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Tight Sand Prospects of Nawagam Field, Cambay Basin, India

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Abstract

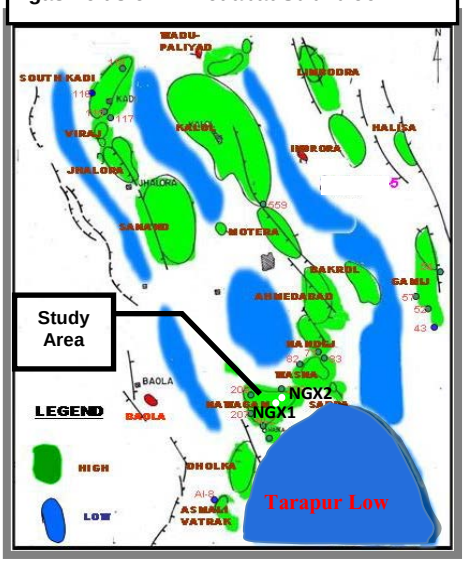
The main objective of this paper is to bring out the potential of tight reservoirs (TSG equivalents)/Shale Oil in Nawagam field along with Dholka, Naika and Mahelaj fields. Such tight reservoirs within oil window have been taken up deliberately for low cost exploration in idle/low producing wells, in India. The promising tight reservoirs/shale oil reservoirs are identified on the basis of geological and geophysical data including direct hydrocarbon shows while drilling along with electro-log characteristics. These tight reservoirs appear to have wide spread areal extent and sandwiched within source rock with TOC varying between 1.2-8% by weight, dominantly type-III organic matter along with 2 to10% type-II organic matter and maturity (Ro %) values between 0.6 to 1.1.Recent well testing of these zones have proved to be oil producing after successful frac job with modified fluid and modified fracking technique to deal with dominantly tight/siltyshale pay zones. This low cost exploration in existing idle/low producing wells is bearing fruits and enabling generation of new prospects. Further assessment is in progress to establish for conclusive assessment of "Tight Oil"/Shale Oil potential of Cambay Shale Formation.

Introduction

Nawagam Field is located in south-western part of Mehsana-Ahmedabad block of Cambay Basin, India. Cambay Basin is an intra-cratonicrift-basin on the north-western part of Indian craton. Oil and gas exploration, in Ahmedabad-Mehsana Block (Fig.1), Cambay Basin, is mainly focussed on prolific oil producing reservoirs of Kalol Formation with subsidiary interest in Cambay Shale and Olpad formations. Exploration for hydrocarbon had reached mature stage in Cambay Basin two decades ago. During the initial exploration stage emphasis was on structural traps with easily identifiable sandstone and siltstone reservoirs. However, with the enhanced pace of exploration, the structural elements in the block are more or less exhausted and the focus has now shifted to exploration of stratigraphic plays, deeper prospects. Through this paper, an attempt is made to share recent exploration activities on shale resources plays in Nawagam field.

Resource plays are characterised by wide geographical extent, insignificant structural juxta-position and presence of source-reservoir rock with mature organic matter. These plays spreading over large area shows considerable variability in terms of lithology, porosity and permeability. It is time to move on to these unconventional reservoirs/resource plays. Focussed and deliberate efforts are needed for tight/shale reservoirs, Tight Sand Gas (TSG) and shale oil/gas (resource plays). Leads obtained from drilling activities in Cambay Shale section in Nawagam Field provided one such exciting exploration opportunity of entire basin.

