Association of Petroleum
Geologists. India
Registered under Societies
Registration Act,No. 21 of 1860

GEO India 2022

Chasing for Hydrocarbon Bearing Horizons Using Low Frequency Micro-Seismic (LFS) Technology: A Case Study in Gandhar Field, ONGC Ankleshwar Asset

Chaitanya Kumar Varanasi[1], D R Sharma, Divya Palathoti, T Chandrashekar, P Damodar, Babita Kumari T, Rajesh Chandra, B.P Singh
[1]Email: kumar_vchaitanya@ongc.co.in, Oil and Natural Gas Corporation Limited

Abstract

Days of easy oil has gone. Ankleshwar Asset, being one of the oldest and matured Assets of ONGC has again proved that like legendary Phoenix it can rise from its ashes again and again. When, even the biggest optimist lost all the hopes from this matured, brown Asset of ONGC, a new technology adopted by Team Ankleshwar Asset, showed a silver lining in Ankleshwar history. It requires new strategies and technologies to deal with production downfall in matured fields like Gandhar of Ankleshwar Asset. Since almost all the sands are on depletion drive, reservoir pressure is maintained by water, WAG injection schemes were implemented ab initio, resulting in recovery 29.6% with average water cut of 80.3%. One of the most challenging task is to minimize the dry wells in highly matured fields like Gandhar. In the quest of new strategies to deal production downfall by identifying bypassed hydrocarbons as well as delineation of its boundaries for further field development. Society of Petroleum Geophysicists (SPG) conference-2015 held at Jaipur, gave hopes through Low Frequency micro-seismic Sounding (LFS) Technology which has a claimed success ratio above 80% at global level.

After thorough discussions with geo-scientists of M/s Stork International GmbH, LFS study was implemented for the first time in Gandhar Field of Ankleshwar Asset. Within Gandhar field, two areas of 5sq.km each were identified for LFS survey. Based on the LFS survey results, identified hydrocarbon potential areas and proposed optimal location for drilling new wells. It resulted in successful drilling of hydrocarbon producing wells. Three wells are producing hydrocarbon out of four proposed locations i.e with 75% success during pilot project. Based on these encouraging results, another 15sq.km area adjacent to earlier LFS surveyed area was identified to delineate extension of present hydrocarbon boundaries around the newly drilled wells.

Introduction

Dearth of new well drilling locations was gradually leading Ankleshwar Asset in the gulf of pessimism. There was a time when there was acute shortage of drilling location. The Asset was thirsty for oil like a Jacobin cuckoo, which is looking for rain drops. Then, to identify by passed hydrocarbons in Hazad member of Ankleshwar formation of Gandhar field and positioning of exploratory and drilling wells to enhance recovery and reduce the drilling risk, Team Logging Services suggested applying LFS technology in Gandhar field. Nearly 784 wells have been drilled so far resulting in a respectable recovery about 30%.

Gandhar field is one of the largest onshore brown fields of ONGC. It is a part of Jambusar-Broach fault block of Cambay basin located in the western part of India (Fig.1). Multi-layered hydrocarbon bearing clastic reservoirs of Middle to Upper Eocene are found in Gandhar. This field was discovered in 1983 and has been producing hydrocarbons for almost four decades, having a large geographical extent with horizontal and

