



P 253

## A New Approach to interpret Shaly/Silty Reservoirs

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### Summary

Anklav field is located in Cambay Tarapur block of Cambay Basin. Eight wells have been drilled of which two are hydrocarbon bearing and rest are dry. Reservoir characters are masked due to complex lithology and bad borehole conditions. In general, formation is characterized by low density, high neutron and high sonic travel time. Evaluation of such reservoir is difficult with conventional deterministic approaches. Various cross plots have been generated to understand the lithology and its variation with depth as well as with respect to different axis. From the cross plots and correlation profiles, wells are grouped in three clusters, out of these western side clusters are significantly deeper and compact with absence of coal peaks.

NGS cross plots indicates presence of Chlorite and Kalonite, which is further supported by XRD studies. In spite of heavy clay mineral, shale manifests low density and high neutron porosity, possibly due to lack of compaction. CMR data shows high capillary bound porosity and low free fluid porosity. This is in agreement with capillary pressure studies carried on the cores. A model consisting of Quartz, Kaolinite, Chlorite and Coal has been found appropriate in explaining reservoir characteristics. The processed results are consistent with testing results and CMR porosities.

The study has successfully explained the hydrocarbon potential of the formations in question. It is expected that this model will help the future exploration in the field.

Keywords: Cambay Basin, Data Interpretation

### Introduction

Anklav Field is located on the eastern rising flank of Tarapur depression in Cambay-Tarapur tectonic block of Cambay Basin. The Paleogene sequence in the area is represented by Trap, Olpad, Cambay, Kalol & Tarapur formations. Few wells have been drilled in this field. These wells form three clusters in the field (Plate1). Sand-I in Tarapur formation has been found hydrocarbon bearing in wells C & G. The formation has been dated as Middle & Upper Eocene.

Apart from the conventional suite of logs, Spectral Gamma Ray Logs have been recorded in Well # C, E and G. CMR log has been recorded in selected intervals of well #G.

Conventional cores in Kalol and Cambay sections have been taken in wells #B,D & E. Detailed lithostatigraphic descriptions for these cores have been carried out (Ref-2).XRD studies were conducted for cores of well B only. (Ref-1)

X-Ray diffractometer study in Well #B (Ref-1) has two significant findings from the core reports:

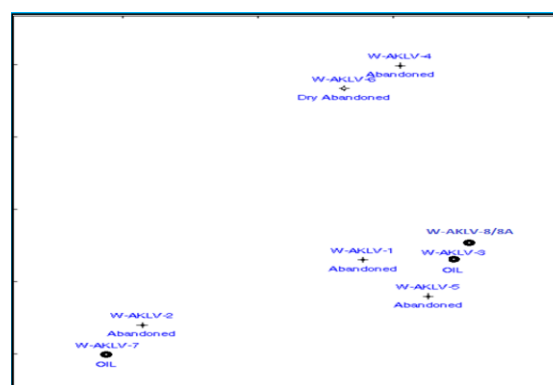


Fig 1.: Location Map of Wells in Anklav Field

- Kaolinite & Chlorite as main clay mineral and complete absence of Montmorillonite right from Top to bottom.
- The general description of formation are as carbonaceous and pyritiferous. These findings have



guided in fixing the petrophysical model for this study.

### Challenges in Log Interpretation

The Cambay Shales and Kalol Formations in this field do not show good reservoir facies anywhere. In general the formation is characterized by low density-very high porosity (0.5-0.7pu) throughout. The silty portions present themselves as slightly high resistivity streaks with subtle SP and mud cake development. The formations seem to be deposited in reducing conditions and dispersed with minerals like pyrite and coal which have opposing tendencies on logs. The cores have reported presence of small coal fragments in these formations.

The formations have not reached enough depth of burial to get fully compacted. Differential under-compaction trends seen within the field further complicates the problem. As the depth of burial increases from northern end to the south, change in the values of RHOB, NPHI and DT curves can be seen. This trend is quite visible on the RHOB-NPHI cross plotted points towards lower NPHI, higher RHOB domain as we go from north to south. (Plate-2). The lack of compaction of these formations can also be inferred from the high DT values in shales(plate:6-11).This lack of compaction is manifesting itself as good amount of capillary bound water (15-20% in general) as seen in CMR log of well #G. Therefore to identify the potential zone it is imperative to

- Understand the complexity by cross plots and lab data
- Formulate a model for processing/evaluating log data

### Analysis of Available Data

#### Cross plot Trends

The RHOB-NPHI, NPHI-GR and DT-GR cross plots for all 6 wells # B to G are for different formations, (Plates 2). It is evident from the location map that drilled wells are in three clusters and same observation is clearly visible in the cross plots. From cross plots it can be clearly seen that there are three different trends for all formations. Two wells#B & G, wells#C & E and wells#D & F forming three clusters in the field. On analyzing Cross plots the wells D & F appear quite different from others as the pattern here is elongated along NPHI axis as compared to other wells where it is elongated along RHOB axis. Moving from cluster of Wells#C&E to Wells#B & G, the pattern shifts toward higher RHOB & lower NPHI.