Fig.1: Major structural trends and oil & gas fields of AhmedabadSub- block

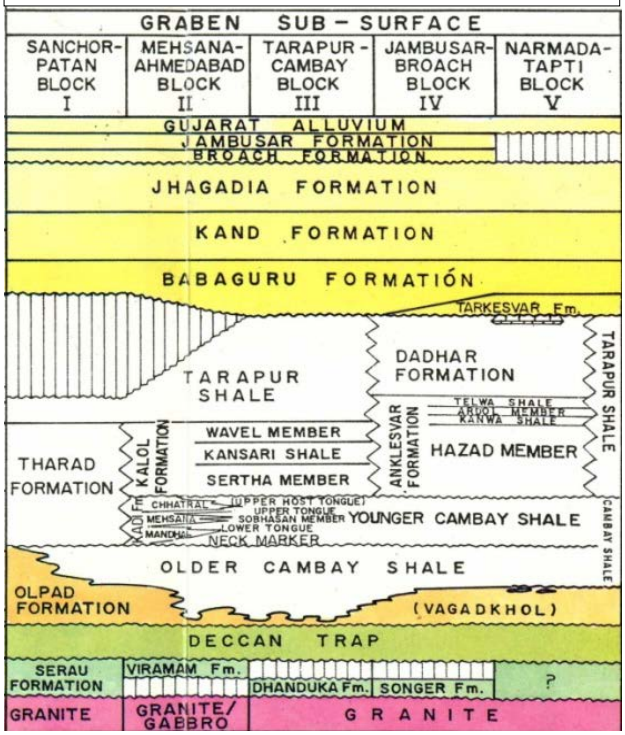


Four of the seven identified sweet spot zones, in Cambay ShaleFormation, in wells of Nawagam Field were tested and found to be hydrocarbon bearing. Production sustainability of two these zones are under progress in two inclined wells NGX-1 and NGX-2 (Fig.3). Three sweet spot zones were tested in one well and another such zone is tested in another well. All the four sweet spot shale zones tested yielded predominantly oil (API-33 to 39, pour point 36-39^{0}C) with feeble gas. To establish the true hydrocarbon potential of Cambay Shale Formation suitable completion and stimulation is required, in Nawagam-Mahelaj-Sadra area.

Geological Setting and Stratigraphy of Tight/Shale Reservoirs, Nawagam Field

High and low trends (NNW-SSE) in the sub-block of Ahmedabad are quite prominent and aligned with the basin margins (Fig.1). All major oil and gas fields are broadly located on the high trends reflecting the basement architecture.General stratigraphy of the Cambay Basin is well established (Fig.2). Deccan trap is considered as the technical basement of Tertiary deposits of Cambay Basin. Systematic data acquisition by ONGC from 1958 revealed number of horst and graben features at Deccan Trap level. During rifting stage syn-tectonic deposits of Olpad Formation are deposited as fault scarp fans to fluvial deposits unconformably over Deccan Traps. Cambay Shale Formation of Lower Eocene to Middle Eocene age, dominant source rock of the basin,is deposited in restricted shallow marine to lacustrine environment. It overlies unconformably over Olpad Formation and overlain para-conformably by Kalol Formation. Cambay Shale Formation is formally sub-divided into Younger Cambay Shale and Older Cambay Shale members. Olpad Formation and lower part of Older Cambay Shale are depositedduring syn-tectonic stage and rest of the Palaeogene sections are deposited during thermal subsidence stage. The Kalol Formation is overlain conformably by basin wide cap-rock of Tarapur Formation of Late Eocene to Oligocene age,in the North Cambay Basin, which includes the three major blocks of Patan-Sanchor, Mehsana-Ahmedabad and Tarapur, from north to south. Hydrocarbon generation,migration and accummulation have taken place in later phase of basinal inversion, ie in Late Miocene-Pliocene age.

Fig.2: General Stratigraphy of Cambay Basin



The Nawagamfield is “Table Top Structure” on a horst block, bounded by two sets of normal faults at top of Olpad and Older Cambay Shale formation top. First set, trending E-Win north and south of the field, another set trending NNW-SSE in the east and west of the field. The field on the horst block having an areal extent of 20km^2 is in the cusp of two prominent hydrocarbon pods, i.e. Jetalpur low in the north and west and Tarapur Depression in the south and east (Fig.1). The geological set-up is ideal for hydrocarbon accumulation in reservoir rocks in addition to in-situ shale oil from mature organic matter (Fig.4).Thickness of Cambay Shale Formation varies from 350-400minNawagam Field.

