# AI based and conventional seismic techniques for reservoir characterization of K-IX and K-VIII pay sands in Nardipur Low area, Limbodra field, Ahmedabad sector, Cambay Basin, Gujarat

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## Abstract

The Cambay Basin is an intra-cratonic NNW-SSE trending aborted rift. The Nardipur Low area (Limbodra Field, Ahmedabad sector) is characterized by development of Kalol pays and shows hydrocarbon entrapment in K-IX, K-VIII and K-V pays. The K-IX and K-VIII reservoirs were deposited in a mixed flat to mud flat environment and are heterolithic in nature. The resolution of the seismic data, effects of the coals on reflection time series, low impedance contrast and heterolithic nature of the K-IX and K-VIII reservoirs make their mapping difficult by deploying standard approach of interpretation. AI based and conventional seismic techniques can act as potent tools for deciphering the distribution of such reservoirs. 'Fitness' attribute clearly distinguishes the K-VIIII reservoir facies from the non-reservoir facies and brings out the likely extension of the same northwards of the established pool limits. The Mean Absolute Amplitude map satisfies ~85% of the observed well behavior in the K-IX pool and corroborates to an amplitude range of 52,000 to >70,000. The Mean Absolute Amplitude map also establishes the likely extension of similar facies away from the established K-IX pool limit. AI and window based seismic attribute maps helped in carving out the K-IX and K-VIII reservoir distribution models and delineated the prospective areas for bringing in further exploratory efforts.

***Keywords:*** Cambay, Kalol, Reservoir, Artificial Intelligence (AI), Seismic attributes, Seisnetics

## Introduction

The Cambay Basin is an intra-cratonic NNW-SSE trending aborted rift forming an integral part of the western margin rift basin systems of India. Evolution of the Cambay Rift Basin could be divided into pre-rift, syn-rift and post-rift stages. The basin is divided into five major tectonic blocks from north to south namely Sanchor-Patan, Mehsana-Ahmedabad, Cambay-Tarapur, Jambusar-Broach and Narmada-Tapti Block, separated by pronounced transfer faults (Fig. 1a). The Ahmedabad sector extends from the Nandasan cross-trend to the north to the Vatrak cross-trend to the south (Fig. 1a). The present study has been carried out in the Limbodra Field lying close to the Eastern Basin Margin and covers the Nardipur Low area (Fig. 1b). The Nardipur Low area is characterized by development of post-rift Middle Eocene Kalol pays and shows hydrocarbon entrapment in K-IX, K-VIII and K-V pays (Fig. 2 and Fig. 3). The K-IX and K-VIII pools exhibit stratigraphic entrapment and are producing oil under depletion drive at 46 $m^3$/d (11 flowing wells) and 71 $m^3$/d (29 flowing wells), respectively. The present study is an attempt towards reservoir characterization of K-IX and K-VIII pays using artificial intelligence (AI) and window based seismic attribute studies to decipher their extension beyond the established pool limits in order to open up avenues for further exploration and field growth.

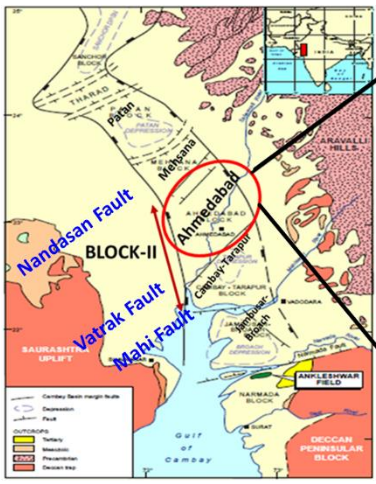


Fig.1a. Tectonic Map of Cambay Basin

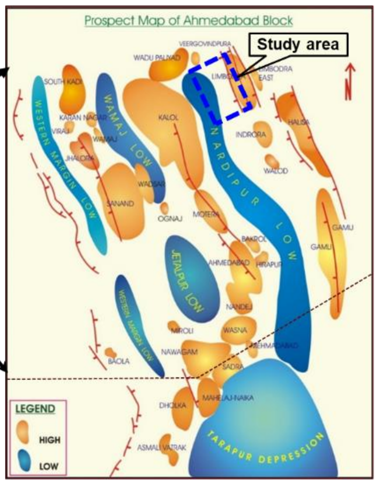


Fig.1b. Study area in Prospect Map of Cambay Basin

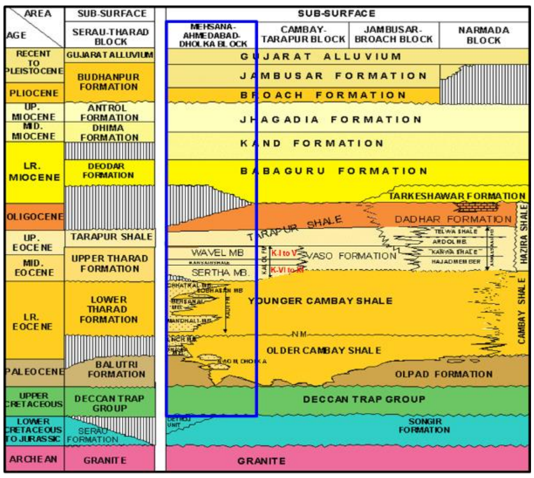


Fig.2. Generalized stratigraphy of Cambay Basin (Modified after Mehrotra and Ramakrishna, 1980)