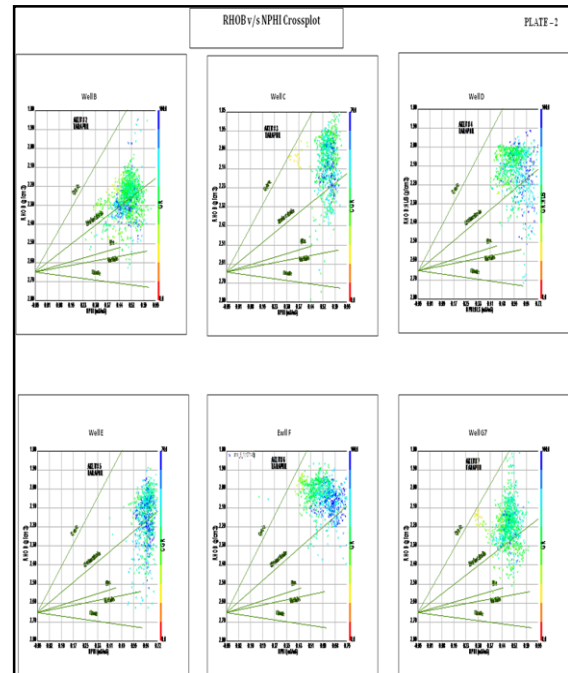


Fig. 2

Th Vs. Pota, PEF Vs Th Pota ratio and PEF Vs Pota (plates 3, Well #G).In general a high thorium, low potassium environment is indicated by these plots. All of them indicate the presence of kaolinite and chlorite with high thorium minerals. This observation is reiterated by the XRD report of well #B. Despite the presence of heavy clay minerals (chlorite-2.9 gm/cc, kaolinite-2.6 gm/cc) the clustering of shale points in low density high porosity domain can be explained only as a result of lack of compaction. The under compactness of the formation is supported by the high DT values against shales in these wells. (Plate-6-11)

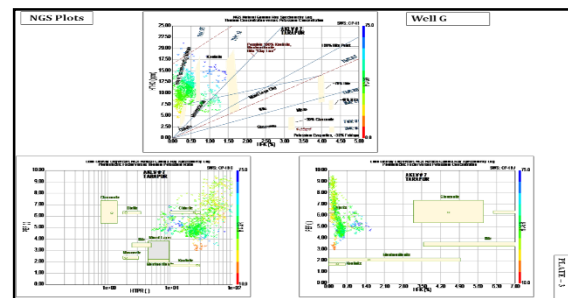


Fig. 3

Most of the points lie outside the range of these conventional lines (Plate-4, Sandstone, Limestone and Dolomite lines) showing pull towards low density-high

porosity domain. The reason of this pull is mainly unconsolidated /loose formation.

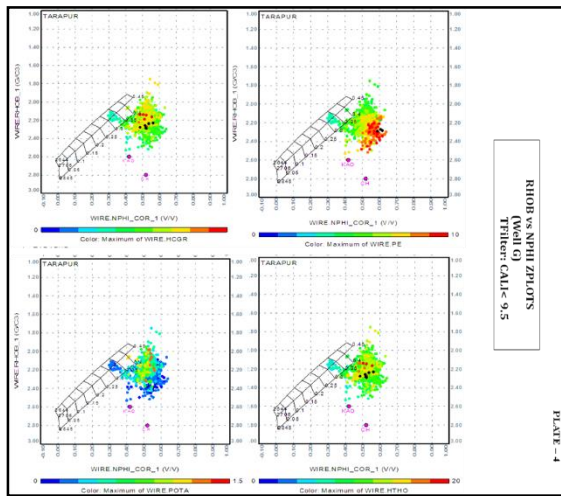


Fig. 4

As seen on CMR log of Well #G this increased porosity appears in the form of capillary bound water. In well #C and G, sand-I has good reservoir properties and has produced oil. These sands stand out distinctly on the cross plots of both the wells. Looking at crossplots Plate-4 for well G few points lie in the category of typical silt facies No association of high PE or THOR is seen with any of the silty points except for the sand-I in Well #C which shows high PE values.