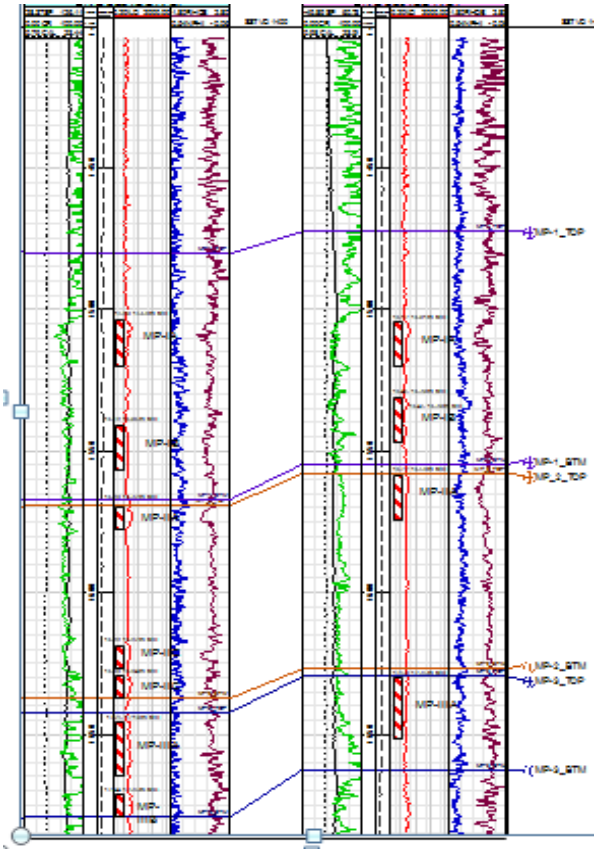
Nawagam Upper (Kalol Pays) and Lower Pays (Olpad Pays) are prolific oil and gas producers in Nawagam Field. Middle Pays (Cambay Shale) are better developed and prolific hydrocarbon producer in Dholka Field. In Naika field two wells are producing from siltstones developed in equivalent siltyshale.Three correlatable and mappablesiltyshale layers can be identified in Nawagam Field and other small fields over an area of about 250km^2. Correlation of these siltyshale layers can be extended to nearby fields of Naika, Mahelaj,andDholka(Fig.5, 6&7).

Study Methodology

The study was initiated on the basis of analysis of oil and gas shows observations made during drilling of development wells, drilled in 2009-2010. Gas and oil shows while drilling through Cambay Shale section are quite common in most part of Cambay Basin. So far only well-developed conventional reservoirs such as sandstone, siltstone and shaly siltstone reservoirs with high resistivity with good reservoir and petrophysicalcharacteristics within Cambay Shale are explored and developed in many fields. But these prospective zones within Cambay Shale Formation of Nawagam Field are characterised by absence of any characteristic feature on standard electrologs except lower density on density logs (Fig.3). Three units are identified within Younger Cambay Shale section on the basis of distinct correlative andmappableshale markers. Then "Sweet Spot" zones are identified within each units on the basis of correlatable oil and gas shows in six wells with comparatively lower shale density on the standard

logs.Few such sweet spot zones are tested. This section need to be characterised with laboratory data as there is no conventional core and special logs recorded for this section, though more than 250 wells were drilled**.**