## Reservoir facies architecture

The Sertha Member (K-XI to K-VI) of the Kalol Formation was deposited during the Middle Eocene Transgressive Systems Tract (TST) that forms a part of the Middle-Late Eocene IInd order sequence recognized within Ist order Early Eocene to Recent rift fill passive sequence (Sahasrabudhe et al., 2007). In the study area, K-IX and K-VIII units exhibit an average thickness of 30-40 m and 30-35 m, respectively. The K-IX unit is distinguished from the overlying K-VIII unit with occurrence of a thick (14-24 m), laterally persistent coal horizon at top and is separated from the K-X unit below by the occurrence of K-X coal (Fig. 4). The K-IX sedimentary package comprises shale, silty shale, siltstone, coal and carbonaceous shale. The K-IX reservoir, in most cases, occurs at the bottom of the K-IX coal (Fig. 4). The effective reservoir thickness varies between 3-11.5 m. The average effective porosity and hydrocarbon saturation for K-IX pays are 22% and 67.5%, respectively. The base of the K-VIII unit is marked by the K-IX coal and a prominent regionally correlatable thin shale unit occurs at the top separating the K-VIII unit from the overlying K-VI+VII unit (Fig. 5). The sedimentary package comprises shale, silty shale, siltstone, coal and carbonaceous shale. However, unlike the K-IX and K-X coals, the K-VIII coals are thin and laterally discontinuous (average thickness:

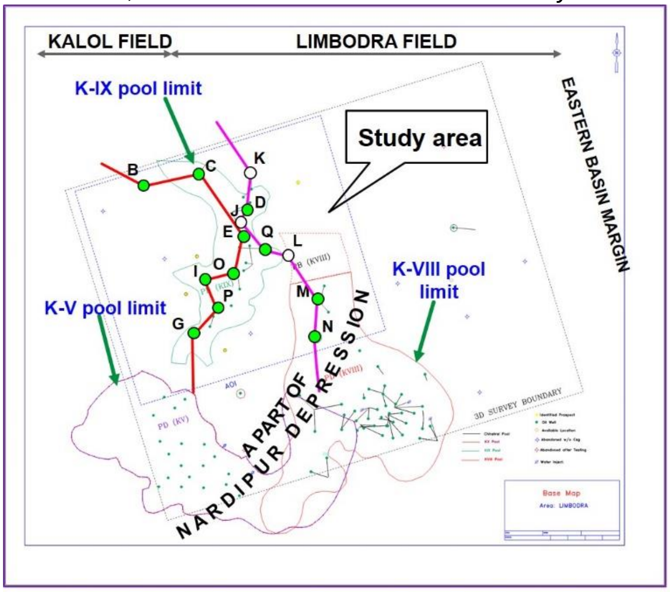


Fig.3. Basemap showing the study area and the different established oil pools in Nardipur Low area, Limbiodra Field

2-3 m). In the overlying K-VI+VII unit, the coals are reduced to mere thin, laterally discontinuous streaks (Fig. 5). The K-VIII reservoirs are mostly found confined within 20 m above K-IX coal top (Fig. 5). The effective reservoir thickness varies between 2.5-18 m. The average effective porosity and hydrocarbon saturation for K-VIII pays are 19% and 55%, respectively. The thick and laterally continuous coal horizons associated with K-X and K-IX units indicate deposition during the early stages of marine transgression (Middle Eocene TST) which not only created the needed accommodation space but also allowed the peat mires to expand laterally (Holz et al., 2002). However, the coarsening upward sequence as observed in the associated K-X and K-IX sedimentary packages indicate towards progradation of the paralic sequences and together with the coal horizons establishes higher order transgressive-regressive (T-R) cycles, within the early stages of Middle Eocene IInd order TST (Fig.6). The presence of tidal bundles, wavy lamination, lenticular sand laminae and occasional streaks of organic matter (OM) in the conventional core cut in K-IX indicate towards tidal flat sedimentation (Nichols, 1999) in the then existing paralic depositional system (Fig.6). Siliciclastic input comes from tidal channels (fining upward electrolog facies) and tidal bars (coarsening upward electrolog facies) (Fig.6). The presence of climbing ripple laminations (CRLs), marked by occurrence of pseudo-beds (resulting from deposition by sub-critical CRLs; Allen, 1982), point towards deposition by strong unidirectional flows (Chaudhuri, 2005) which might be induced by tidal currents. The presence of lenticular

