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Passive Seismic Monitoring over Wavel oil field of Cambay basin, Gujrat for quick assessment of Hydrocarbon Reservoirs.

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Summary

Passive seismic attributes based on spectral properties, usually between 1 to 6 Hz.have been suggested as potential indicators for sub-surface hydrocarbon targets. Low Frequency (LF) seismic anomalies associated with hydrocarbon reservoirs have been observed by various industry and academic groups in different parts of the world. Passive data can be acquired in hydrocarbon exploration areas to focus seismic data collection, corroborate Trap and optimizing drilling location.

Institute of Seismological Research (ISR),Gandhinagar had acquired low frequency passive seismic (Micro-tremor) data in and around Gandhinagar / Dholera regions for H/V site response ananlysis in seismic microzonation deploying 5sec Broad Band Seismometers (BBS). These data have been analyzed to verify reservoir / non-reservoir response utilizing Infra-sonic Passive Differential Seismic technology. Preliminary analysis provides anomalous spectral signatures over Gandhinagar area which has later been proved to be hydrocarbon prone area.

Motivated by the anomalous spectral observations across Gandhinagar region of Gujrat , a 2D profile was acquired, covering a distance of 3km with 15 stations at 200m station interval using 5sec BBS, over the producing oil field in Gandhinagar area . The results were not only encouraging but clearly delineated additional reservoirs pockets which need to be corroborated with seismic / log data for further drilling.

The present work is a first step that has been initiated by this Institute to verify effective use of the IPDS technology which has been reported by many authors.

Introduction

Gujarat state has huge potential of Hydrocarbons in many pockets of Kachchh, Saurashtra, and Mainland South Gujarat. The state has already proven discoveries and prospects of Hydrocarbon in Cambay Rift Basin and Gulf of Cambay since 1960. Even after decades of exploration activities, drilling dry wells could not be avoided till date which reflects uncertainty with added costs. This is due to complex hydrocarbon reservoir entrapment condition and non linear behavior of fluid systems in porous medium.

To avoid the risk, in year 2003 a new method of Low Frequency Infrasonic Passive Differential Seismic (LF IPDS), Patented Technology Geospectra IPDS or more precisely Passive Seismic came in light which uses the passive energy of earth. This method is based on the principles of non linear behavior of fluid systems in porous media. Hydrocarbon in the pore system of reservoirs can be detected as a characteristic deformation of the natural, omnipresent earth noise spectra in the low frequency range between 0.2 and 10Hz. These Low Frequency (LF) seismic signals can be recorded at surface with ultra high sensitive seismometers.

Institute of Seismological Research has continuously been acquiring low frequency passive seismic signals (micro-tremors) for H/V site response in

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and around Ahmedabad / Gandhinagar region which have been analyzed for hydrocarbon monitoring in this region. Finally, a survey (2D profile) was undertaken over the known oil field (Wavel) which is discussed in details in this article. The results are not only interesting but also encouraging.

Theory and Methodology of IPDS technology

The modern technique LF IPDS is based on the method of Hydrocarbon micro-tremor analysis (HyMAS). Principle of this technique acts as an innovative seismic spectroscopy identifying the hydrocarbon content of geological structure by analyzing low frequency background wave signals within 1 to 6 Hz. The Hydrocarbon reservoirs act as frequency converter. The signals are spectrscopically analyzed to produce a unique spectral signature which is used as a direct Hydrocarbon indicator.

The association of low frequency passive seismic anomalies with hydrocarbon reservoirs is an empirical result reported by a number of independent companies and academic institutions. Current working hypotheses for the observations are based on an extension to far field elastic theory incorporating phenomena associated with multi- phase fluids in pore-elastic media.

