



Reservoir Classification and Geological Remodeling of Kalol Sands of Sobhasan Complex, North Cambay Basin, India

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Summary

Kalol sands of Middle Eocene age in Sobhasan Complex hold potential for substantial contribution. But it has not been optimally exploited yet, due to the presence of major potential hydrocarbon layers of Mandhali and Sobhasan Pay Sands, which are the easy targets for exploitation and remained the focus of development activity since discovery. Presence of hydrocarbon was established in Kalol Pays in 1980. The need has been felt to look into Kalol Sands of Sobhasan Complex in greater detail and the present study is a part of this effort. The method adopted is extensive micro level electro log correlation with integration of 2-Dimensional seismic data along with the consideration of pressure and production data. With this methodology, the geological model consisting of six independent, correlatable (eight in Mewad area) Kalol pay units has been prepared afresh. For the first time faults have been introduced in the geological model of Kalol sands of Sobhasan Complex. Property maps of each pay sands have been prepared keeping in view the depositional environment to have a better understanding of the Kalol reservoir as such. The new geological model has resulted in substantial increase of Initial Oil in Place for Kalol sands of Sobhasan Complex.

Introduction

Cambay Basin, explored since 50s, is one of the most prolific hydrocarbon basins situated in western part of India. The Cambay Basin hosts more than 75 oil and gas fields. Sobhasan Complex located at a distance of 7 kms. south of Mehsana town was discovered in September 1968 and came into production in the year 1969 from Sandstone reservoir of Eocene age. The Complex comprises of six fields – Sobhasan, West-Sobhasan, South-Sobhasan, Mewad, South-Mewad and Kherwa (Fig.1). Presence of hydrocarbon was established in different fields at different times within the complex e.g. 1969 (in Sobhasan & South-Sobhasan), 1976 (in West-Sobhasan), 1978 (in Mewad) and 1983 (in South-Mewad).

Hydrocarbons have been established in four different reservoir sand units – Kalol, Sobhasan, Below Coal Sand (BCS) and Mandhali from top to bottom. Considering the comparative importance, most of the studies of the Complex were carried out for the reservoirs of Mandhali and Sobhasan. Initially Sobhasan Sands were the main area of focus. Detailed study of Kalol revealed that there are six (eight in Mewad area) correlatable pay units, separated by persistent impervious non-reservoir layers (Shale and Coal). It has also been observed that, the non-reservoir layers within the formation are sufficiently sealing to act as barriers and disband the field into various permeable pay units.

Kalol sands account for 22% of total Initial Oil in Place of Sobhasan Complex. The cumulative oil production from this sand is again about 22% of initial oil in place. Average production rate from Sobhasan Complex was 991 tpd. during 2003-04, out of which Kalol Sands contributed an average 296 tpd with 67% water cut. In Kalol Sands, due to active aquifer support, oil contribution from self flowing wells is almost double as compared to the production from wells on artificial lift. It is pertinent to mention that in the present study, data from wells upto Sob # 225 and MW # 15 has been considered.

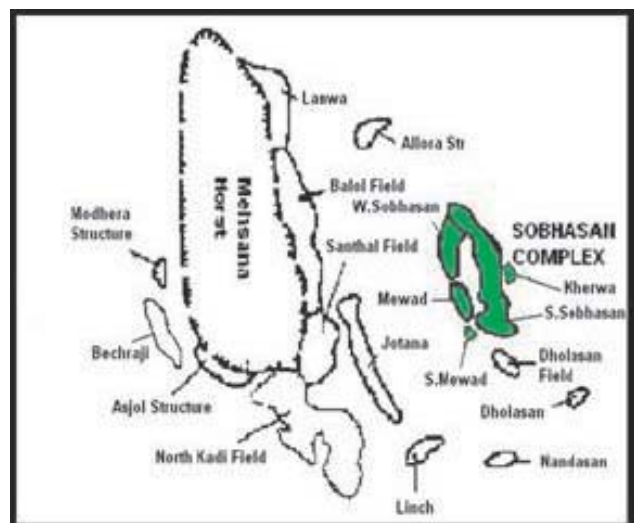


Fig. 1: Location map of Sobhasan Complex

Methodology

An extensive well log correlation for the entire Sobhasan Complex has been carried out. Top of Tarapur shale has been taken as the marker for preparing log correlation profiles. Thickness of Tarapur shale varies between 30m to 40m. and can be easily picked up on logs. The bottom of Kalol sands is also marked by a shale layer designated as upper tongue of cambay shale. Like the top marker, it is characteristically present throughout the field and can be picked up easily because of typical low resistivity feature. There are persistent shales/coals of varying thickness within the Kalol Formation, which serve as good markers for refining the correlation (Fig.2&3). A persistent carbonaceous shale/coal layer separates the overlying KS-V from KS-VI. A thick coal layer has been found to be present just below KS-VI in the entire field. A carbonaceous shale/coal marker in between KS-II and KS-III is very conspicuous covering the entire complex. A coal / shale layer of 2 – 6 m. thickness has been found to be present on the top of KS-V. The trajectories of faults are corroborated from 2 Dimensional seismic data, well data, hydrodynamics and fluid characteristics in different pay units.