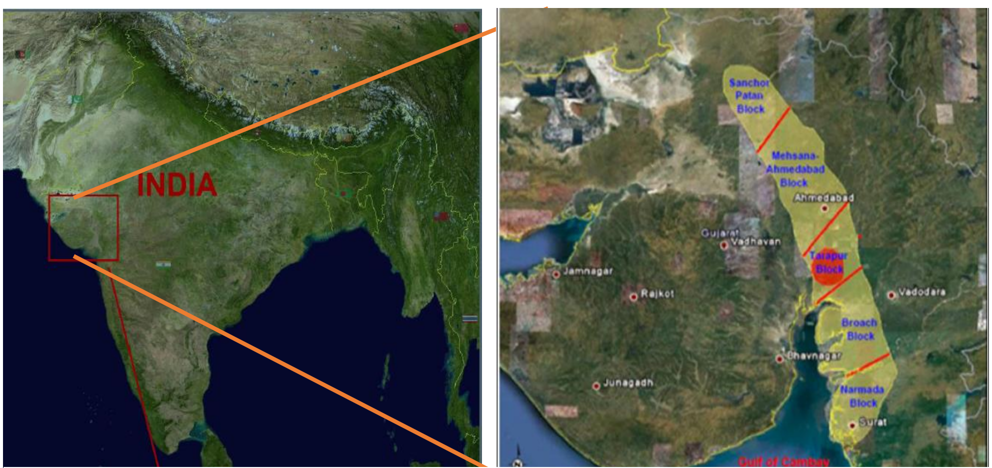

Figure 1: Location Map of Cambay Basin

vertical heterogeneities. Total 12 no. of sands within Hazad member of Ankleshwar formation are proven hydrocarbon producers in various areas of Gandhar field with porosity ranging from 10 to 26%. Oil produced from these reservoir is of 38-55API gravity with average water cut of 80.3%. Recovery of individual reservoirs ranging from 13 to 62% which is at par with global standards. The biggest challenge today in this field is to maintain the production from existing wells which are producing with average 80.3% water cut and also finding new locations for drilling.

After preliminary noise survey, two most suitable areas with less cultural noise were selected for the LFS survey. Area-I (Fig. 6) identified for LFS survey has high heterogeneity with water bearing wells not far from the oil producing ones from S-1. A well (G-XAX) drilled primarily for shale-gas prospects was found to be oil bearing in sand S-1 and south of G-XAX, wells were not drilled. So it was decided to identify the hydrocarbon prospects in south of this lead well. Accordingly an area of ~5sq km was identified for LFS survey to delineate the hydrocarbon bearing area between the G-FHG, G-FOG, G-BEC and G-XAX.

Area-II (Fig. 6) identified for LFS survey has only one exploratory well G-XBG, which is a producer from Hazad sand S-4. To know the lateral extent of the reservoir, LFS was planned.

The main objective of this paper is to focus on LFS technology and results.

Geological Setting

Cambay basin is a narrow elongated intra-cratonic NNW-SSE treading rift graben basin. It is filled with tertiary sediments which were deposited over Deccan trap volcanic basement. The basin is divisible into five tectonic blocks, based on the transverse fault system, and the associated depo-centres are governed by rifted basement (M. A. Hassel et.al).

Gandhar field is situated in Jambusar-Broach block. The main reservoir rock is sandstone of Middle to Upper Eocene. Hydrocarbon are mostly accumulated in multiple sands S-1 to S-12 (bottom to top) of to Hazad member within Ankleshwar formation. Extensive coring done in Hazad section and identified the main clay minerals as kaolinite and chlorite. Core data in sandstone shows moderate to good sorted with round to sub angular grains.

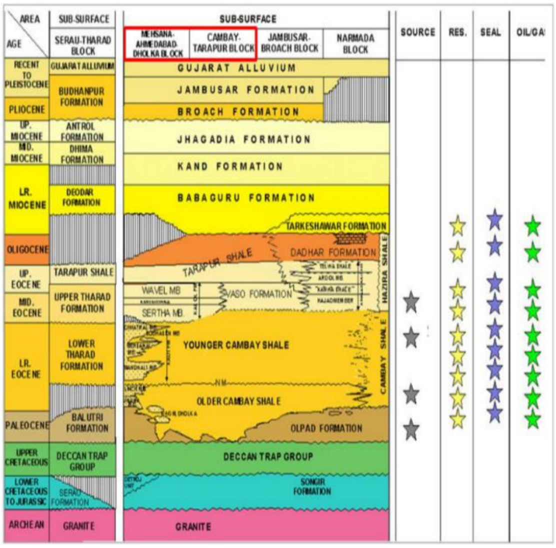

Figure 2: Generalized Stratigraphy of Cambay Basin.

Basic Theory & Work Flow

Low-frequency seismic sounding technology is based on the phenomena of anomalous natural low-frequency seismic background above an oil and gas reservoir. The assumption that a hydrocarbon saturated reservoir is characterized with anomalous reflection of low-frequency waves, based on a combined influence of several factors:

1. Oil compressibility at reservoir condition is 5-10 times higher than that of water and surrounding rock.
2. Oil viscosity is much higher than viscosity of water and surrounding rock. As is known, absorption in a medium is proportional to viscosity.
3. Physical model of multiphase media shows significant frequency dependence between Vp and Q-factor at frequencies below 10Hz.

As a result of reservoir multiphase composition, enhanced absorption of elastic energy occurs and compressional wave velocity drops in the frequency range from 1 to 10 Hz, which leads to a significant increase in the reflection coefficient modulus.