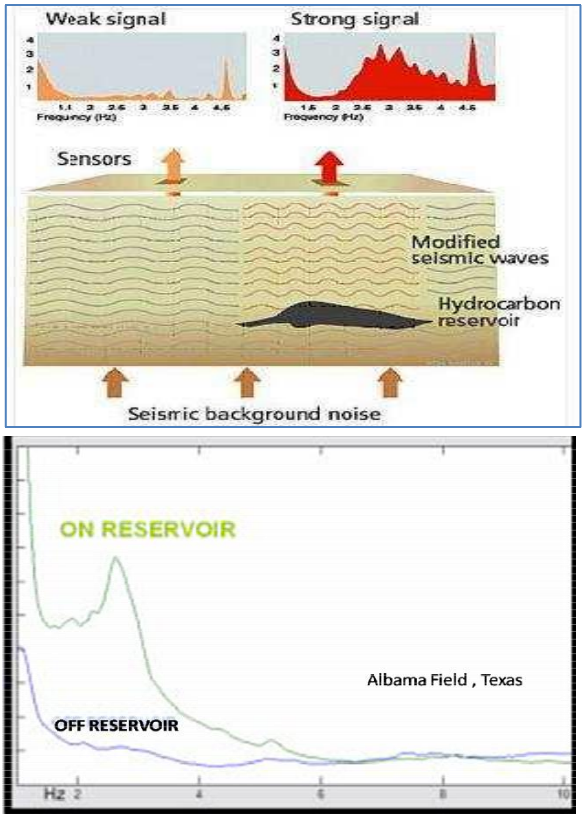


Figure 1: Subsurface hydrocarbon reservoir and passive seismic wave field along with Spectra

Hydrocarbon reservoirs (Figure 1) are unique in the subsurface because they contain multiple fluid phases on the pore size scale. The different compressibility of two fluid phases gives rise to pressure differentials that can be stimulated by a passing seismic disturbance. At low frequencies, seismic waves can act more like pressure gradient disturbances rather than transient stimulations. As such, fluid flow is induced between connecting but differing regions in a porous medium.

These pore level phenomena may give rise to intrinsic attenuation, energy absorption / re-emission, and even nonlinear effects that can be used to describe how energy is redirected from the earth's energy field toward the surface (Figure 2) so that it can be measured by broadband seismometers located on the surface. Statistical analysis of spectral attributes should then be used to discriminate this effect from near surface site effects and seismic noise.

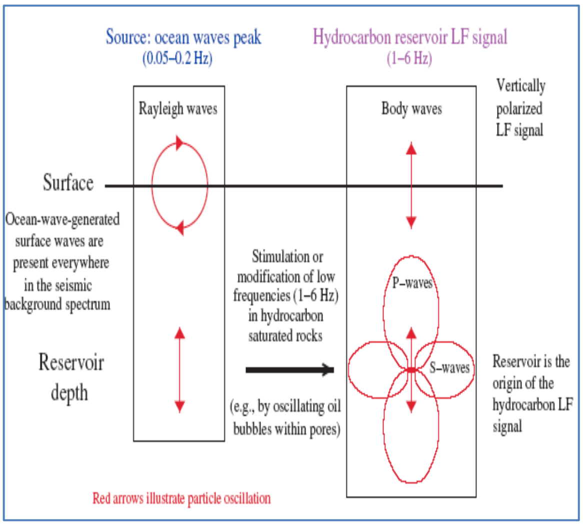


Figure 2. A preliminary model that explains the origin of hydrocarbon-indicating tremors and that is consistent with the spectral attributes (i.e., PSDIZ and V/H signal).

Tecnology perceived and survey done by ISR

Institute of Seismological Research (ISR) had collected low frequency passive seismic (micro-tremor) data for about 40 sites in and around Gandhinagar / Dholelra regions for H/V site response analysis in seismic micro-zonation deploying Broad Band Seismometers (BBS) .These data have been analysed to verify reservoir / non-reservoir response utilizing IPDS technology as shown in Figures 3 to Figures 7. Preliminary analysis provides anomalous spectral signatures in and around Gandhinagar area as shown in Figure 6 highlighting in green circle which is absent or flat in Dholera area.