Static data (reservoir extent, structure, heterogeneity) was collated with dynamic data (production, water cut) to confirm the interpretation of reservoir units. Fluid contacts, reservoir parameters, Pressure Volume Temperature (PVT) properties etc. were used to predict fluid movements. Spatial distribution of petro-physical properties e.g. porosity and permeability of each sand unit has been mapped. The new geological model with eight sand units has resulted in increase of Initial Oil in Place, which has been supported by simulation after history match.

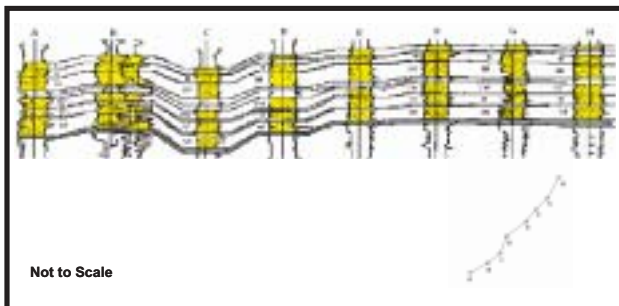


Fig. 2: Correlation of different Kalol sand units across the Sobhasan Complex

Geological Setup of Kalol Reservoirs

Sobhasan Complex is situated in Mehsana – Ahmedabad block of Cambay Basin that has been

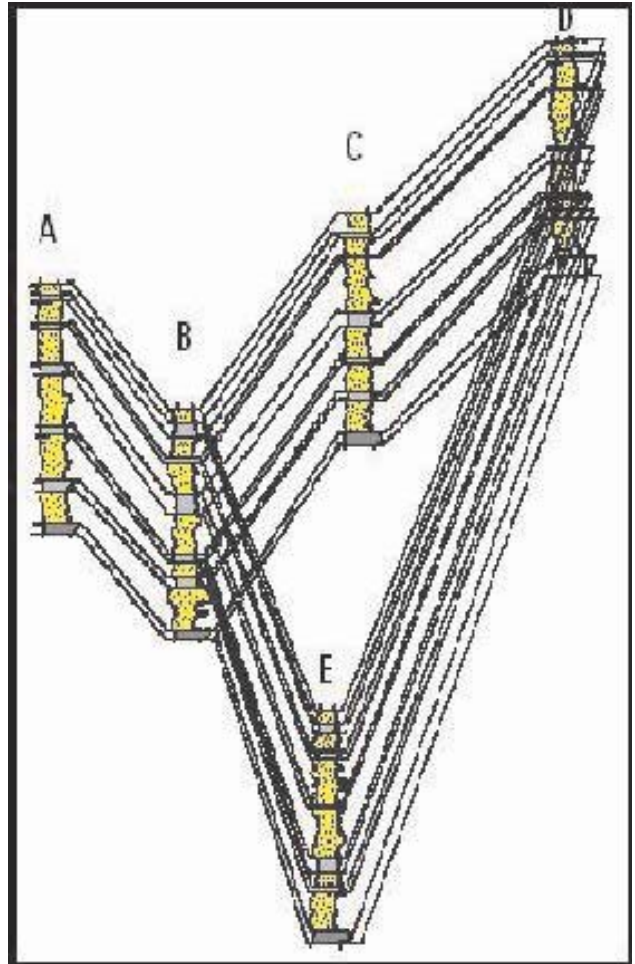


Fig. 3: Fence diagram depicting layer continuity in Kalol sand units

established (Pandey et.al) as a narrow elongated rift graben. Mehsana Horst, a prominent tectonic feature in the northern side of this block divides the block into eastern and western depression. The Kalol Formation of Middle Eocene age lies between Tarapur Shale and upper Tongue of Cambay Shale. Thickness of Kalol Formation varies from 150mts. to 300mts. Major lithological units are Sandstone, Shale, Carbonaceous Shale and Coal. The thickness of sandstone varies from 2mts. to 50mts.

