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An unconventional approach in deciphering reservoir distribution and hydrocarbon prospectivity of sands within Older Cambay Shale in Linch Area of Cambay Basin. –A case study

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Abstract:

The prospectivity of hydrocarbon bearing sands within Mandhali & Older Cambay shale in north Cambay basin (Fig-1) has been carried out mostly with structural interpretation. These sands are thin (5-8) m thick and at considerable depth ranging from 2200 to 3000 m. To further worsen the delineation scenario the sands have limited areal extent. These sands are divided in eight units and are distributed vertically. The thick Kalol coal units mask these formations with very less energy penetration and high attenuation. The conventionally processed seismic data mostly aimed with retaining higher frequencies for delineation of thin sands is neither able to bring reflector corresponding to these individual sand units nor able to bring prominent reflectors at these depth, for generating horizon/stratal slices , probably due to least emphasis on lower frequencies. The post stack filtering is also not able to bring any deeper reflector. The reprocessing of the data aimed with preservation of lower frequencies since initial stage of processing combined with some noise attenuation and multiple suppression processes resulted in bringing deeper reflectors within older Cambay shale and amply clear amplitude anomalies. The interpretation on interactively processed data resulted in proposing locations and drilling of one well which produced hydrocarbon.

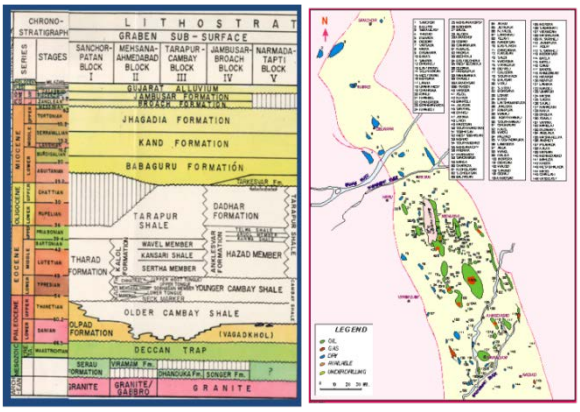


Fig: 1 Generalized Lithostratigraphy of Cambay Basin and area of study

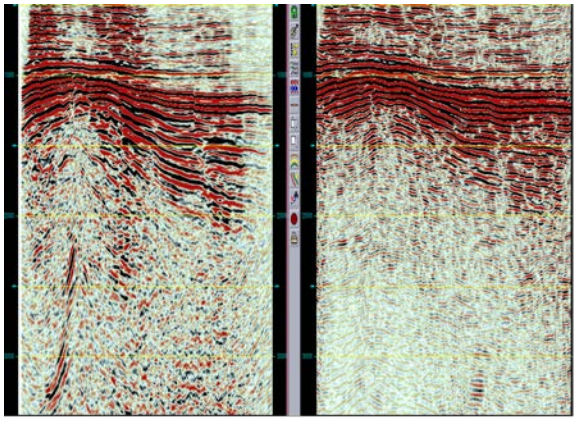


Fig-2 Seismic section processed with 1)low frequencies preservation and Earlier processed 2) with conventional processing- deeper horizons have distinct standouts

Introduction:

Seismic events at Mandhali and below are not correlatable in conventionally processed data. The low pass filtering also was not fruitful to segregate the events below Kalols and adding to this the multiples were inseparable and cause distraction in the correlation (Fig-2). With this any possibility of reservoir delineation is near impossible. Individual sands are below seismic resolution and do not give separate seismic event. The unconventional part of the study was to process the data with preservation of low frequencies rather than go for higher frequencies, in order to bring out regionally correlatable seismic events, which could be taken as geologic time equivalents and used for stratal slicing for reservoir delineation. In new reprocessed data at least four additional seismic markers below Mandhali are correlatable with distinct standout and are free from multiples. These four markers were used for generating horizon slices/stratal slices with different combinations to bring out the dispersal pattern of amplitude anomalies to corroborate with geologically feasible features/model.

Stratal slicing has been used as useful tool for basin analysis and reservoir delineation, especially in wedge depositional sequences and more so when the study area encompasses margin to the basinal deeps, appropriate in present case when the area spans from Mehsana horst to Warosan low to Nandasan field. The very basic of the startal slicing is based on the concept that-Time transgression of seismic events is the rule rather than the exception. Seismic events are frequency dependent also and the dependence on frequency is evidence of their transgressive nature. The frequency independent seismic events are also the most continuous and coherent events in most of the cases and are geologic time equivalents. These events are clearly brought out in low frequency filtered data so in a way it can be summarized that low frequency events are regional and coherent and are frequency independent whereas frequency dependent events are time transgressive and non geologic time equivalent and are stratigraphic in nature.