Low frequency spectral anomalies are being used as hydrocarbon indicators as reported earlier. Four different spectral attributes may be derived from the low frequency micro-tremor data which corresponds to hydrocarbon anomaly in subsurface as described below

Attribute 1 PSD spectrum (Energy anomaly in vertical particle velocity)

This attribute is based on the observation of energy accumulation in the low frequency range above reservoir. The energy accumulated is integrated within a specified bandwidth that quantifies an anomaly proportional to energy curve of vertical (or Z) component of Broad Band Seismometer.

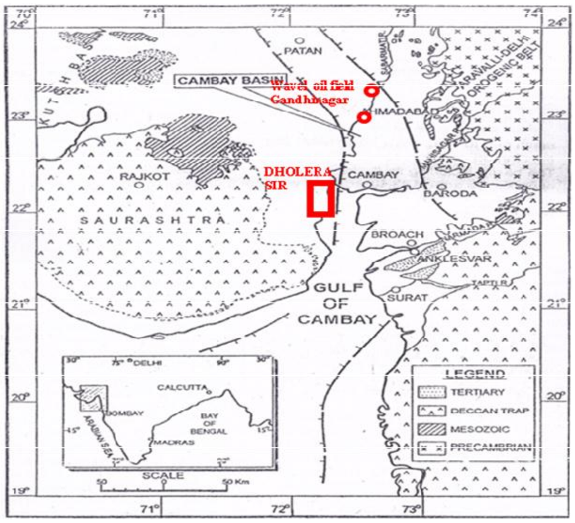


Figure 3. Gandhinagar / Dholera regions in the Cambay Basin.

Attribute 2 Peak amplitude of V/H-ratio

This attribute is based on the observation that the hydrocarbon related energy anomaly is usually stronger in the vertical component compared to the horizontal component.