In the final analysis the distribution of points in the RHOB-NPHI crossplot can be explained by the presence of kaolinite and chlorite (converging in higher RHOB, higher NPHI, low THOR and higher PE) due to capillary bound water. Silty facies in the area don't seem to be associated with heavy minerals.

### CMR Data

CMR log was recorded in Well #G covering two formations, very rarely the T2 distribution crosses 33ms mark. However Total CMR porosities recorded are high throughout the interval (more than 0.24 pu), except for the interval 1167-1178m (where small pore porosity dominates). Capillary bound fluid dominates throughout the recorded interval. Free fluid porosity remains very low throughout. Even in hydrocarbon bearing sand-I (interval 1102-1110 m) max recorded free fluid porosity is 0.12 pu (out of TCMR porosity of 0.35 pu)

Also high capillarity in these formations is confirmed by the capillary pressure studies carried out on the cores of

Well #D and E. The low amount of clay bound water is in agreement with the presence of chlorite (WCLP~ 0.1 p.u.) and kaolinite (WCLP~ 0.06 p.u.) as the main clay minerals.

### Petrophysical Study of Cores

From the core study in Well# D (CC-1, Int.746-755m),  $\Phi_e$  varies from 29.36-34.57% with 31.27% as geometric mean  $\Phi_e$ . (Plate-9)

In Well #E (CC-1, Int.791-799m), observed wider variation (17.89%-46.47%) in  $\Phi_e$  with maximum frequency in between 23%-35% & geometric mean  $\Phi_e=27.6\%$ . large variation (6.17-26.24%) in  $\Phi_e$  is also visible from Well #E CC-2, Int.799-808m). (Ref-2) (Plate-10).

However significant findings of generalized nature were obtained from the study which has corroborated with the CMR porosities (recorded in well #G). The results confirm the existence of high effective porosities in the shaly/ silty sections.

### Formation Evaluation Technique

Different literatures have been promoting the idea of using clay end points instead of cross plotted shale end points for better porosity evaluation and honoring the presence of bulk porosity or "effective porosities" in shale (Ref-3 & 4). Plate-5 is an illustration of what different researchers have found for a function of shale porosity versus depth working in different basins. Above the depth of burial of 5000 ft, (=1500M) the shales may have high ranges of bulk porosities. Of primary importance to the log analyst (as stressed by references) is to recognize that, shales do have bulk porosities in addition to clay ionically bound water. As the shales become more compact, this clay bound porosity approaches 100% of the shales pore space since the bulk water is driven-off in the compaction process.

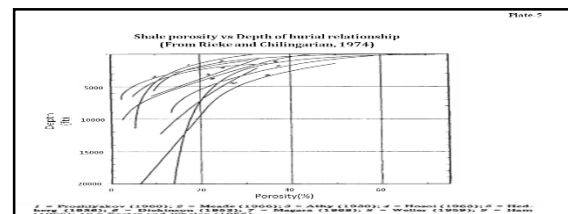


Fig. 5

Acceptance of high effective porosities in silty shaly formations is important to properly evaluate the prospectivity of silty reservoirs juxtaposed with these.



Traditionally silty reservoirs have been evaluated by identifying end points for matrix (quartz), shales and silt porosity-medium on RHOB-NPHI cross plots. Silty facies generally differentiate themselves because of its association with fine grained heavy minerals. In the present field it is even difficult to fix the end point for shales because of clustering of high GR points in the middle of the plot as seen in Plate-4, well#G. Also two types of clays (Chlorite & Kaolinite) are evident in the cross plots. A technique multiminerall approach has a reasonable control over fixing of mineralogical parameter.

It is beyond the capability of multiminerall modeling approach to differentiate between capillary bound and free fluid porosities. This limitation presents itself as a poor contrast between effective porosities computed against shaly and silty portions, which, however represents the reality. In general it has been observed that High effective porosities (upto 0.35 p.u.) are disproportionate to the volume of quartz. This is on account of presence of bulk/effective porosities in shales. The water saturation (SWE) computed using these porosities will however be closer to reality and differentiates between potential and non potential reservoirs. Therefore, CMRFF and effective porosity in silty shaly formation will not be the same.

## Log Processing

### Mineralogical Model

From the core report of Well # B, analysis of cross plots of Wells, in Well # C, E & G the major minerals were identified to use for processing are: Quartz, Kaolinite, Chlorite and Coal. It is difficult to model silt separately as end points for silt are close to chlorite. The volume of chlorite and silt has been presented together. Multiminerall Module of GEOLOG (M/s Paradigm) was used to process the data.