The regional structure at the top of Kalol Formation can be described as a north-south trending broad anticline plunging south. The axial part of the structure shows flattening south with local culminations and depressions. Excepting the oil culminations in south Sobhasan accommodating KS-V and KS-VI, the oil pools in the rest of the field are developed within these local culminations, where 2 – 5m. thick oil columns overly the aquifer. Since the structure is more flattened at Kalol level in comparison



to Sobhasan and Mandhali, oil pools have formed in small isolated closures. The flattening of structure might have been as a result of less pronounced post Kalol tectonic disturbances in the area.

Sand relief maps were prepared at all the stratigraphic levels (pay units) on the basis of sand continuity established through electrolog correlations. The trajectories of faults are corroborated from 2Dimensional seismic data, well data, hydrodynamics and fluid characteristics in the different flow units. Kalol pay sands of Sobhasan Complex are traversed by a longitudinal fault (F1) trending almost NNW – SSE, which is extending from South upto the Central part of Sobhasan Complex. Parallel to this fault on its right, one more longitudinal fault (F2) has been picked up from seismic, which gradually dies towards the South. Another fault (F3) in the West Sobhasan area trending NNE – SSW has been derived from seismic interpretation as well as from fluid anomaly. In the Mewad area a fault (F4) passing in between the wells MW # 15 and MW # 2 in a NW – SE trend has been mapped on the basis of well data and fluid distribution anomaly. Three NE – SW trending transverse faults (F6, F7 & F8) divides the Central Sobhasan into three small compartments (for KS–V & VI, for rest of the sands there are two faults). All these three transverse faults are derived on the basis of fluid distribution anomaly. Fault patterns brought out after integrating well data with seismic data are supported by fluid distribution as well as production history. (Fig.4).

Observations and discussions

Difference of fluid contacts has been observed in all the layers at various places. Structurally Sobhasan Complex is a combination of several localized highs and lows dissected by faults. Sand geometry of different Kalol sands indicates that the source of sediments is from the north-west direction (Fig.5&6). All the blocks are acting under aquifer support. Fluid contacts have been observed in all the blocks, barring in one block in Mewad area for a single pay unit. The water column under the oil pools varies from 5mts. to 40 mts. The aquifer is extensively developed throughout the Sobhasan Complex. The reservoir size being much smaller compared to the aquifer, strong water drive has been observed, indicated by well maintained pressure in the reservoir sands. Strong bottom water drive, coupled with high viscosity of oil in the upper sands caused cusping and coning in the reservoir during the production history of the field. Uneven rise of the aquifer water in different areas is noticed by the OWC values encountered at structurally higher levels at different stages of production.

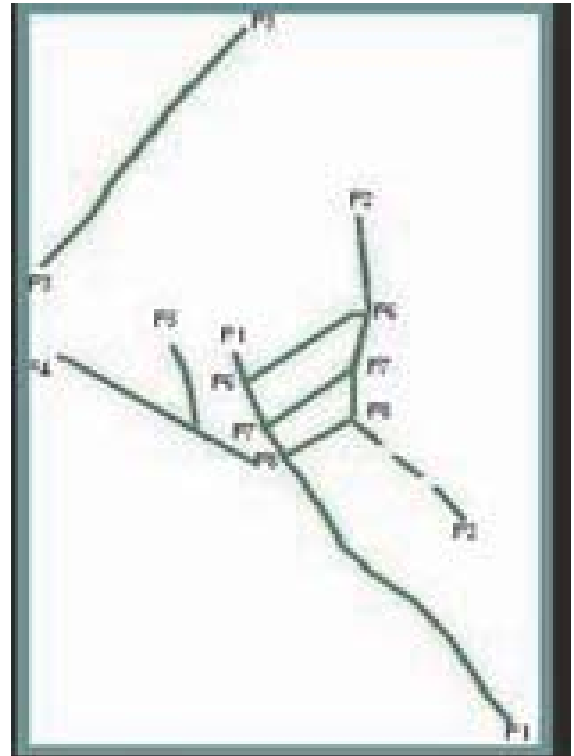


Fig. 4: Fault pattern of Kalol sands of Sobhasan Complex



Fig. 5: Sand isolith map of KS-I

Generalised stratigraphic column covering the pay horizons in sobhasan complex

AGE	FORMATION	PAY HORIZON	APPROX. THICKNESS, m	BRIEF LITHOLOGICAL DESCRIPTION
Upper Eocene to Oligocene	Tarapur Shale	-	60-100	Greenish, with little sand
Middle Eocene	Kalol	Kalol Pays (Kalol I to VI)	150-300	Alterations of coal, shale and sand stone.
Early Eocene	Kadi	U. Tongue Mehsana (Sobhasan Pays Ia, Ib, II, III)	10-100 50-200	Dark gray shale Sand with intercalations of coal and shale (Sandwiched between two coal beds namely top Coal and Bottom Coal)
		Lr. Tongue Mandhali (MP-I to MP-VIII)	10-40 50-350	Dark gray shale Alternations of shale and fine grained sand stone, and/or siltstone with some coal seams in between)
	Older Cambay Shale	-	2100	Dark gray shale (Occasionally carbonaceous and silty)
Paleocene	Olpad	-	20-1500	Trap conglomerates with occasional clay stone
Upper Cretaceous	Deccan Trap	-	-	Basalt