Methodolgy:

The seismic volume used under current study covers an area that straddles across Linch, Nandasan, parts of North Kadi and South Kadi fields in the Mehsana Block of North Cambay Basin. Important formations which have known and estimated hydrocarbon pool are Kalol, Mehsana, Mandhali and Older Cambay Shales. The sands which are dispersed within Older Cambay Shales (OCS) are thin and discrete.

Stratigraphy:

The generalized stratigraphy of the Cambay basin is provided in the fig-1, In the area only one well has penetrated Syenitic basement. It is assumed that Mesozoic sediments area not represented in the area and Olpad Formation of Palaeocene age, comprising of conglomerate, sandstone, siltstone and clay/claystone, unconformably overlies the Geological Basement. Cambay Shale formation of Palaeocene to Early Eocene age represents the early transgressive syn-rift sequence and has an inter-tonguing and gradational relation with underlying Olpad Formation. These are overlain by Kadi Formation which is lower part of the late syn-rift sequence. Kadi Formation has an inter-tonguing relation with Cambay shales. This formation of Lower to Middle Eocene has been sub divided into Mandhali, Mehsana and Chhatral members each being demarcated by a shale tongue. Mandhali Formation comprises mainly of progradational fine to medium sandstone, silt stone and coaly patches while Mehsana has thicker coal seams, lesser sandy units and predominance of silty portions. The upper most Chhatral Member has, at places, an unconformable relationship with upper Kalol Formation of Late Eocene age. The Kalol

formation is overlain by late Eocene transgression of Tarapur shales. These shales form the regional cap and mark the end of active rift stage.

Petroleum System and Hydrocarbon Plays:

There is huge sedimentary thickness available in the nearby Warosan Low to generate the hydrocarbon. The Cambay Shale is the prime source rock. A closed petroleum system exists in Older Cambay Shale Formation and Mandhali wherein petroleum generated from the source have migrated out to the rocks of the same age. The regional seals have been fractured tectonically thereby opening the Early Eocene system for hydrocarbon occurrences in Middle and Late Eocene reservoirs. Oil-Source & Oil-Oil correlation suggests that the Older Cambay Shale source rocks have charged the Linch pays. Mandhali Member reservoirs have received oil from Older Cambay Shale and shales in Mandhali. The organic matter occurrence is moderate to rich and organic matter facies recognized is humic-sapropolic and mixed organic matter facies (Humic- sapropolic). Overall sequence has been rated as having good to very good hydrocarbon generation potential. The source/kitchen for hydrocarbon accumulation in deeper sands of Older Cambay Shale may extend further down dip towards the Warosan low within Older Cambay shale. Major accumulation and hydrocarbon entrapment is in the up-dip direction on the rising flanks of Mehsana Horst. Migration has been through major longitudinal faults various cross faults presented barriers. These major longitudinal faults were important factors in conducting migrating petroleum fluids vertically. The migrating hydrocarbons reached both the eastern slope of Mehsana Horst and the Linch Main Structure and charged the traps. The hydrocarbon accumulation is found in clastic reservoirs at multiple stratigraphic levels within OCS and Mandhali. The transgressive shales within OCS formations have also acted as top seals/local seals. Entrapment of Linch units and Mandhali are strati-structural in nature.

Present work:

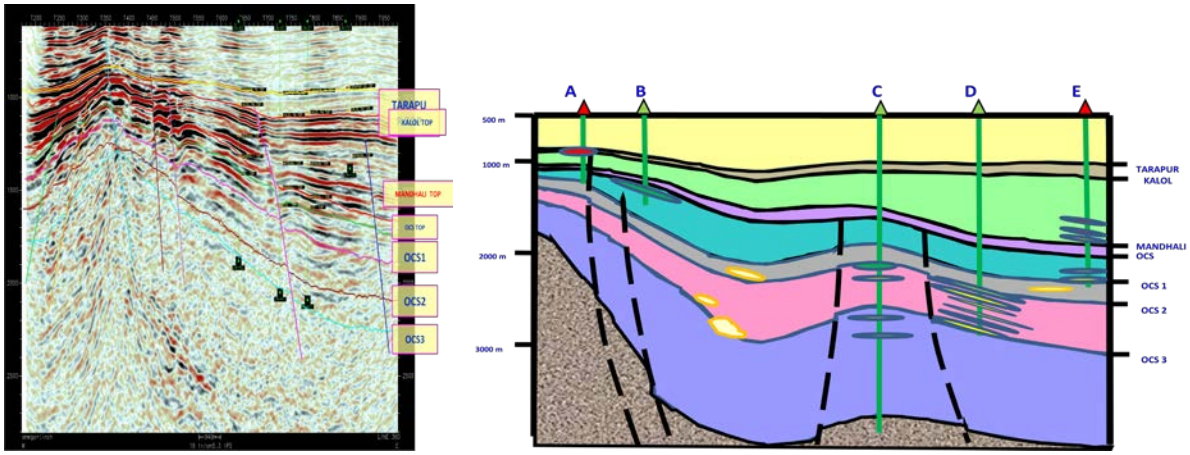
The well log correlation of different stratigraphic formations from Kalol to OCS top was carried to bring out the vertico-lateral distribution. Most of the wells drilled in the area are terminated within Older Cambay Shales covering the producing zones, except one well which was drilled up to Basement. With an emphasis on the OCS formation eight subunits are marked on log correlation from LU-I to LU-VIII. Most of the wells from Linch and South Kadi fields have potential hydrocarbon bearing sands underlying OCS TOP.The Tarapur, Kalol, Mandhali and OCS Tops, in logs, were used as key references for well to seismic tie-up. Synthetic seismograms were generated for 30 wells across the study area. Horizons corresponding to major stratigraphic boundaries like tops of Tarapur, Kalol, Mandhali and OCS were correlated (Fig-3).In addition, the OCS sequence was sub-divided into three horizon based broad packs with the help of horizons - OCS1, OCS2 and OCS3 tracked along correlatable seismic markers within OCS.

To study disposition of stratigraphic features / amplitude anomalies and to understand the clastic dispersal pattern, amplitude attribute analysis (generally RMS) was carried out with Reflection Strength and Sweetness volumes. Stratal slices were generated between different units within OCS) namely OCS-1, OCS-2 & OCS-3 with different combinations to bring out the features associated with amplitude anomalies. High amplitude anomalies are observed to be hydrocarbon bearing along the rising flank of Mehsana horst. Inversion was attempted over a limited volume spanning the area of interest using Constrained Sparse Spike Inversion algorithm on full stack seismic data over a time window between Mandhali Top and OCS3 horizon. Seven wells falling in the vicinity of the proposed locations were considered for well to seismic tie-up. The correlation between well synthetics and full stack seismic was found to be around 30 to 60 %. The estimated multi-well wavelet has been used for constrained sparse spike inversion. Some anomalous change of P-Impedance (generally lowering) is distinctly seen at the features being targeted in the locations proposed.

Depositional Model

The Linch unit divided into eight sub units, based on presence of sands at various depths with intervening shale pack suggests that deposition of Oder Cambay Shales encompasses a large time period (comparatively) within which certain processes were active that caused deposition of very fine to silty reservoir units (character of OCS sands varies across the northern portion of Cambay Basin.

Attribute studies between OCS1 & OCS2 and OCS2 & OCS3 brought out some geobodies which are distributed proximate to Mehsana horst. The bright amplitude are observed alongside the marked reflectors in various forms like angular conformity, polarity reversal and dumps along the dipping recflector. Based on Seismo-geological analysis and the depositional model envisaged, a seismo-geologic cross- section (Fig-4) was generated using the depth converted horizons of the major sequence tops (Tarapur, Kalol, Mandhali and OCS) and those of the seismic events tracked within OCS (OCS1, OCS2 and OCS3) along with the well data of drilled wells A,B, C,D and E.



F-g-3 Correlated Horizons F-g-4 Schematic seismo-geological cross section through wells from west (Mehsana horst)to east Nandasan fiield showing markers, reserrvoir bodies encountered at wells (lenticular shape) and identified amplitude anomalies (golden color) . The identified body near well C Encountered sand and hydrocarbon at Mandhali.level (hump in seismic section with extra cycles)

Results:

Four locations were identified (three in Fig-5) as an outcome of study and subsequently by other agency also the locations were proposed. One location drilled based on the study, the middle one in Fig-5, (deviated well) has produced oil @ 7m3/d & gas from OCS/Mandhali and has influx of oil & gas at deeper OCS level. This has opened new area for exploration in Nandasan area around well drilled.