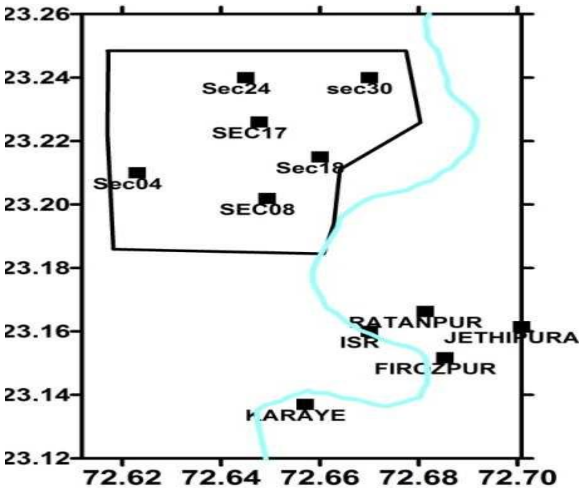


Figure 4: BBS stations network in Gandhinagar

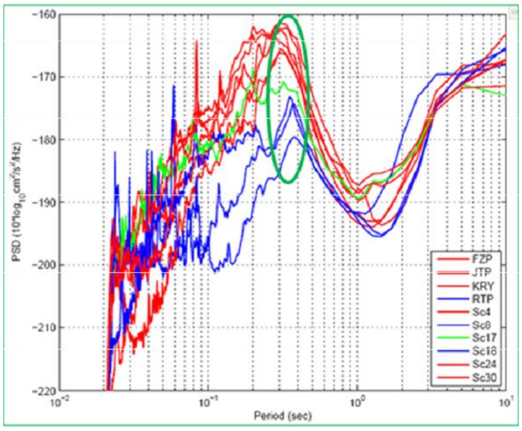


Figure 6**:** PSD response of BBS stations network in Gandhinagar

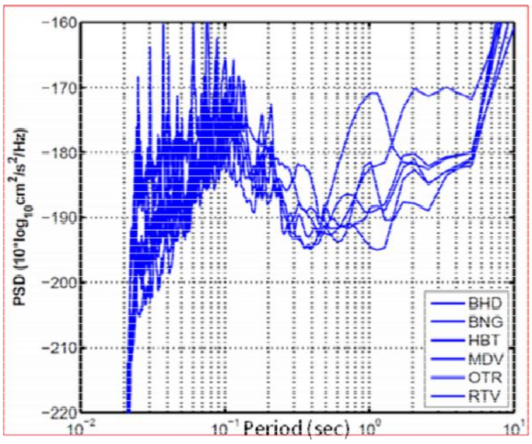


Figure 7: PSD response of BBS stations network in Dholera SIR

Attributes 3 and 4 Peak frequency of the vertical and horizontal spectrum

Peak frequency in vertical and horizontal spectrum is usually more stable than the corresponding peak amplitudes.

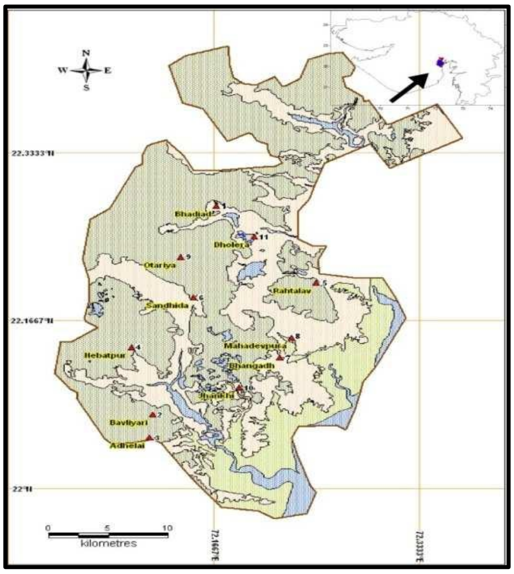


Figure 5: BBS stations network in Dholera SIR.

Data Acquisition

Motivated by the anomalous spectral observations across Gandhinagar –Dholera region as described above, a 2D profile was acquired covering a distance of 3km with 15 stations at 200m station interval using 5sec BBS, across producing oil field in Gandhinagar area as shown in Figure 8a & 8b. Figure 8c displays the field lay- out of BBS.

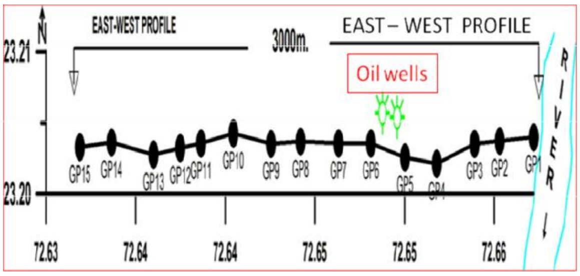


Figure 8a: Survey profile across JTI oil well in Wavel oil field, Gandhinagar.

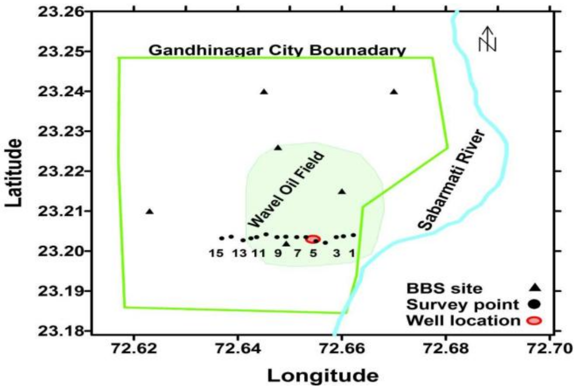


Figure 8b: BBS stations and 2D line of 3km with 200m station interval in Gandhinagar city.