(Modified after: Srivastava et. al.)

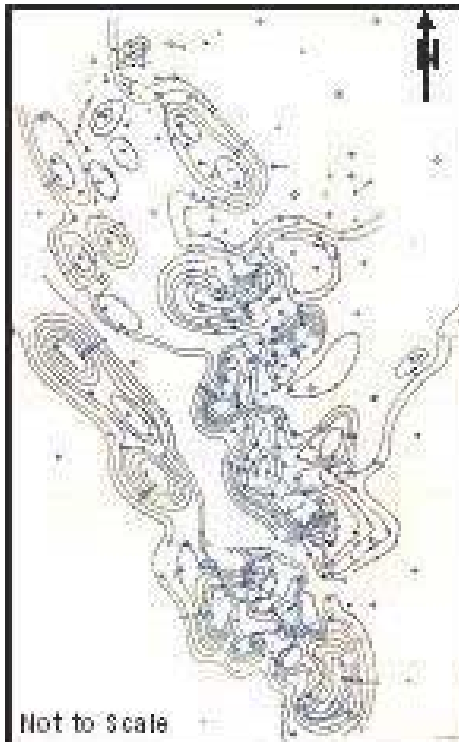


Fig. 6: Sand isolith map of KS-VI

Small localized structural entrapments have created 27 hydrocarbon bearing pools in Kalol sands – 2 in KS-I, 7 in KS-II, 2 in KS-III, 2 in KS-IV, 6 in KS-V, 1 each in KS- Va, Vb & Vc and 5 in KS-VI. Most of these pools have produced less than 5% of Initial Oil in Place. To augment production from these pools, additional infill wells and zone transfers are required.

Kalol Sands are acting under strong bottom water drive mechanism. Pressure drop of 6 – 8 kg/cm² is observed even after production of more than 40% of Initial Oil in Place in some pools.

Reservoirs have excellent petro-physical properties. Permeability is in the range of 300 – 3000md. Crude is under-saturated with bubble point pressure 35-68 kg/cm². It is marked by low GOR, low saturation pressure and low formation volume factor. In the upper layers, sand incursion and wax deposition lead to low productivity and need for frequent work-over jobs (Deepti Tiwari et al, 2005). Wells are rate sensitive. The wells are therefore, required to produce under regulated conditions. High withdrawal rates will result in cusping / conning leading to a quick rise in water production.

Due to strong water activity, good reservoir properties and relatively smaller columns of oil within the pay sands, in most of the wells, water cut has been observed from the beginning itself. To exploit this type of reservoir, wells have to be produced with high water cut.

A reasonably good history match at well and reservoir level has been achieved in the simulation model based on the new geological model (Fig.7). Thus dynamic model has substantiated the static model very well (Fig.8,9).

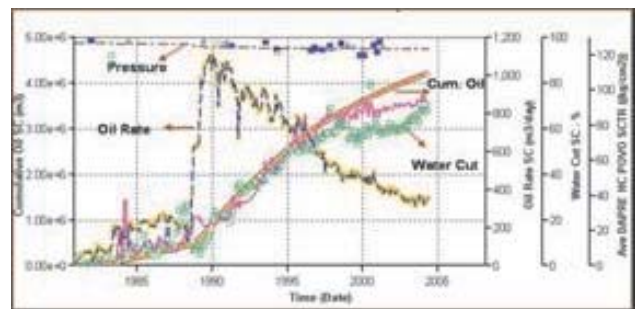


Fig. 7: History Match of Kalol Sands

Environment of deposition

The lithology, sand geometry of various arenaceous members of Kalol Formation and log motifs indicate that the environment of deposition seems to be river dominated delta environment, where slope is very gentle and almost penepplain conditions are reached (U.N.Sharma et al, 1985).