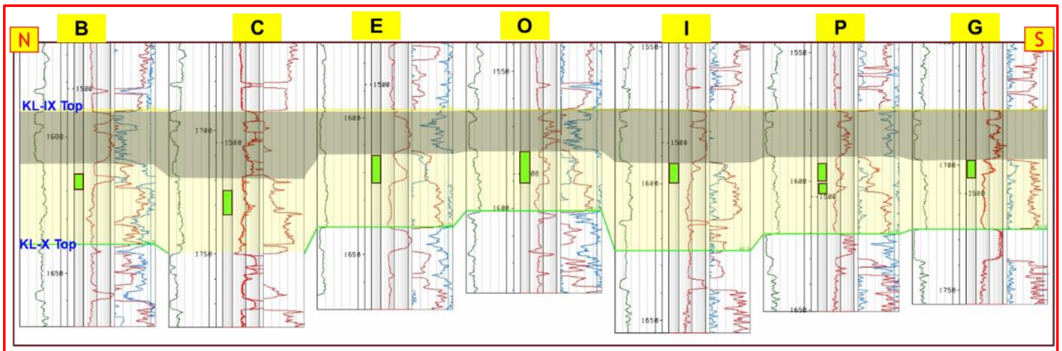


Fig.4. Electrolog correlation exhibiting the development of K-IX reservoir facies in the study area

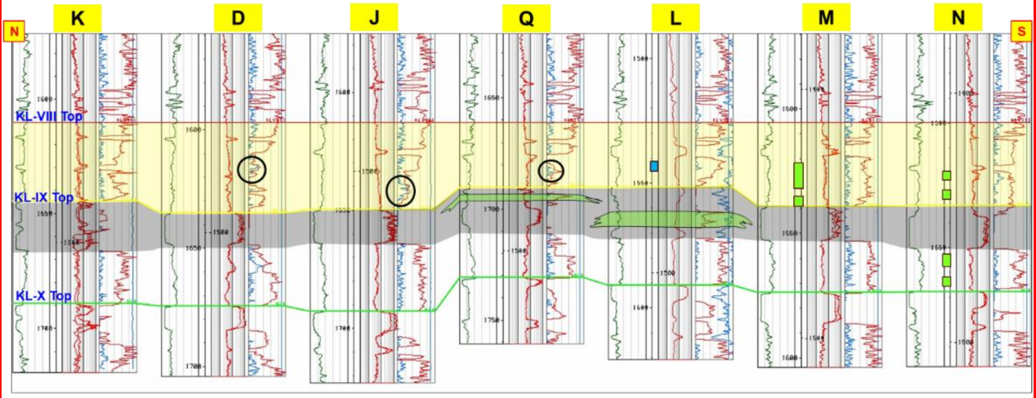


Fig.5. Electrolog correlation exhibiting the development of K-VIII reservoir facies in the study area

sand laminae and wavy lamination indicate towards fluctuations in the sand/mud ratio within the system (Reneick and Singh, 1973). The core photograph further reveals that the rythmic sequence of the tidal bundles is punctuated by emplacement of massive lenticular silt/sand bodies having an erosional base. These might represent deposition by tidal channels or bars as also supported by the electrolog characteristics. Hetrolithic tidal bedding as observed in the core photographs indicates towards deposition in mixed flat environment (Desjardins et al., 2012), wherein, sedimentation through suspension fall out goes hand in hand with bed load transport (Fig.6). The core cut in K-VIII unit exhibits similar sedimentary features as in K-IX indicating towards tidal flat sedimentation (Fig.7). However, the core photograph suggests distinct transition from mixed flat to mud flat facies towards the top of the K-VIII unit indicating towards waning of bed load transport processes due to strengthening of the Middle Eocene TST as evidenced by the retrograding log signature of K-VIII unit. Fence diagrams (Fig.8 and Fig.9) reveal that the thick, laterally continuous coals of K-X–K-IX give way to moderately thick to thin laterally discontinuous coals within K-VIII and K-VI+VII. This is indicative of gradual strengthening of the Middle Eocene transgression resulting into creation