Fig.3: ElectrologCorrelation of Wells NGX1&NGX2



These three units are named as Middle Pay Unit-I(MP Unit-I), Middle Pay Unit-II(MP Unit-II), and Middle Pay Unit-III(MP Unit-III). MP Unit-I is youngest and MP Unit-III is stratigraphically oldest. Top and bottom of the entire section is marked by correlatablehigh gamma zones. This section represents the lower part of Younger Cambay Shale. Top of Middle Pay Unit-I is about 110-140m below top of Cambay Shale Formation top in the field. While the base of Middle Pay Unit-III is Older Cambay Shale top. Within these units sweet spot zones (low density zones) are identified. Two sweet spot zones in Middle Pay Unit-I are named as MP-IA and MP-IB (Fig.3). Correlatable equivalents reservoirs of these two zones are oil producers in some wells of Dholka, Naika and Mahelaj fields. In these fields equivalent zones are siltstone to siltyshale and on the basis of subsurface data and electrolog characteristics these are interpreted to be oil bearing and are producing oil in few wells. The correlatablesiltyshale layers are extending over an area of 250 Km^2 to nearby fields of Naika, Mahelaj, Sadra and Dholka (Fig.1,3,5,6 & 7).

In Nawagam Field these layers appear to be most promising hydrocarbon prospects. MP-IA is not only wide spread but also its thickness is considerable andof all identified zones has most encouraging and consistent electrolog characteristics. Incidentally, maximum numbers of hydrocarbon shows were observed while drilling through it. Three such sweet spot zones are identified within Middle Pay Unit-II as MP-IIA, MP-IIB,MP-IIC, top to bottom. MP-IIA and MP-IIC was tested for oil and completed in wells NGX-2 and NGX-1 respectively. Two sweet spot zones MP-IIIA and MP-IIIB in lower most unit, Middle Pay Unit-III, tested oil in well NGX-1 (Fig-3).Middle Pay Unit-I, Unit-II and Unit-III are virgin prospects of Nawagam Field. Average cummulative prospective pay thickness is 45m in wells of Nawagam Field.

Source Rock Potential

Source rock potential of Cambay Shale Formation is well documented, with TOC varying between 1.2-8% by weight, dominantly type-III organic matter along with 2 to10% type-II organic matter and maturity (VRo%) values between 0.5 to 1.1 (Fig.4). However, maturity map based on vitrinite reflectance value indicates that Cambay shale section in Jetalpur low and Tarapur depression are hydrocarbon generating kitchen area. In Nawagam Field source rock data is sparse and limited to few wells only, have low to moderate maturity values of VRo% between 0.5-0.9. In the Nawagam Field temperature in Cambay Shale section varies between 108°C to 125^{0}C.

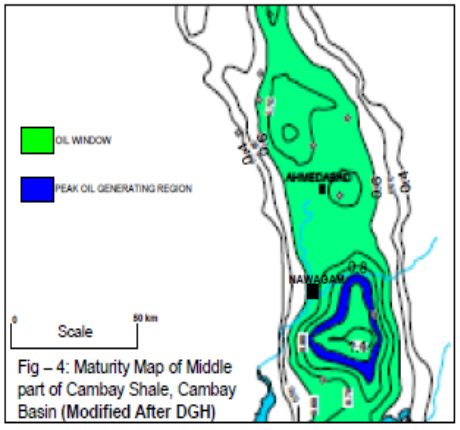


Fig – 4: Maturity Map of Middle part of Cambay Shale, Cambay Basin (Modified After DGH)

Available data indicate that the hydrocarbon bearing potential zones, in Cambay Shale Formation, range from lenticular tight sandstone reservoir to shale oil, conventional reservoirs in shallower part of the basin to Basin Centre Gas Shale (BCGS) in deeper part of the basin. On prima facie the potential shale sections in Cambay Shale Formation appear to vary between tight siltstone to shale. Detail focussed laboratory studies and

application of required technologies need to be appliedto prove the hydrocarbon potential of the prospective zones.