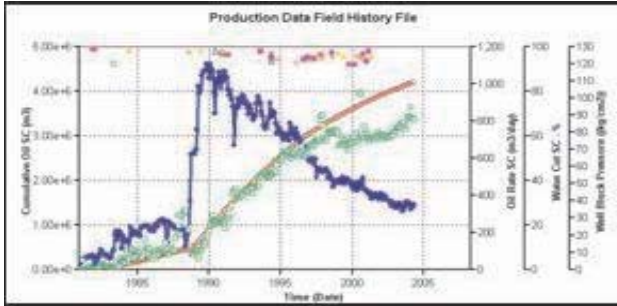


Figure 8 Performance of Kalol Sands

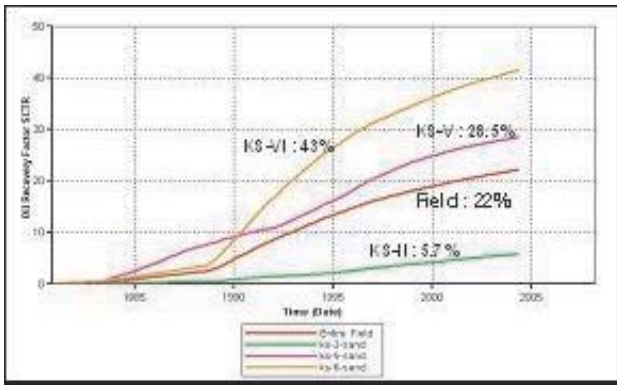


Fig. 9: Recovery at the end of History Match

Presence of hydrocarbon, in the Kalol sands, may be in the point bars of meandering streams. Sand-coal sediment facies with fining upward log characters and also box shaped log-motifs indicating channel deposits and channel-fill sand facies. Core study of W-Sob # 1 (1071-1077m) indicates 57.15% matrix, quartz content less than 40% and grain size analysis indicate a fluvial environment (Dr. D.P.Singh & Dr. Madan lal, 1979). Similarly well Sob # 2 sands are also interpreted as fluvial sands.

Description of units

KS - I

KS-I is the topmost sand unit of Kalol Formation. Top of KS-I is marked by a high resistivity sideritic sandstone layer. A shale of 4 – 10m. thick underlies KS-I and separates it from KS-II. This shale layer shows both lateral facies and thickness variation. In the northern part of the field it is mostly carbonaceous. KS-I is oil bearing in West Sobhasan and North Sobhasan only. However, the sand can be identified in other parts of the field also (Fig.10). Two small oil pools, separated by a low around well numbers WS # 3, 8, 12 in West Sobhasan and around wells Sob # 24, 37, 50 in northern parts of Sobhasan have been established.



Fig. 10: Structure Contour map of KS-I showing different oil pools.

Both the pools are having oil water contact at different levels. There is no oil production from the pool of Sob # 50 and the Initial Oil in Place is in the possible category. Three wells are completed in the pool of West Sobhasan and till date, about 4% of Initial Oil in Place has been produced. Water cut started with commencement of production and ranged between 40-60% till March 1988. But with no decline in reservoir pressure, water cut gradually increased to 80% and oil component came down to about 5m³/day, which suggest strong aquifer support, and relatively smaller column of oil in KS-I reservoir unit

KS - II

KS-II sand has developed throughout Sobhasan Complex and can easily be correlated. Thickness gradually increases towards the South. A coal (at places carbonaceous shale) marker separates KS-II from underlying sand KS-III. The thickness of the coal gradually decreases from north to south. In KS-II seven oil pools are spread over the entire Sobhasan Complex (Two in West Sobhasan and five in Central and South Sobhasan, (Fig.11). A total of 13 wells are completed in different pools. Current oil production from



Fig. 11: Structure Contour map showing different oil pools of KS-II

KS- II is 25m³/day with 87% water cut. Three of the oil pools (WS#8, Sob#133 and Sob#62) have not produced any oil and Initial Oil in Place is in PS category. Sand incursion and wax deposition have led to frequent work-over jobs in wells of this sand unit. Viscous nature of crude leads to fast development of water cone resulting in high water cut. Artificial lift has to be installed from the beginning of production.