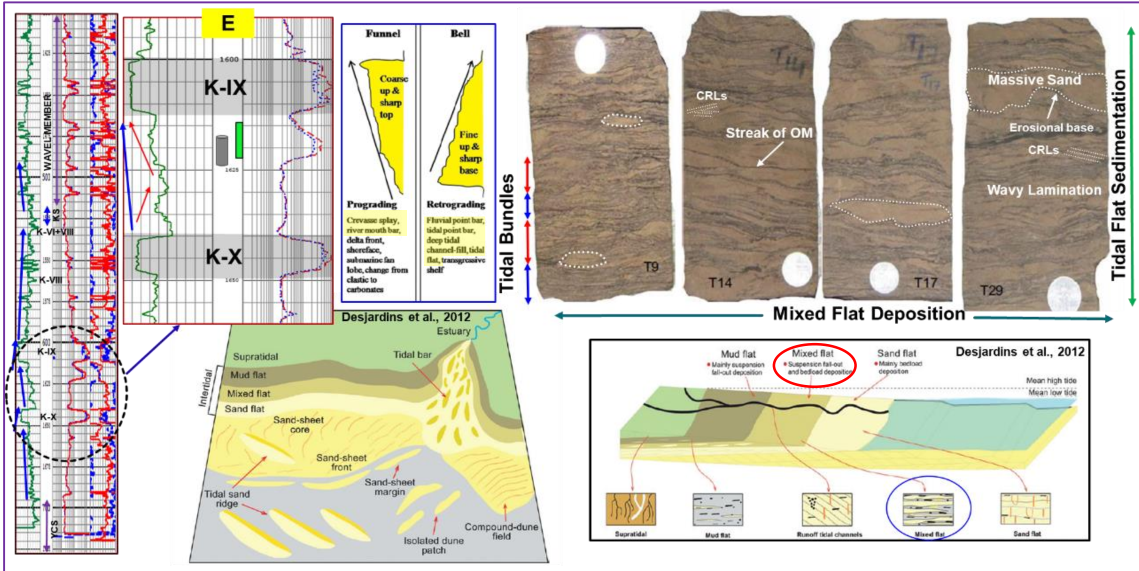


Fig.6. Depositional model for K-IX

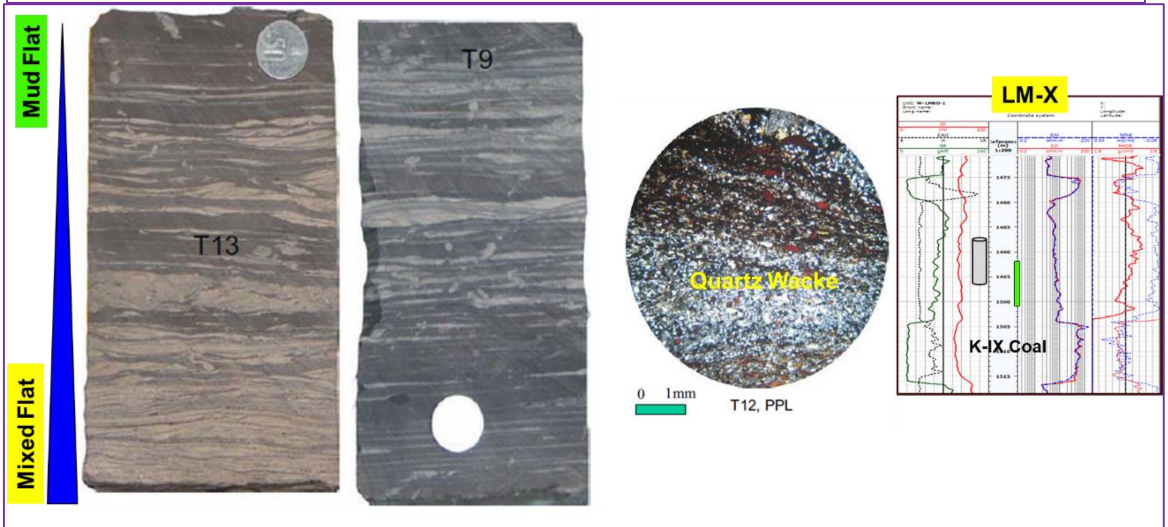


Fig.7. Depositional model for K-VIII

of accommodation space which outpaces the vertical growth and lateral expansion of peat mires resulting into development of thin, discontinuous coal horizons (Holz et. al., 2002).

## Reservoir characterization

Synthetic seismograms were generated using the minimum phase 3D seismic data for the wells in the study area. With calibration by synthetic seismogram, the K-X coal Top, K-IX coal Top and Bottom, K-VIII Top, K-V Top and Kalol Top were mapped at correlated zero crossing (Fig.10). Time and depth maps were generated for K-IX and K-VIII to gain an insight into the structural configuration (Fig.11 and Fig.12). The resolution of the seismic data, effects of the coals on reflection time series, low impedance contrast and heterolithic nature of the KIX & K-VIII reservoirs make their mapping difficult by deploying standard approach of interpretation. To this end, AI based and conventional seismic techniques were applied to decipher the distribution of K-IX and K-VIII reservoir facies in the study area.

### (i) AI based approach

The analysis identifies unique waveform segments that relate to surfaces or horizons and are referred to as GeoPopulation. Each GeoPopulation has a set of attributes associated with each member of the population. One of these attributes is called "fitness" which provides a measure of "genetic likeness" for each member in the population when compared to the common waveform (Genotype) of the same population. These are automatically extracted

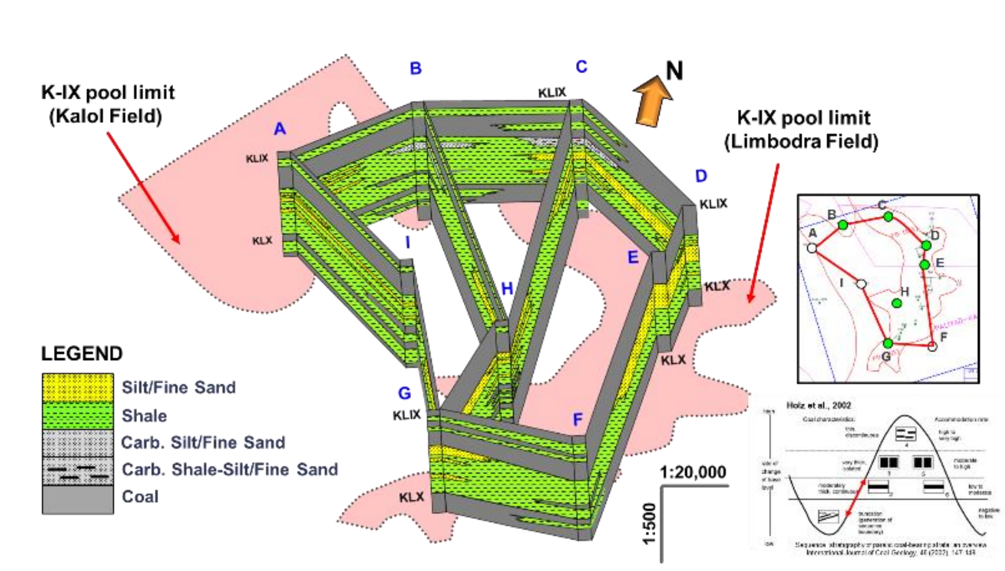


Fig.8. Fence diagram exhibiting the latero-vertical facies distribution of K-IX unit