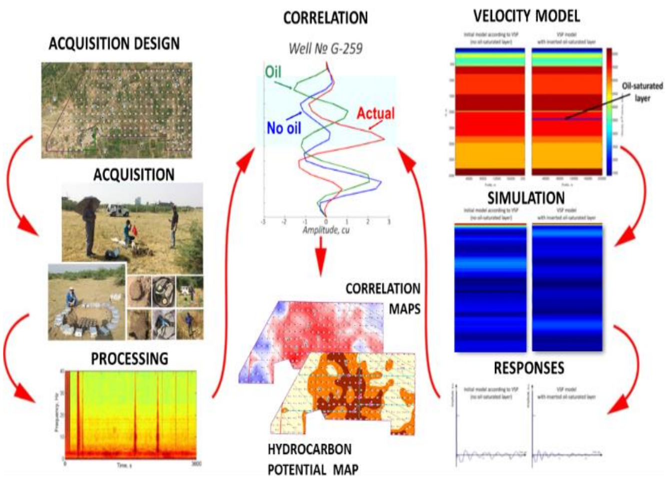

Figure 3: LFS API (Acquisition, Processing & Interpretation) Workflow.

Data Acquisition

Measurements of the passive micro-seismic wave field were performed in each area with 250 x 250 m survey grid and 5 observation points at each well in and around surveyed area. During the field survey, data is acquired by equipment kits consisting of three-component broadband seismometers SME-4311LT and Scout designed recorders for recording the vertical component and two horizontal components of seismic vibrations and their digitalization with a common time reference.

Figure 4: Geophones

Seismometers (Figure 4) are installed at the bottom of the pit at a depth of 30-50cm, with a glance to its horizontal position using the bubble level. Three-component micro-seismic signal recording was performed at a sampling frequency of 250 Hz. Recording time in the observation point was, at least, 18-48 hours that provided the time series necessary for a reliable statistical evaluation of the data obtained with due account for daily variations.

Processing and interpretation

The goal of the LFS Technology data processing is to get the spectrum of vertically directed P-waves from ambient background microseismic noises. The major problem is Roll waves and other types of waves which are mixed with useful background signal (vertically directed P-waves). Roll waves are of two classes one is from non-moving surface sources such as pumps, drilling equipment etc. and the later one is ambient background roll waves from omnidirectional roll waves. The first type of Roll waves generated by non-moving surface sources effectively filters out on the base of the linear prediction algorithm, which is considering correlation dependence between components of roll wave of microseismic record. This algorithm subtracts from vertical component of record correlated with horizontal components part of the noise.

To reduce the second type of noises (omnidirectional roll waves), simultaneous records from two Z-components from sensors which are enough distance from each other and all possible different combinations between operation points (o.p) are used for dipole creations.

Acquired field data (time series) was processed with basic set of narrow band pass and broad band pass noise filters and 2D spectra which are further generated by using Fourier transform. The processing was done on software complex NSZ-professional developed by M/s CJSC "Gradient".

Simultaneously, velocity model of the media constructed with possible two simulations, one is with oil layer and another is without oil layer. Then actual spectra matched with two simulated spectra (with oil and without oil). By analysing the spectral curves obtained as a result of numerical simulation, were identified the biggest difference in frequency position of spectral peaks between the spectra of two simulated cases is observed in the frequency range of 1.1 to 1.6Hz and the same was considered as the target frequency range (Figure 5). Oil layer was set with acoustic impedance contrast 0.4 and attenuation contrast 10 relative to the surrounding formation. The simulated spectra obtained with this contrast have good similarity with the actual spectra.

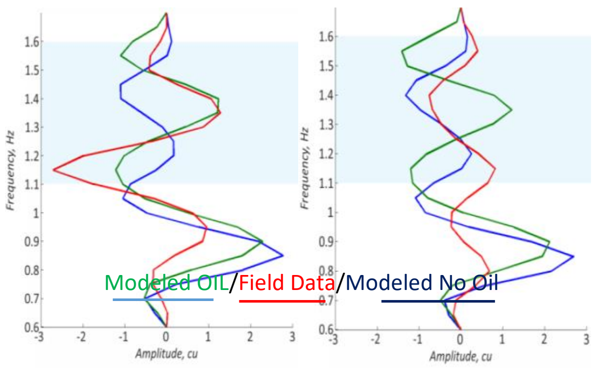

Figure 5: Spectra with (left) & without (right) Oil near Wells.