KS - III

KS-III is oil bearing in Central and Southern part. In the existing model this sand has been classified as KS-IIIa in the Central part and as KS-IIIb in the Southern part. In the present study detail correlation from north to south suggests a single correlatable and mappable sand unit of KS-III. Basically, the oil occurs only in the top part of the sand unit. Though there is intervening shale of varying thickness in between, the lower part is water bearing and assumes no importance from hydrocarbon point of view. Therefore, in this paper based on the present study, both the oil pools of KS-III in Central and South Sobhasan have nomenclatures as KS-III (Fig.12). The total effective



Fig.12: Structure different showing oil pools of KS-III

thickness of the sand varies from 25 – 45m.; out of which only top 2 – 8 m. is oil bearing. KS-III is separated from KS-IV by coal, carbonaceous shale and shale layers ranging in thickness from 7m. to 25m. The coal layer between KS-IV and KS-III shows gradual change in facies in the southern part of the field. No well has produced from the pool of Central Sobhasan area. Two wells have produced from the pool of Southern part of the Complex. Total contribution of this sand is only 12115m³. Immediate increase of water cut was observed in both the wells. Bottom water drive mechanism and viscous nature of crude have led to water conning in early stages of production.

KS - IV

Out of the six sand units identified, KS-IV is the thickest layer and is water bearing in most parts. Similar to KS-III, this unit is also having only two small oil pools developed in Central and South Sobhasan area (Fig.13). This layer is separated from the underlying reservoir unit KS-V by a 4 - 6m. thick coal / shale layer. There is no production from KS-IV unit. In the central pool two wells were tested in this zone, but produced only water with traces

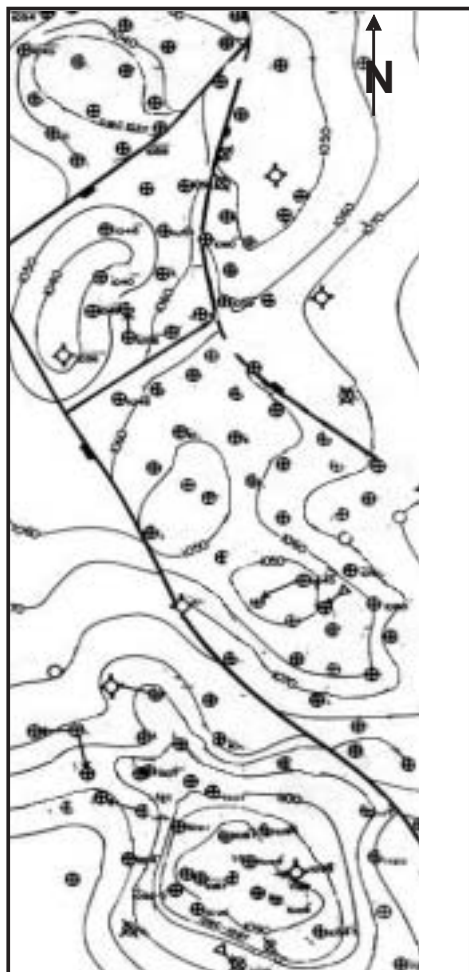


Fig. 13: Structure map showing different oil pools of KS-IV

of oil. In the southern pool also two wells were tested in this unit but there was no oil production.

KS - V

KS-V is characteristically developed in South Sobhasan area (Fig.14). Its equivalent has been identified in Mewad and Central Sobhasan areas which are oil bearing. A persistent carbonaceous shale / coal layer separates KS-V from the underlying KS-VI. Thickness of the layer gradually decreases towards eastern and southern part of the field.

In Mewad area KS-V has been further subdivided into three pay units having different fluid contacts. Intervening shales of 4 to 7 m. thickness separates these three independent pay units. Iso-porosity and iso-oil saturation maps show that porosity value ranges from 26%