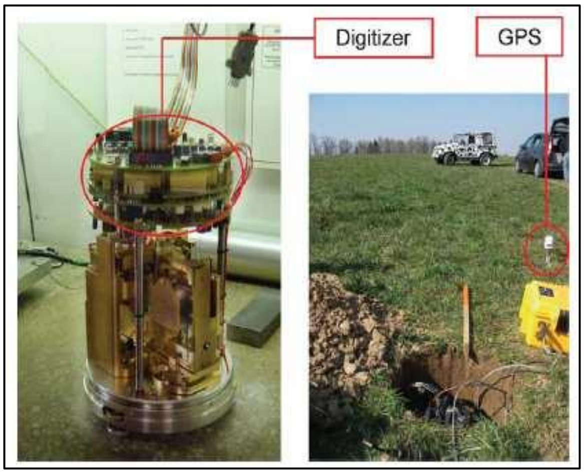


Figure 8c: BBS Instrument & its filed Installation.

The data used in this study recorded at night time from01:00 A.M to 02:00 A.M deploying 5sec BBS sensors, which represents relatively quiet time period. Data was recorded at night time because the amplitude of wave field (V & H) generally increases during the day because of anthropogenic noise and temperature effect

First level quality control is conducted in the field to maximize quality and consistency. Once the data is imported into the database, a rich suite of analytical and graphical tools developed at ISR are used to evaluate the data with regards to noise, spectral content, and time variability.

Data conditioning and processing

Processing of low frequency passive seismic time series involves separating man-made noise by following processing steps displayed in Figure 9 A, B & C

1. First stage spectrogram generation of raw time series data.
2. Application of Band pass filter from 1 to 10 Hz.
3. Second stage spectrogram generation of filtered data.
4. Selection of time series data.
5. Third stage spectrogram generation of selected time series.

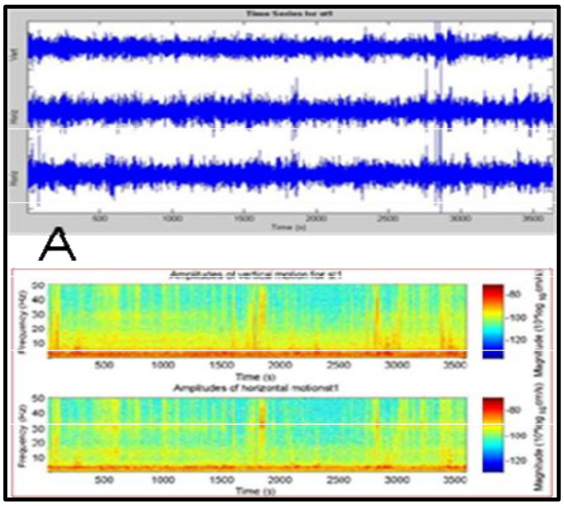
Man made noises, high frequency cultural noise, production well noise and typically low frequency infrastructure related noise (e.g. due to buildings & buried pipelines) etc are normally associated with acquired data. Although these noises are not found resonance in frequency range 1 to 6 Hz but at times distort the amplitudes of signal.

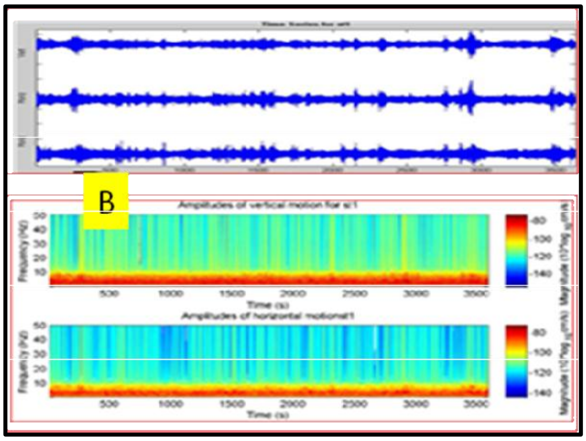
Processing of Data collected

Now according to IPDS technique, V / H spectral ratio and Power Spectral Density (PSD) of vertical particle velocity are main passive seismic attributes, which are estimated in this study using standard processing tools available in Matlab software.

In band pass filtered time series data, a Hanning window of 10.24sec with 20% overlap was applied to each component (i.e. Z, N and E) and then average the Fast Fourier Transform of each window. The attribute V/H is estimated using ratio of spectral amplitude of Z component with Root Mean Square of spectral amplitude of N & E component. Similarly, PSD is estimated applying Hanning window of 10.24sec with 20% overlap to Z component and average the PSD of each window.