Thus, the analysis of the spectra obtained in the wells area, depicted that simulated spectra matching with the spectral characteristics in general and close to wells with known oil saturation for the respective cases of oil saturation in this well area, indicates the adequacy of the chosen velocity model for this area. Two maps of correlation coefficients of actual spectra from survey data with simulated spectra which characterises absence & presence of hydrocarbon. Both the maps were overlaid to get map of hydrocarbon presence probability (LFS Hydrocarbon Prospect Map) as shown in the Figure 6 & Figure 8.

Discussion of the Results

During the LFS pilot project, 3 wells in Area-A & one well in Area-B were proposed and drilled (log motifs of these wells presented in Figure 7), in which 2 wells in Area-A and one well in Area-B produced hydrocarbons.

Proposed wells drilled in Area-A & Area-B:

Recommended four wells (Figure 6 & 7) were drilled as per LFS results, in which 3 wells (proposed location no. 2 & 3 in Area-A and no. 4 in Area-B) produced hydrocarbon and location no. 1 in Area-A produced water,

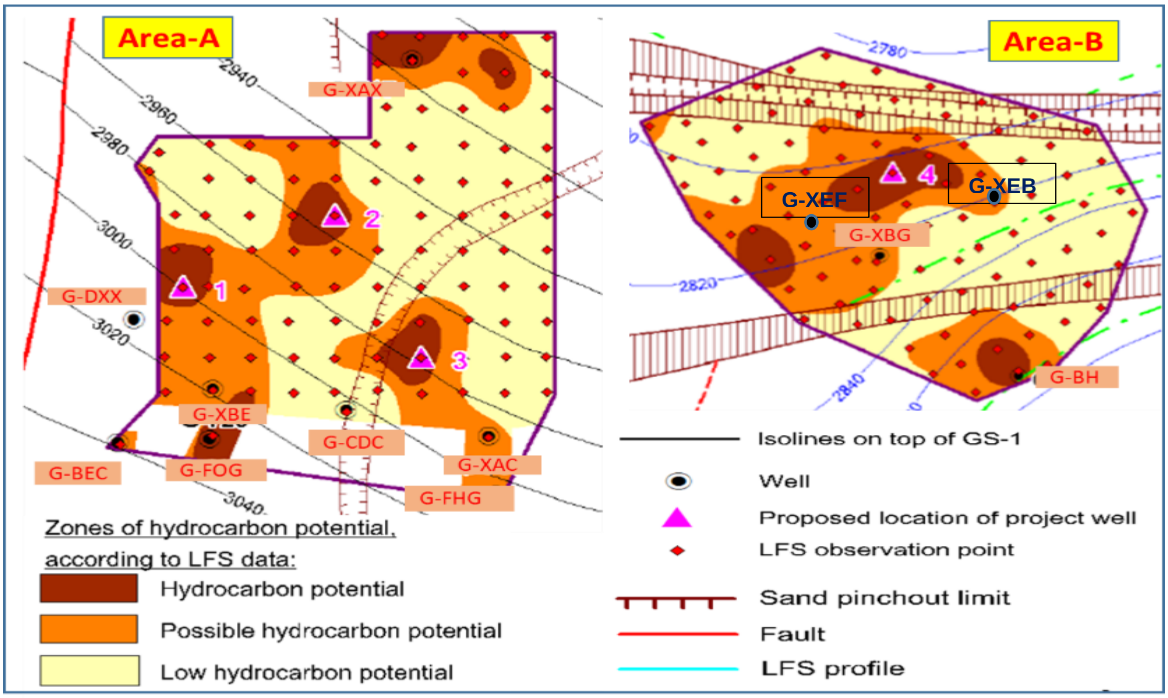

Figure 6: LFS Prospect Maps of Area-A & B on Isoline of Sand S-1 & S-4.

which is worked out to be 75% success of predictions. However, the well that produced water has been converted as water injector in sand S-1 to accelerate the reservoir pressure of S-1 which was under sub-hydrostatic pressure.