Fig.5 :ELECTROLOG CORRELATION ALONG MAIHELAJ, NAIKA AND NAWAGAM WELLS

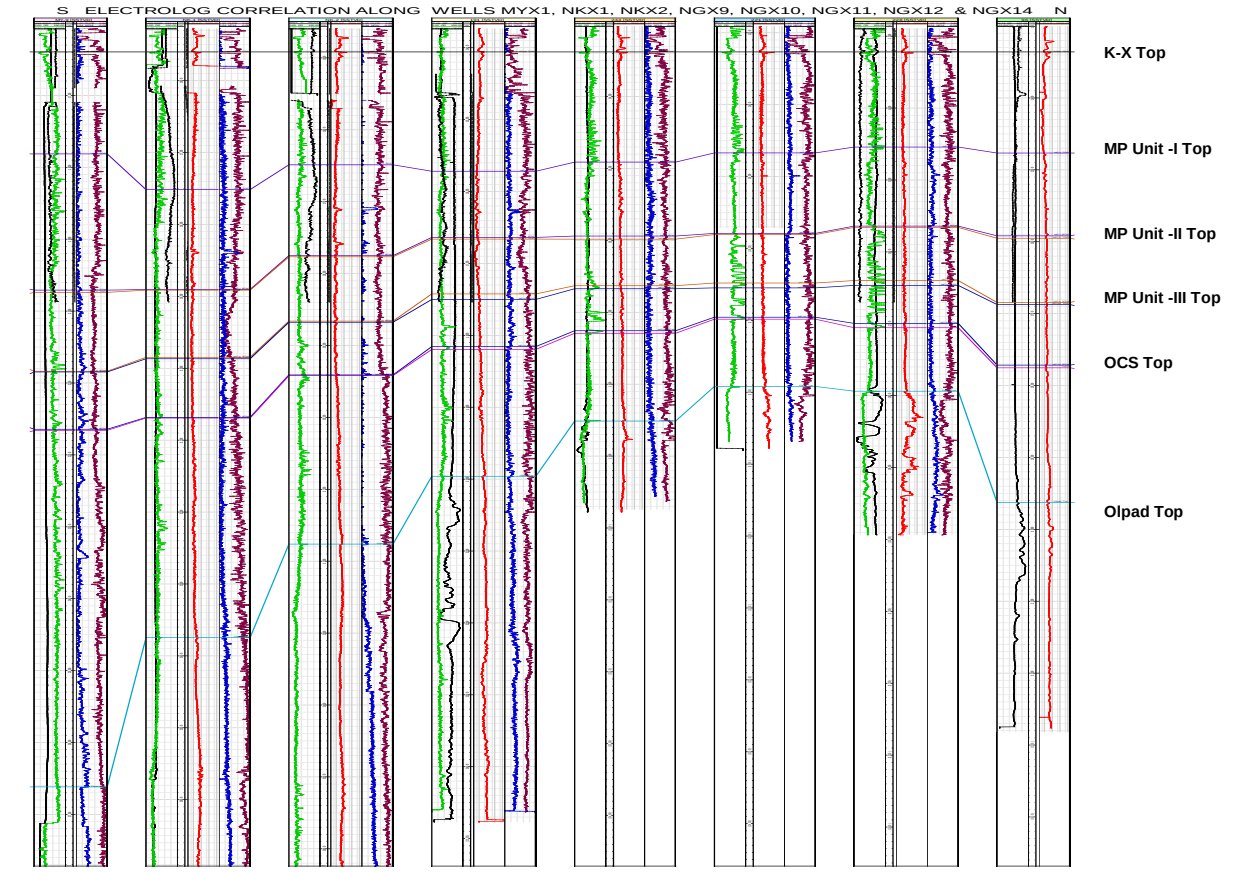