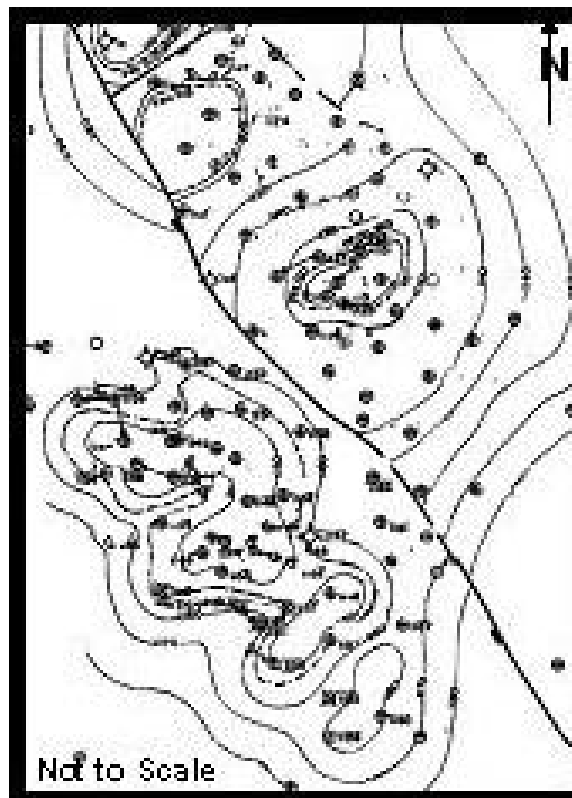


Fig. 14: Structure Contour map showing different oil pools of KS-V

to 35% in South and Central Sobhasan area. In Mewad area porosity ranges from 23% to 30%. In KS-V, seven oil pools are spread over in Sobhasan, South-Sobhasan and Mewad area. One is in the Mewad area, having three independent flow units. Three pools are situated in Central Sobhasan and other three are in South Sobhasan. Out of these seven pools three pools (pool of Sob#127, #180 and #93) are in possible category. 97% of the total oil production from this sand unit is from the southern most pool (pool of Sob#131,64), having an areal extent of 2.51 sq. km. and average porosity and oil saturation of 31% and 75% respectively. Till 1987 there was water free oil production from KS-V. Water cut started increasing after that.

In Mewad area KS-V has been subdivided into three independent mappable pay units, designated as KS-Va, KS-Vb and KS-Vc from top to bottom (Fig.15a,15b &15c). As the newly drilled well MW# 15 is devoid of hydrocarbon in KS-V level, the existing geological model of KS-Va, KS-Vb and KS-Vc of Mewad has changed accordingly. A fault passing in between the wells MW# 15 and MW# 2 in a NW – SE trend explains the fluid anomaly