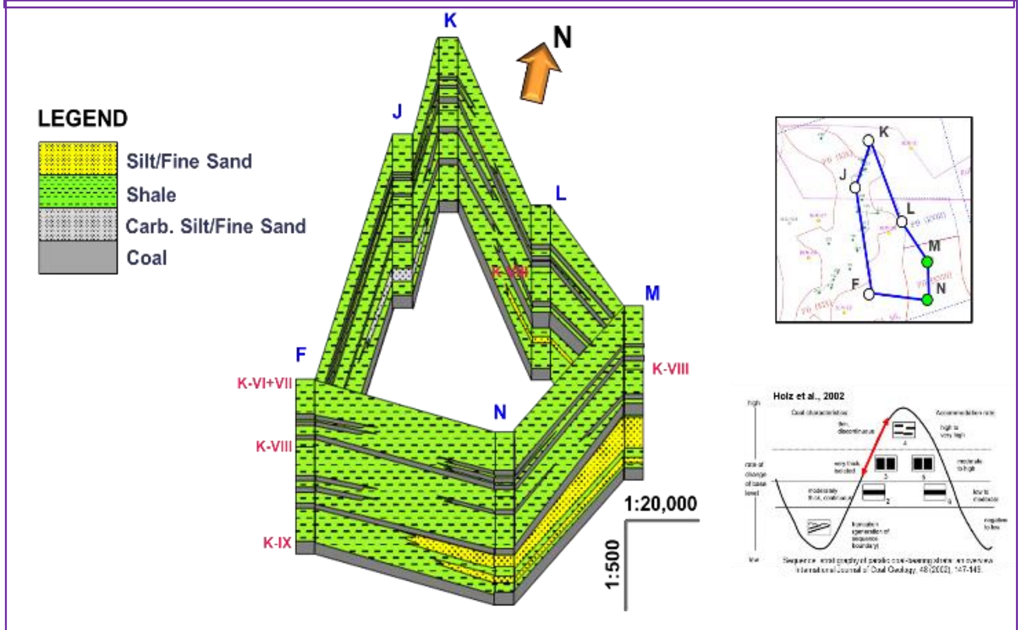


Fig.9. Fence diagram exhibiting the latero-vertical facies distribution of K-VIII unit

quickly, accurately and in an unbiased manner. Initially, the seismic volume is automatically segmented into a population of individual waveforms. Individuals within this collection of waveforms are randomly selected as new populations. This waveform then looks (both locally and globally) for other waveforms with the most similar genetic characteristics (such as amplitude values, trace shapes, frequency or any combination of attributes that are associated to each sample). Each 3D seismic volume has hundreds of identified GeoPopulations. The evolution continues throughout the entire volume until all GeoPopulations have been identified and categorised into a database of surfaces. Qualitative surfaces are automatically extracted by the Seisnetics processing algorithm. The interpreter then reviews the resulting meaningful geological insight (Dirstein and Fallon, 2011). In the present study surface associated to the K-VIII reservoir was extracted using the Seisnetics algorithm. The map shows the 'fitness' of a single GeoPopulation (Fig.13). The areas of lower fitness values are distinctly getting separated out from those of higher fitness values (shown as green) and thus effectively discriminates two different seismic facies. The superimposition of the K-VIII pool map on the Seisnectics derived output distinguishes K-VIII reservoirs from the non-reservoir and establishes the northward extension of the K-VIII reservoir facies away from the established pool limits (Fig.14).

## (ii) Conventional seismic attribute studies

Conventional seismic attribute studies were carried out in an attempt to establish the presence and continuity of reservoir facies away from the established pool limits of K-IX. Different seismic attributes such as most negative amplitude, most positive amplitude, RMS amplitude and Mean Absolute Amplitude were attempted for delineating the K-IX reservoir. The Mean Absolute Amplitude attribute generated within a window of 20 ms below seismically correlated horizon of K-IX Coal Bottom was found to be best suited for the present study as it satisfied ~85% of the observed well behavior (Fig. 15). The Mean Absolute Amplitude map seen in conjunction with the producing and the non-producing wells clearly depict that the principal Mean Absolute Amplitude range favoring the likely development of K-IX reservoir facies lies between 52,000 to >70,000. The wells that were abandoned due to non-development of reservoir facies exhibit Mean Absolute Amplitude values of <52,000 except for J and DD' (Fig.15). Well J showed