Fig.6: ELECTROLOG CORRELATION (E-W) OF NAWAGAM WELLS

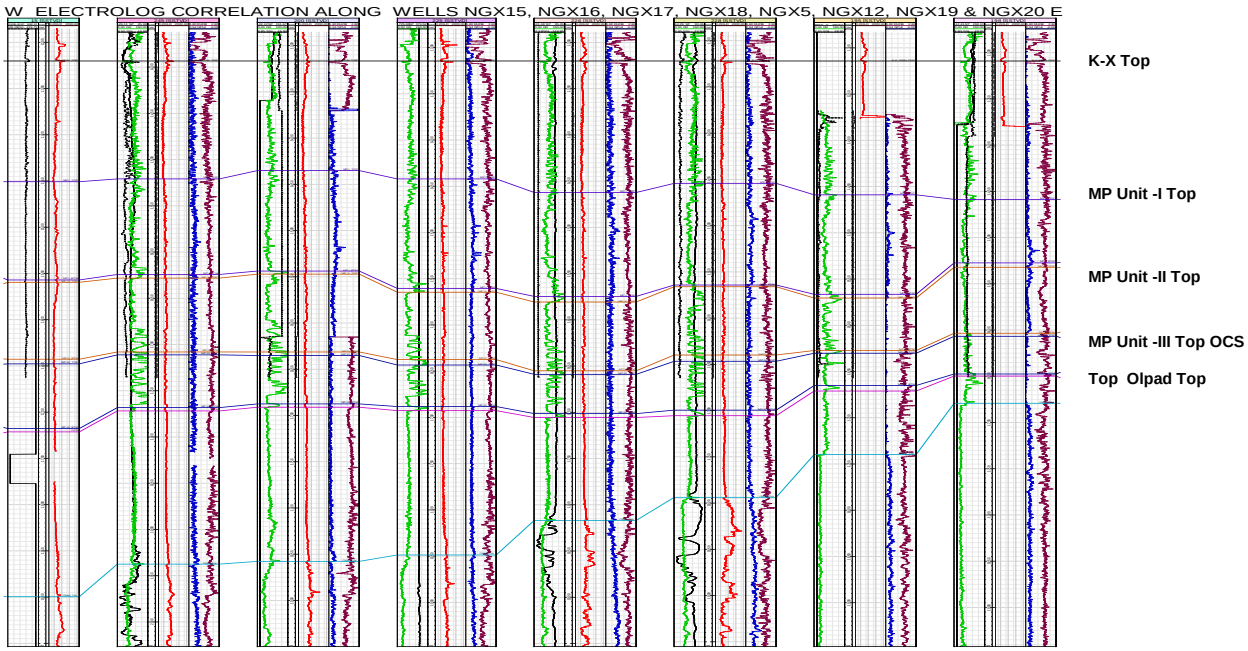
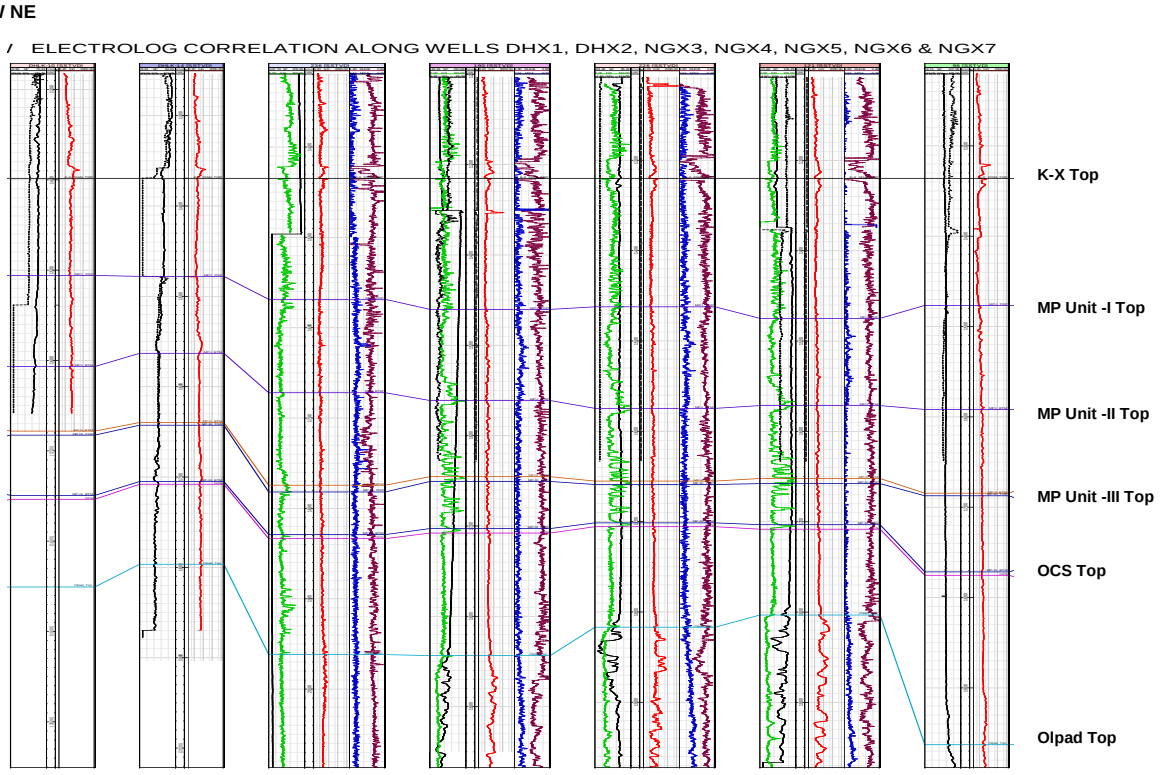