Re-evaluated the LFS output of Area-A based on testing results and comprehensive study along with VSP & 2D seismic data. The predictions are in very good agreement with production results. Production details of LFS Phase-I (Area-A & Area-B) are tabulated below:

Well	Proposed Location No. as per LFS	Oil (tons)	Gas (MMm3)
G-XCE	2 (Area-A)	9110.4	4.1433
G-XCF	4 (Area-B)	19280.3 (cond)	0
G-XDC	3 (Area-A)	30711.1	10.4029
G-XDD	1 (Area-A)	Produced Water. Converted as WI.	

Subsequently, a development well G-XEB (Area-B in Figure 6) was drilled for oil production from sand S-4 based on geological model. As per LFS prospectivity map, this location is falling at boundary between possible hydrocarbon potential & low hydrocarbon potential zone of Area-B i.e less than 60% of hydrocarbon possibility and close to water contact. These predictions are complemented by production behaviour of this well with cumulative production 950.7ton of oil & 0.6233MMm3 of gas and subsequently it produced 100% water. Another development location G-XEF (Area-B in Figure 6) was proposed and drilled in Area-B which is falling in more than 65% possible hydrocarbon potential zone based on LFS results and three no. of sands were found to be interesting from hydrocarbon point of view. This well unlocked new horizons for further development of this field apart from existing hydrocarbon bearing sand S-4.

Based on this encouraging results and successful predictions of LFS, another area (Area-C) of 14.29sq.km adjacent to previously surveyed Area-A was identified to delineate extension of S-1 & S-3 pools in north direction. Phase-II LFS survey was carried out in Area-C in North of Gandhar field and proposed 8 no. of location for drilling (LFS hydrocarbon prospectivity map of Area-C is presented in Figure 8).

Initially, proposed locations 6 and 5 were drilled as G-XFB & G-XFE and not found any zone interesting from hydrocarbon point of view. These two locations were side-tracked as G-XFB_Z & G-XFE_Z and drilled to target the proposed locations 2 and 3 of LFS recommendations. In these side-tracked wells, sand S-1 found to be interesting and produced hydrocarbon. Proposed location no. 8 was drilled as G-XFX and it produced hydrocarbon. In LFS Phase-II, out of 8 proposed locations, 5 locations were drilled in which 3 wells found to be potential in hydrocarbon point of view (depicted in Figure 9 for two wells), which worked out to be 60% success.