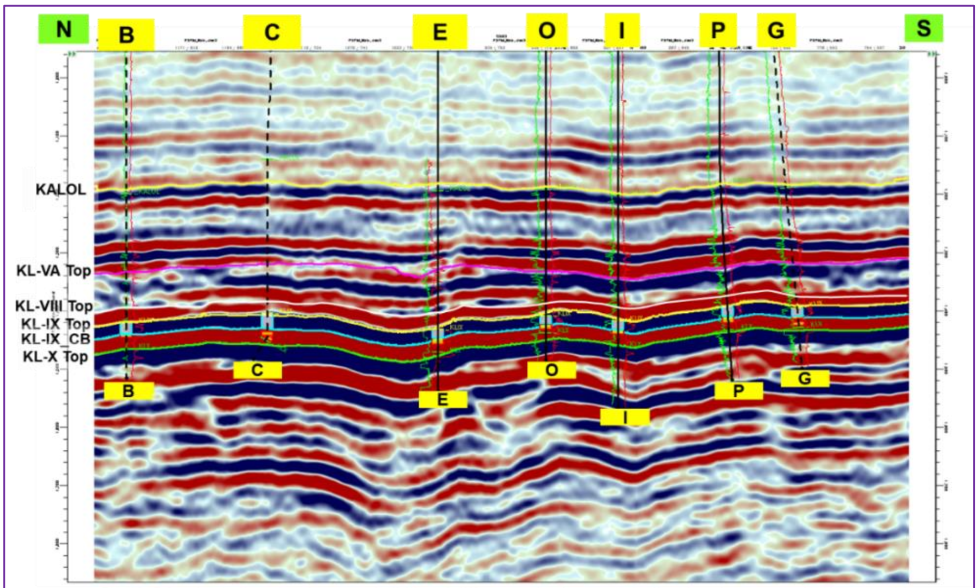


Fig.10. RC seismic line showing correlatibility of different seismic events (yellow bar demarcates K-IX reservoir)

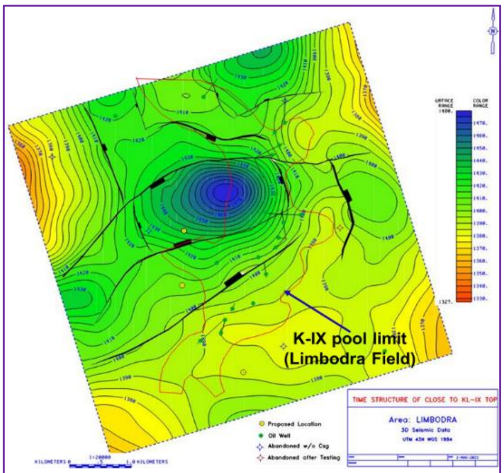


Fig.11. Time structure map close to K-IX Top

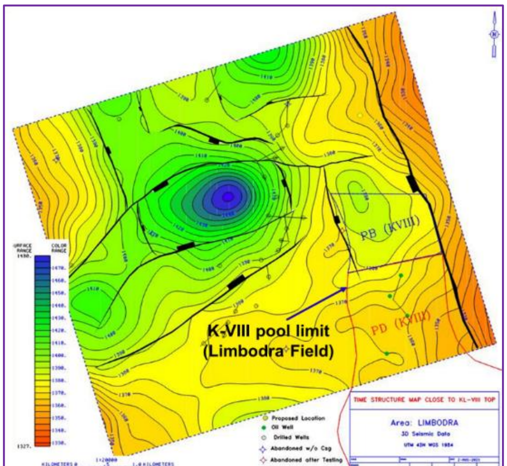


Fig.12. Time structure map close to K-VIII Top

moderate development of K-IX reservoir facies. However, the well was not tested in K-IX but was abandoned and side-tracked to D.