Dual Water Saturation equation was chosen with default parameters ( $a=1$ ,  $m=n=2$ ). Conductivities of these shales will depend on the CEC/ Wet Clay Porosity (WCLP) parameter defined for the two shales. In the absence of clean water bearing formations in the region,  $R_w$  values for Tarapur 0.3 at 176 °F, Kalol 0.25 at 176 °F and Cambay 0.22 at 180 °F have been used based on testing results.

## Discussions of Processed Results

**Well#G**, Plate-6 presents the processed results of Tarapur section. Against sand-I (1103-1107m) computed effective porosities are in the range of 0.23 to 0.27 and SWE 54% to 60%. The interval 1103-1106.5m produced oil @ 52m<sup>3</sup>/day on self. For all other zones' computed porosities are in the range of 0.15- 0.3. It matches closely with CMR\_3ms porosities.

Plate-7 presents the processed results of Kalol section, where 3.75 lts of water at 1267.5 m (MDT sample) was found. Effective porosities computed are in the range of 0.15-0.20 p.u. It matches closely with CMR\_3ms porosities.

In this well CMR free fluid porosity is only 10 -12 % if this is to be considered as effective porosity instead of computed porosity (about 20 % and more) then computed water saturation will be around 90 % or more which will be against the testing results. Therefore it can be concluded that effective porosity is more and it consists of both free fluid as well as capillary bound porosity. This free fluid porosity is for the purpose of production whereas effective is to assess the potential of zone.

**Well#C**, Plate-8 presents the processed results of Tarapur section. Sand-I in the interval 651.5-655.5m oil @ 9m<sup>3</sup>/d. Computed effective porosities are in the range of 0.30-0.35 p.u. and SWE between 10-20 %. This is in agreement of testing results.

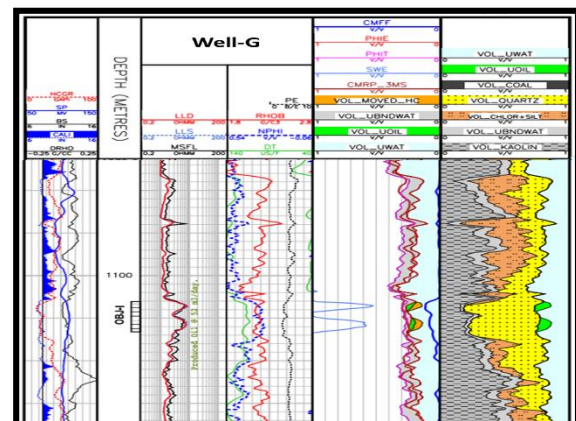


Fig. 6

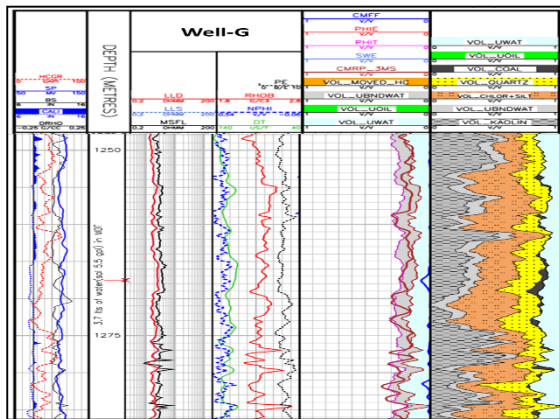


Fig. 7

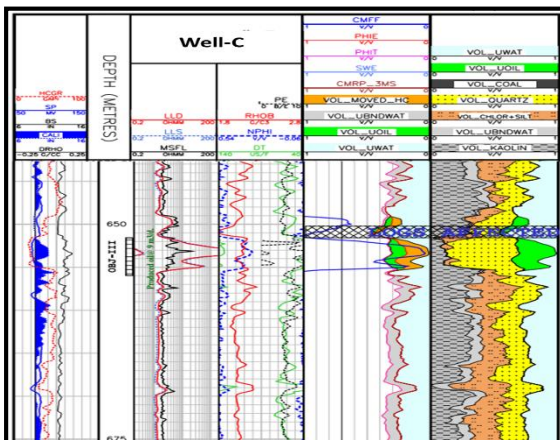


Fig. 8

Well#D. Plate-9 presents the processed results for Kalol and Cambay shales. Effective porosities are between 0.20 to 0.35 p.u. which is in agreement of core study CC-1 (Int.746-755m),  $\Phi_e$  varies from 29.36-34.57%.