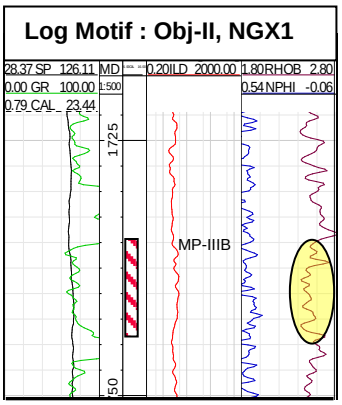
Fig.7: ELECTROLOG CORRELATION ALONG DHOLKA AND NAWAGAM WELLS



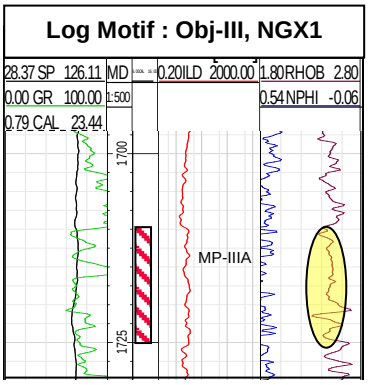
Well Testing of Shale oil and Discussion

In poor producing well NGX1, Object-II in the interval 1735-1744m, MP-IIIB, gave influx of oil @ 6.04m3/day (24-hours influx study) after hydraulic fracturing. Object-III in the interval 1710-1725m (MP-IIIA) also yielded oil with feeble gas during conventional activation. This zone was not fracked. Object-IV in the interval 1682-1688m and 1694-1699m (MP-IIC) gave intermittent flow of oil with feeble gas after hydraulic fracturing (Fig.8). Bottom hole study carried out indicated liquid level at 23m with total oil gradient. The well was completed as oil well with SRP. All these sweet spot zones tested gave influx of Shale Oil for the first time in Nawagam-Naika and Mahelaj fields.

Fig.8:ElectrologCharacters of ObjectsTested in Well - NGX1



Obj-II:(1735-1744m), MP-IIIB. Poor influx of oil. Carried out HF. Initially observed intermittent flow of oil& gas.
Status: Oil Bearing, to be put on SRP.