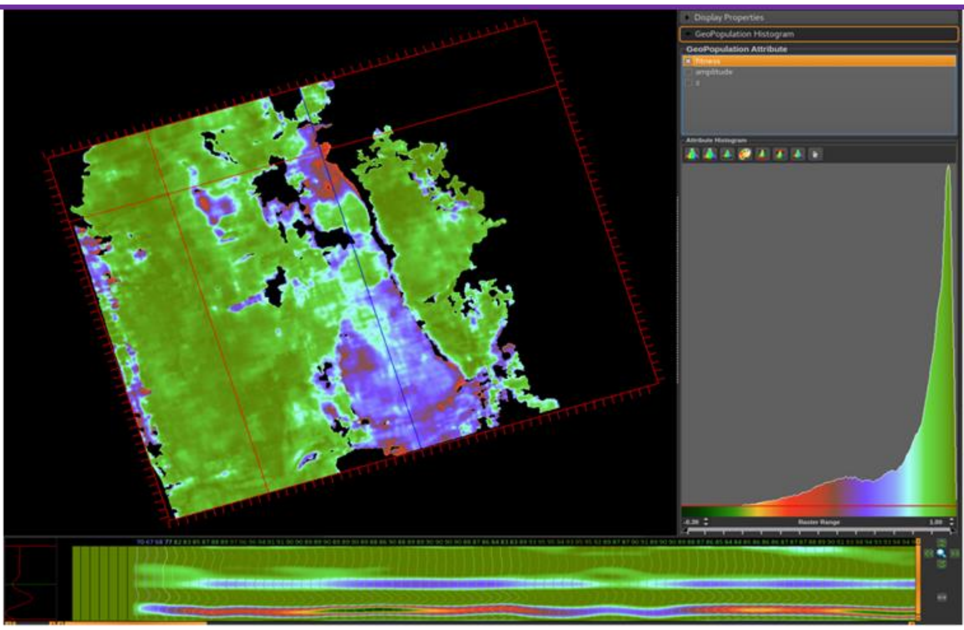

**Fig.13. Fitness attribute map exhibiting the distribution of K-VIII reservoir facies**

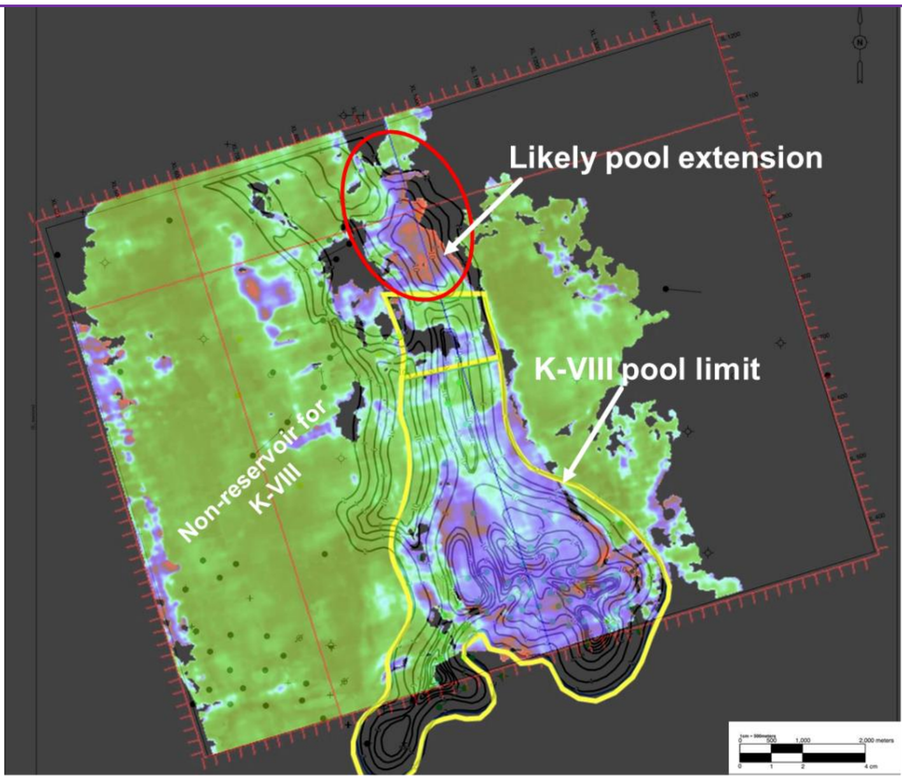


**Fig.14. Reservoir model for K-VIII based on 'Fitness' attribute**

## Reservoir model and exploratory implications

Reservoir characterization of K-IX and K-VIII pays in the Nardipur Low area of the Limbodra Field clearly brings out the likely extension of the reservoir facies away from their respective pool limits. Reservoir distribution maps were generated using the AI and attribute based facies maps in conjunction with the drilled well data (Fig. 14 and Fig. 16). Prospective areas showing the likely presence of K-IX and K-VIII reservoir facies have opened up avenues for bringing in further exploratory efforts which is likely to augment the existing in-place hydrocarbon volume by 64% and 12% in K-IX and K-VIII pays, respectively.