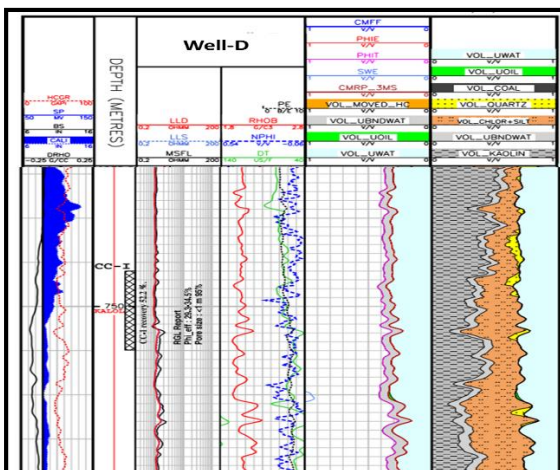


Fig. 9

Well#E. The processed result (Plate-10).Matches closely to those reported in the core study. (CC-1 791-799m) where variation in  $\Phi_e$  23%-35% and 6.17-26.24% (CC-2 Int.799-808m).

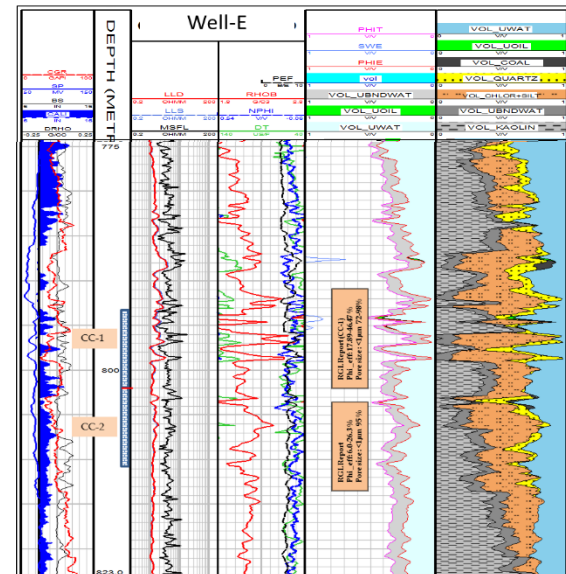


Fig. 10

Well #B, The intervals 1203-1200m and 1211-1208m of Sand -IV in Kalol formations were tested which gave traces of oil with water. Interval (1190-1250) was processed. The results are presented in plate-11. Effective porosities of about 0.20 p.u. were computed. SWE comes out to be 80-90 %. This is in agreement of testing results.

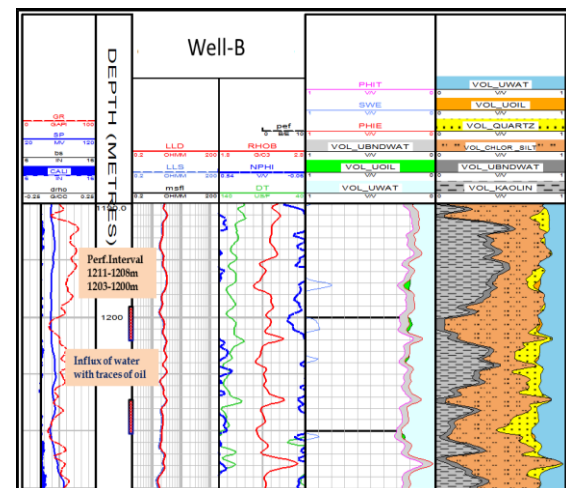


Fig. 11



## Conclusions

- The problem of evaluation of silty reservoirs is compounded by the under compacted nature of formations.
- Multi-mineral approach taking mineral end points (quartz, kaolinite and chlorite) and dual water saturation equation comes out as a better evaluation technique for such areas.
- Natural Gamma Ray Spectrometry Log data calibrated by XRD studies of Well#B has played a major role in identifying the type of clay minerals in the formations.
- In order to properly evaluate prospective of silty reservoirs, it is important to honor/ accept the presence of effective porosities in silty shale formations. The processed porosities are in close agreement to CMR porosity in well #G as well as petrophysical studies of cores of Well #D and Well #E.
- High effective porosities in silty shale formations in this field are because of the reason that, shales not being able to expel the water completely.
- The mineralogical model used is easier to extend to other clusters/ fields. The processed results of Well#C & Well#G are consistent with the actual tested results.
- It is beyond the capability of multimineral modeling approach to differentiate between capillary bound and free fluid porosities. In fields with prominence of capillary bound water, CMR data is very important for evaluation of both good and poor reservoir facies.

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