Obj-III: (1710-1725m), MP-IIIA. Influx of oil & gas.
Status: Oil Bearing req. HF

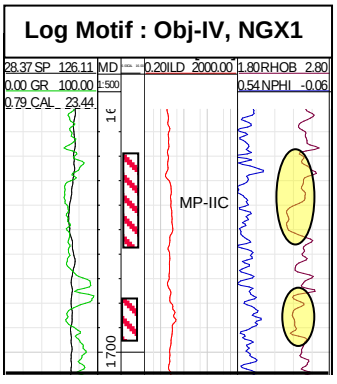
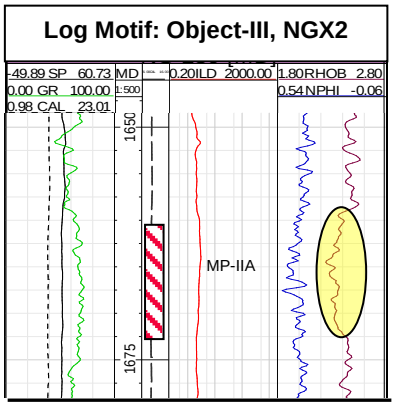


Fig.9 :Electrolog characters of object tested in well-NGX2



Obj-III: 1659-1672m, MP-IIA. Carried out HF.Observed oil Influx .
Status: Oil well on SRP.

In ceased well NGX2, only Object-III in the interval 1659-1672m, MP-IIA, was tested and it gave influx of oil @ 5.28m3/day (24-hours influx study) after hydraulic fracturing (Fig.9). The well was completed as oil well with SRP.Both wells are now producing oil during technical water knockout stage with SRP.

Successful exploration in present wells is closely related to other aspects of exploration; activation and stimulation techniques. Modified hydraulic fracturing job carried out in the three sweet spot zones of the wells lead to new oil pools in shale. These four zones tested in MP Unit-III & II, in these two wells, for the first time in the Nawagam-Mahelaj-Sadra area whereas equivalent pay zones in MP Unit-I are producing from Naika, Mahelaj and Dholka fields. Success of such modified HF job in a well in northern part of Ahmedabad block having similar electrolog characteristics gave impetus to carry out such job in wells of Nawagam Field.

Conclusions

Tested prospective hydrocarbon bearing zones yielded excellent lead for further exploration in idle/low producer inclined wells for deeper horizons. This attempt to initiate exploration in shale section, which posed problems while drilling, was known from the beginning of quest for hydrocarbon, in the area, has thrown up immense scope and opportunity. The organically rich and mature shale (source rock) of Cambay Shale Formation of Cambay Basin calls for focussed exploration as there are number of hydrocarbon prospective zones in Nawagam Field.

In absence of core data, high shale content estimated from electrologs and nuclear logs, it is not possible to quantify the effective porosity with any degree of confidence. Same goes for permeability data estimate. It is postulated presently that these are *in situ* oil and gas generated in shaleswith matured organic matter which could not migrate out of the source rock. However, possibility of migrated hydrocarboncannot be ruled out for some part of Nawagam field and other areas, particularly along the faults. Again in Nawagam-Mahelaj-Sadra area temperature regime is on the higher side in Cambay Shale section. Temperature varies between 108^0C to 130^0C in Cambay Shale Formation, with temperature gradient varying between 5.0-5.6°C/100m,may be aiding oil generation even today.

Undoubtedly, “Shale Oil” lead obtained in Cambay Shale of Nawagam has thrown-up exciting hydrocarbon prospects for the entire basin. However, shale specific mineralogical, lithological, geochemical, geo-mechanical and petro-physical data need to be generated, calibrated and standardized through extensive coring in new wells. Mapping of seismic extensions of these units are in progress. These mature shale sections (Organic maturity as reflected by Ro%-0.5-1.9) appear to have basin-wide extension. In order to realise the true production potential of shale oil from these prospective shale zones horizontal/high angle wells need to be completed with multi-stage fracking with compatible fluid, effective technology application for stimulation and suitable completion. In these wells modified HF techniques developed in-house through proactive integrated approach lead to satisfactory results. More wells have been identified to establish sustainable oil production from Cambay Shale of Nawagam field.

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