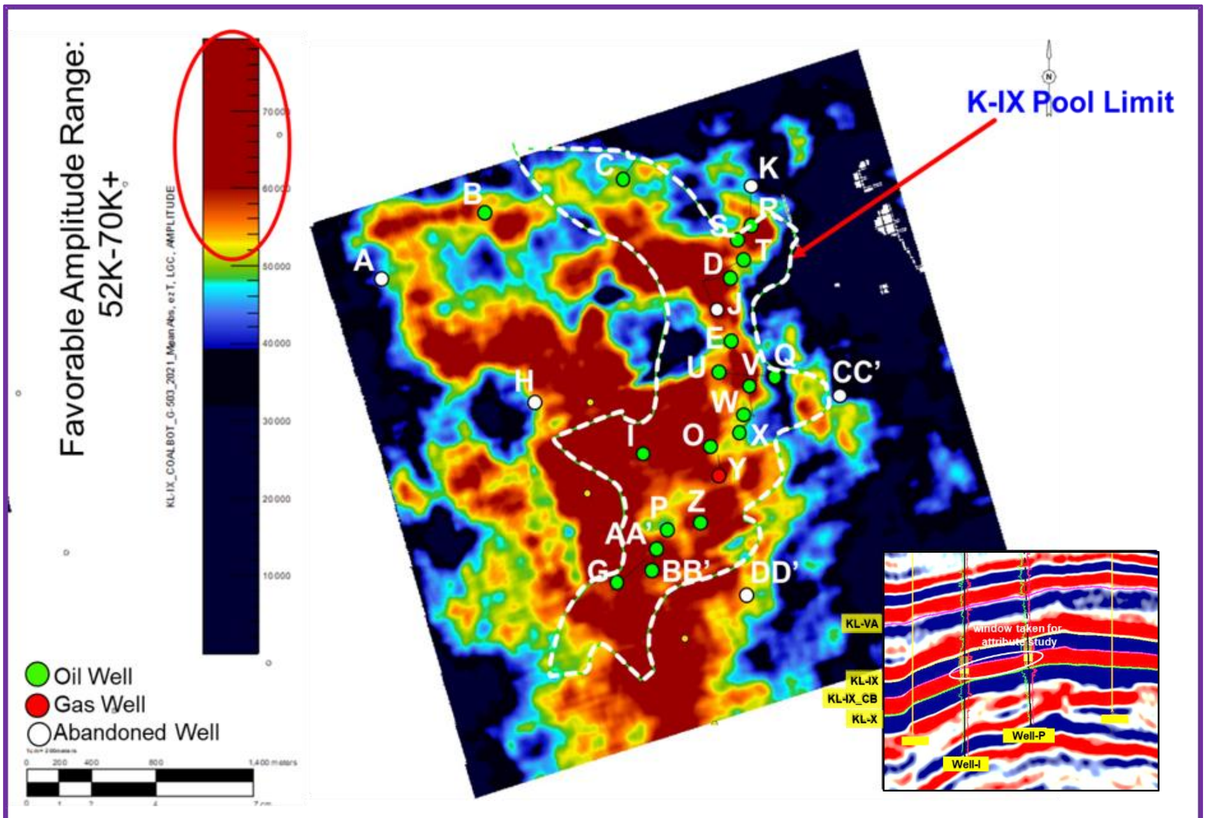


Fig.15. Mean Absolute Amplitude map exhibiting the distribution of K-IX reservoir facies (Within 20ms window from KIX Coal Bottom)

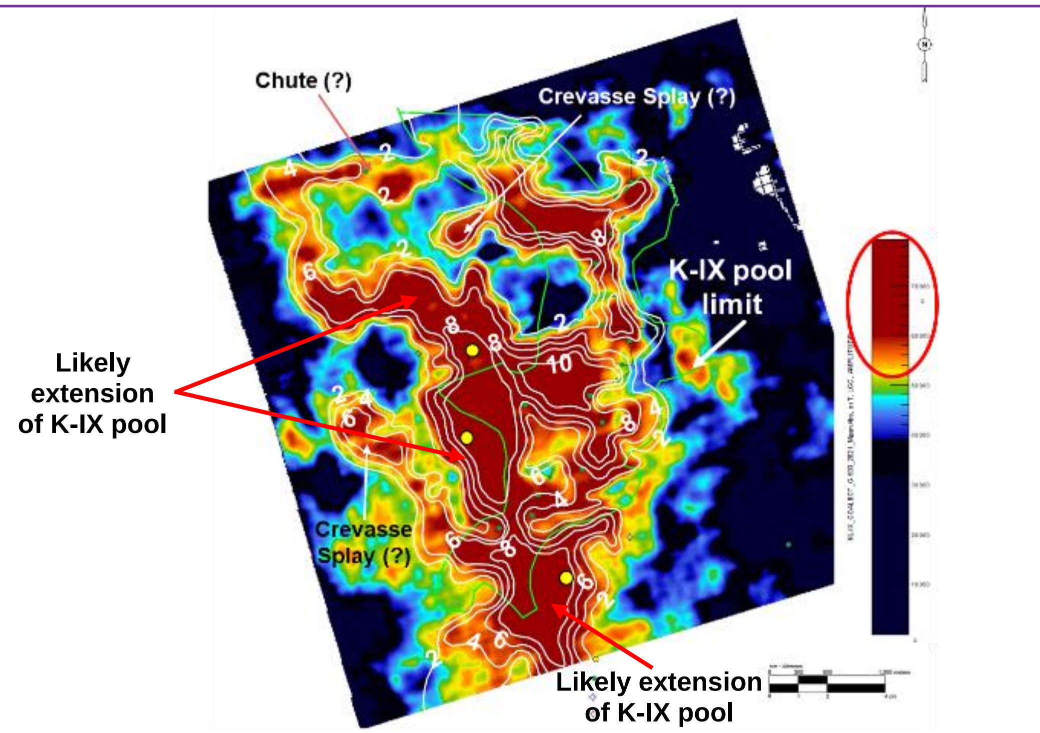


Fig.16. Reservoir model for K-IX based on Mean Absolute Amplitude map

## Conclusions

The K-IX and K-VIII reservoirs are prolific producers in the Nardipur Low area of the Limbodra Field. Seisnetics derived 'fitness' attribute clearly distinguishes the K-VIIII reservoir facies from the non-reservoir facies and brings out the likely extension of the same northwards of the established pool limits. The Mean Absolute Amplitude map satisfies ~85% of the observed well behavior in K-IX pool and corroborates to an amplitude range of 52,000 to >70,000. The Mean Absolute Amplitude map also establishes the likely extension of similar facies away from the established K-IX pool limit. AI based and conventional seismic attribute maps helped in carving out the K-IX and K-VIII reservoir distribution models and delineated the prospective areas for bringing in further exploratory efforts and is likely to accrete substantial in-place oil reserves.

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