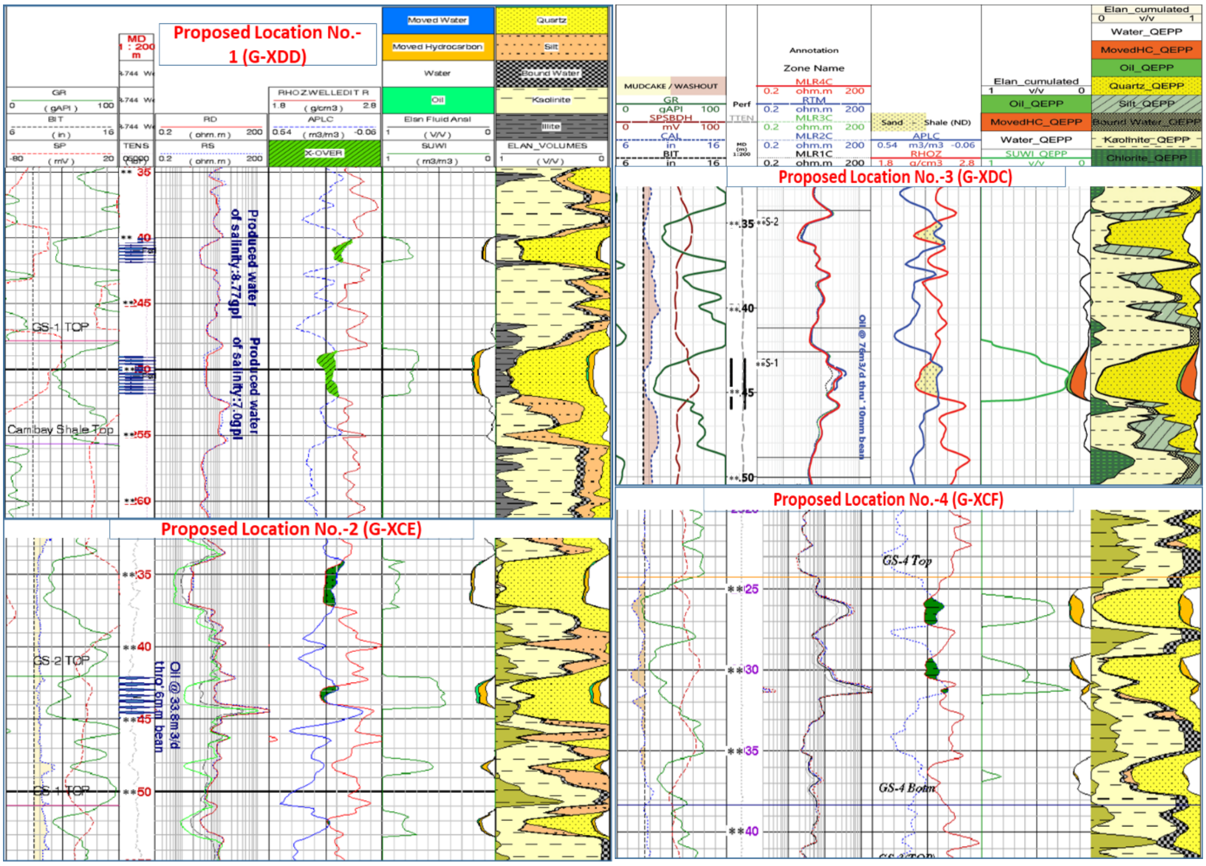

Figure 7: Log Motifs of Locations Drilled Based on LFS Results in Area-A & Area-B.

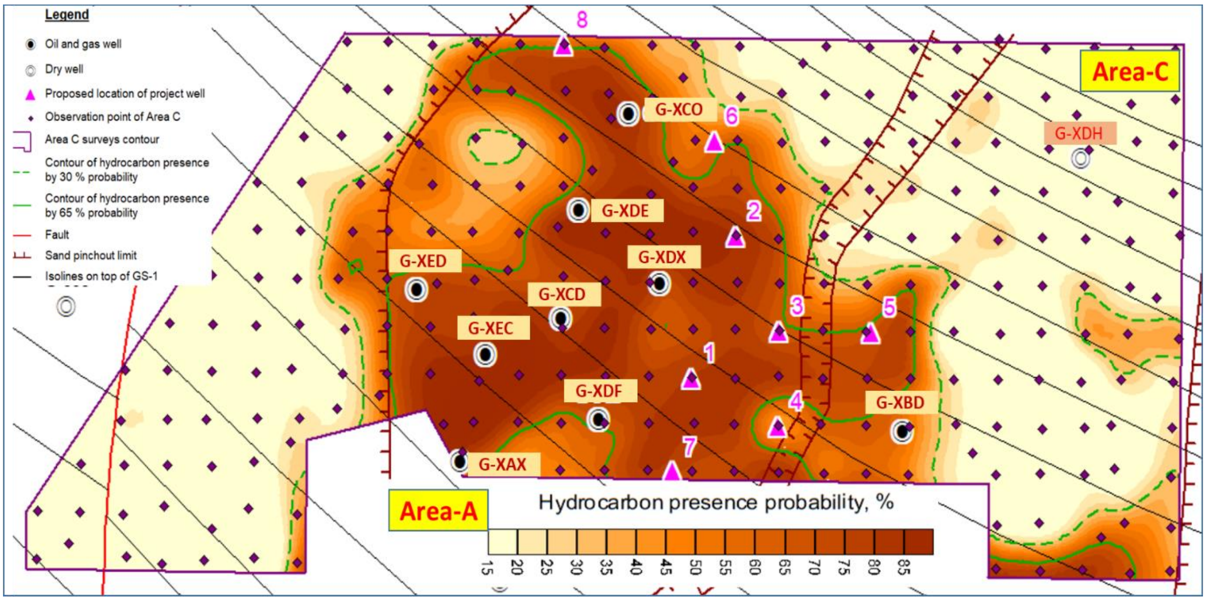

Figure 8: LFS Hydrocarbon Prospectivity Map and Proposed Locations for Drilling of Phase-II, Area-C

Cumulative production details of LFS Phase-II (Area-C) is given below:

Well	Proposed Location No. as per LFS	Oil (tons)	Gas (MMm3)
G-XFB	6	No zone is interesting.	
G-XFB_Z	2	325.7	0.3401
G-XFE	5	No zone is interesting.	