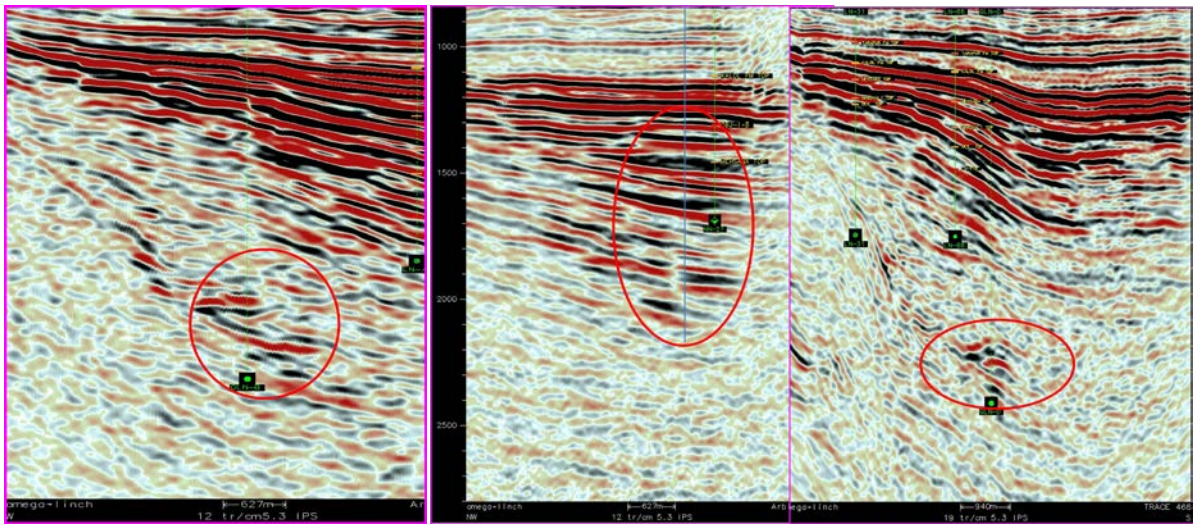


FIG-5 SECTIONS SHOWING AMPLITUDE ANOMALIES ASSOCIATED WITH 1) FLAT SPOT AGAINST THE DIPPING BED 2) HUMP AT SHALLOWER LEVEL AND POLARITY CHANGE AT DEEPER LEVEL 3) AMPLITUDE HUMP AT TRANSPARENT SHALE BACKGROUND

Table-1

The processing sequence and parameters:

Geometry merge, Field statics, Band pass 5/12 to 100/72 Hz cascaded mode, Noise attenuation, shot & receiver domain, Surface consistent amplitude balancing, Surface consistent DCON, Initial velocity analysis 1*1 km, Noise attenuation in CMP domain, Residual statics correction, Second pass velocity analysis 0.5 * 0.5 km, Residual static correction, Noise attenuation in CMP domain, Offset split in 50m interval, Noise attenuation in offset domain, Offset regularization & noise attenuation, Migration velocity analysis 0.5 * 0.5 km, Kirchhoff migration aperture 8km,Cmp sorting, Spatial continuous velocity Analysis, velocity picked in each migrated gather , picked velocity field is trimmed, smoothed minimum velocity is used for migrated gather flattening, Mute outer- remove stretch, inner mute -remove multiples below Kalol ,Stacking

TVF

Hz dB/octave	LC	Hz dB/octave	HC	Centre window Time ms
6	18	75	66	0
5	18	68	54	600
4	18	60	54	1200
3	18	50	48	2200
3	18	40	42	3200
3	18	30	39	4400
3	18	20	36	5400

Conclusions:

The processing with preservation of lower frequencies from the initial stages of processing in tandem with some noise attenuating processes has given new hope to bring out geological time equivalents, the low frequency seismic events, usually possible with filtering of the stack data itself and a prerequisite for generating stratal slices for delineation of stratigraphic features particularly sub seismic thin sands at deeper depths. The structural aspects also get better with better fault delineation. The intense processing interaction can altogether change the interpretation approach and bring out interesting features not imaged before. The high amplitude reservoir anomalies can be unearthed to great extent with intense interaction during processing stage with clear vision of objective and desired output. The Cambay basin has plenty of such subtle strati-graphic features which need to be probed with interactive processing approach. The reservoirs associated with dim amplitudes found in some of the wells in the area need to be processed / characterized with inversion studies.

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