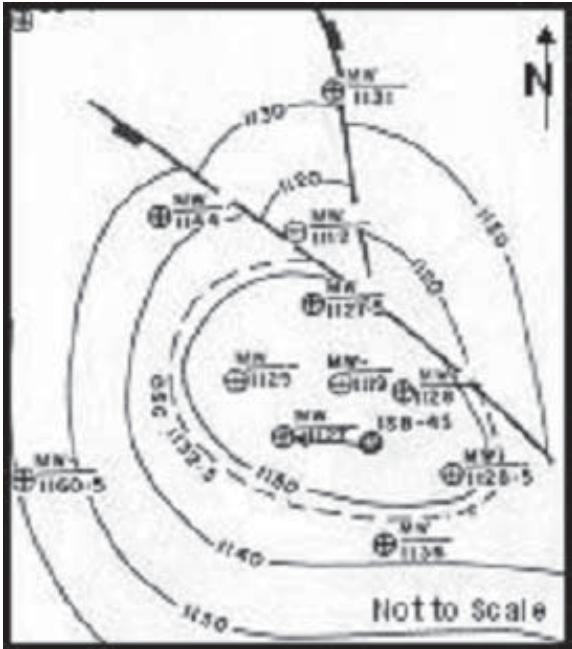


Fig. 15a: Structure Contour map of KS-Va, Mewad Area

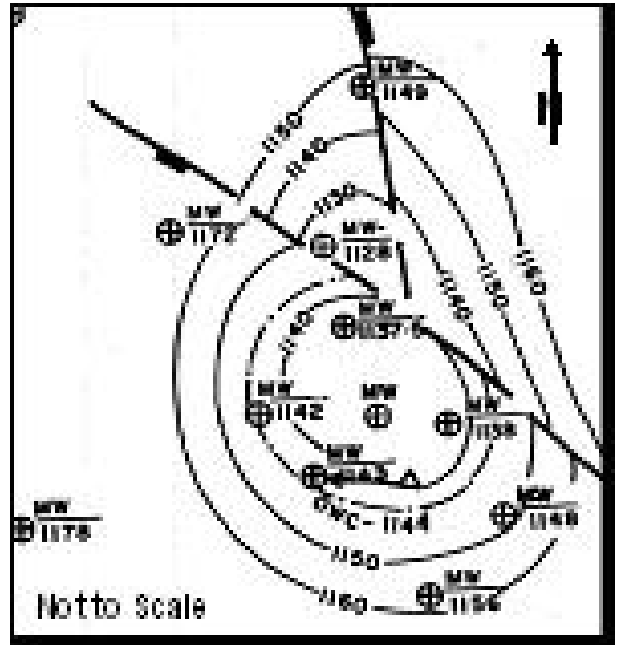


Fig.15c: Structure Contour map of KS-Vc, Mewad Area

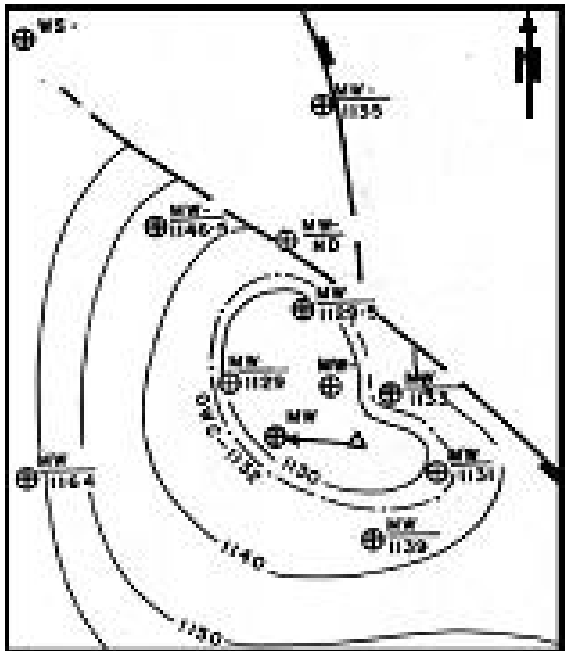


Fig.15b: Structure Contour map of KS-Vb, Mewad Area

in the block. In the up-thrown block the sand, encountered at structurally higher level, is water bearing (MW # 15). On the contrary, in the downthrown part of the culmination the same sand is oil bearing. This explains the sealing nature of the fault. In the existing model, before the drilling of MW # 15 it was considered as a single oil bearing culmination.

This accounts for marginal reduction in Initial Oil in Place for KS-Va and KS-Vc.

KS - VI

KS-VI accounts for around 75% of the total oil production from Kalol sands and has the longest production history in Kalol sands. Initial Oil in Place wise also, KS-VI tops amongst the six Kalol pay units. A thick persistent coal layer is present through out the field just below the KS-VI. This sand is characteristically developed and oil bearing in South Sobhasan area covering a number of oil wells e.g. Sob # 60,77,155, 205 etc. This block is named as 'Field' (Fig.16). This block or pool is the prolific producer for KS-VI as well as for all the Kalol sands. KS-VI sands are fine to medium grained, moderately sorted, carbonaceous at places and appear to have been deposited by distributary channels. Coal / carbonaceous shales were deposited in the inter distributary swamps and marshy areas.

Apart from the 'field' area of South Sobhasan, there are four other oil bearing culminations also present in Sobhasan Complex (Fig.17). Out of five, two pools (Sob#198 and #180) have the reserves in possible category. About 95% of production of KS-VI is coming from the pool 'Field' in the south. 20 wells have produced from this pool. Total production for this pool is more than 40% of Initial Oil in Place. Initially the water cut behavior of this sand unit showed a gradual increasing trend. Subsequently, high



Fig. 16: Field area of KS-VI, biggest pool among all Kalol sands

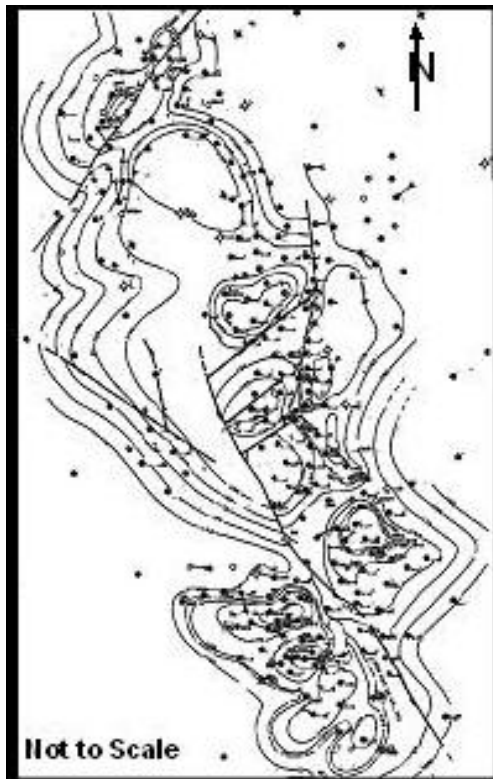


Fig.17: Structure map of KS-VI showing 5 different oil pools

withdrawal rates led to sharp increase of water cut and decline in oil rate.

Conclusions

Importance of proper reservoir management with optimum recovery at minimum cost is the need of the hour. The new geological model of Kalol sands integrated with seismic inputs has not only brought out the prominent sets of faults in the Kalol Formation of Sobhasan Complex for the first time, but also resulted in increase of Initial Oil in Place, which has also been supported by the simulation study. Simulation study based on this new geological model has been very useful in identification of extension of reservoir, nature of fault, hydrodynamic communication between the blocks and the subunits. It has also been very effective to address the issues pertaining to effective reservoir management and provide realistic performance forecasting.

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