G-XFE_Z	3	14105.6	6.9049
G-XFX	8	16136.3	8.1403

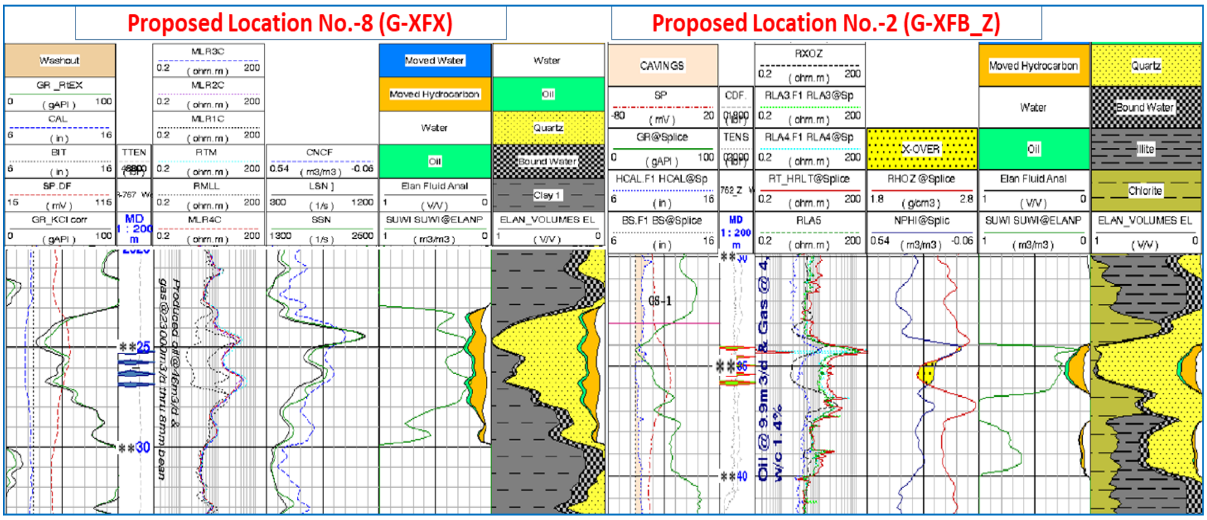

Figure 9: Log Motifs of Locations Drilled Based on LFS Results in Area-C.

Techno-economics

Overall cumulative hydrocarbon production due to wells drilled based on LFS recommendations and based on LFS hydrocarbon prospectivity maps/output is 181873.2ton of oil, 19280.3ton condensate and 63.9422MMm^3 of gas. Expenditure on LFS project is a mere amount when compared to resultant hydrocarbon gain due to LFS results and drilling cost in general. Approximate LFS projects cost is tabulated below:

LFS Project	Area (sq.km)	No. of Wells: Proposed/Drilled/Produced HC	Success	Total Cost (in INR)
Phase-I	**10sq.km (Area A,B)**	**4/4/3**	**75%**	**3.61crore**
Phase-II	**14.29sq.km (Area-C)**	**8/5/3**	**60%**	**4.84crore**

Cumulative revenue generated by wells produced based on the results of LFS Phase-1 & II projects:

Type of Hydrocarbon	Cumulative Production (as on Dec-2021)	Revenue (in INR)
Oil + Condensate Gain	**181873.2ton + 19280.3ton (Rs. 5585.377/bbl)**	**958.36crore**
Gas Gain	**63.9422MMcm ($2.9/mmbtu)**	49.10crore

Limitations

Like any technology, it has also some limitations. The limitations should be understood before implementing it, to be benefited.

1. Diffraction effect influences the boundary effect of the target object.
2. Reflection coefficient of low frequency wave depends on reservoir parameters viz, net pay, porosity, oil & gas saturation.
3. Vertical resolution of the LFS survey is varies with depth of the target reservoirs and much higher than the thickness of reservoirs. In case of multi-layered reservoir, it looks the entire section as one unit.
4. LFS cannot be used in ranked exploratory area as it required one hydrocarbon producing and one water bearing well of that area for processing and generating prospect map.
5. Survey area should be free from cultural noise as it records the natural seismic wave.

Conclusion

LFS technology can be effectively used to identify by-passed/left-over hydrocarbon to ascertain new possible locations or future opportunities in existing fields like Gandhar. LFS can provide the cost effective approach to identify new potential locations and helps in avoiding dry wells.

References

1. Report on LFS survey results of Gandhar field by M/s Stork International GmbH, Russia & M/s Octomaks Technologies Pvt Ltd, India.
2. A bird eye view of exploration history and success in South Cambay basin and future strategy of exploration by M. A. Hassel et.al.