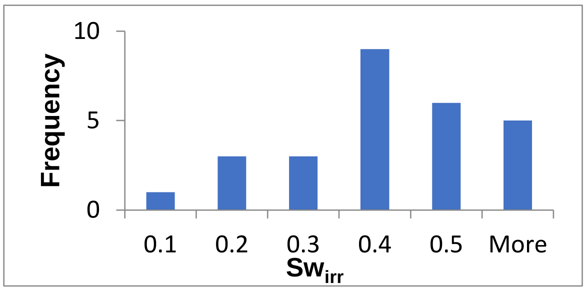


Fig 7: Irreducible saturation for Nannilam Formation

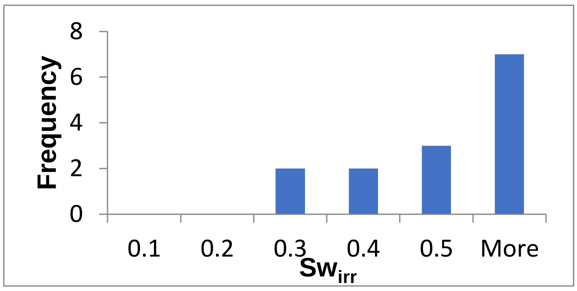


Fig 8: Irreducible saturation for Bhuvanagiri Formation

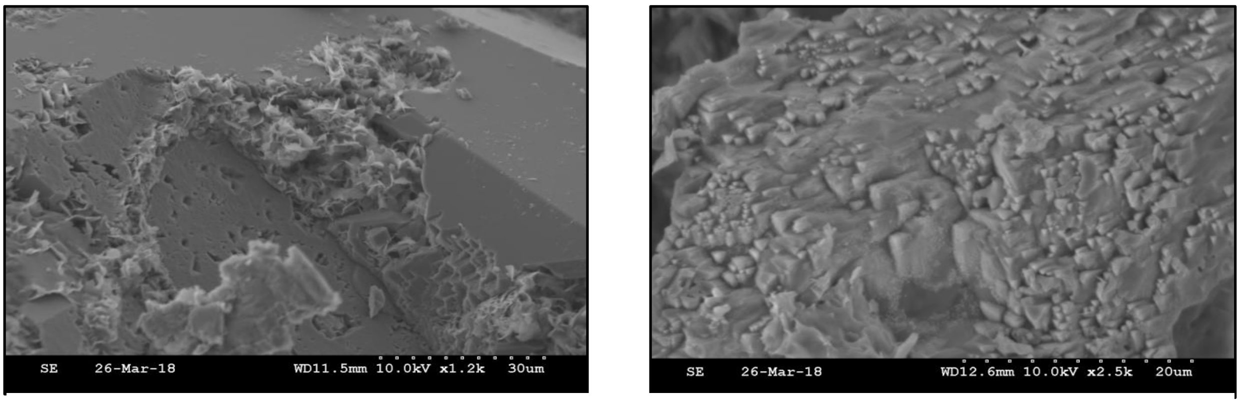


Fig 9. SEM photograph showing development of smectite clay from feldspar grains destroying the porosity (left) and calcium carbonate cementation(right) .