The PSD-IZ i.e. the integral under the PSD curve within a frequency band is estimated using Simpson 1/3rd quadrature rule. The lower limit of the frequency band ranges from 1 to 1.7 Hz, since below this lower limit, the low frequency ocean wave peak (OWP) is observed .The upper limit of frequency band is fixed at 5 Hz because above this frequency level anthropogenic noise dominates the spectrum from 5 Hz onwards.





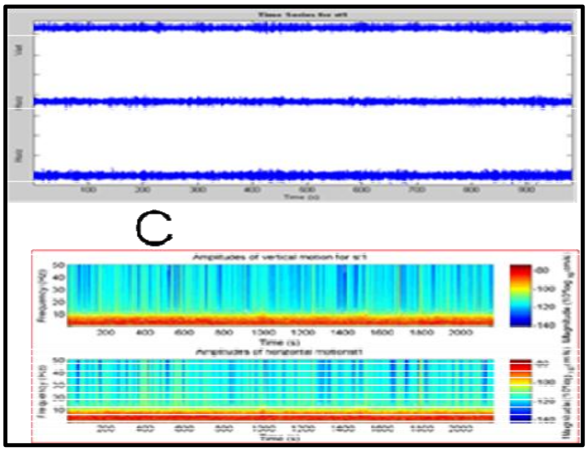


Figure 9: (A) Raw data and its spectrogram; (B) Band pass 1 to 10 Hz applied and its spectrogram (C) Selected data and its spectrogram.

Results and Discussion

Figure 10 describes a characteristic low peak frequency of2.5 Hz within a band of 1 to 4 Hz along 2D survey line for all stations across Wavel oil field area of Gandhinagar. A possible interpretation is that the earth omnipresent Ocean wave peak is the driving force that excites the hydrocarbon reservoir related resonance at 2.5 Hz. The non resonant incoherent high frequency noises (> 6 Hz) are due to anthropogenic noise caused by humans.

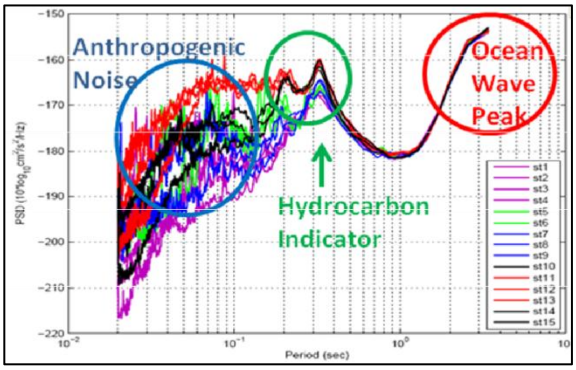


Figure 10: PSD Spectral response of 2D profile across Wavel Oil field, Ghandinagar.

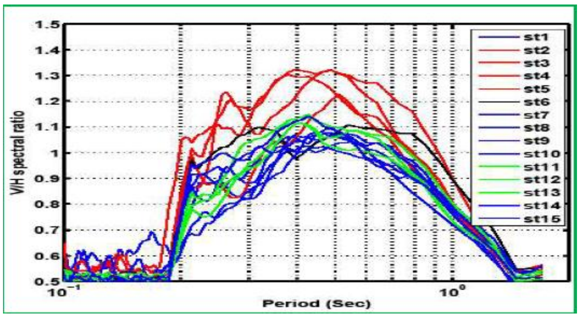


Figure 11: V/H spectral response of 2D profile across Wavel oil field, Gandhinagar.

The PSD attribute analysis shows a peak at 3Hz (0.33sec) in 1 to 4 Hz frequency band for all stations 1 to 15 whereas the stations 10 to 15 shows another peak at 5Hz (0.2sec) in 4 to 6Hz frequency band and flat response observed above 6Hz as shown in Figure10. It appears the peak at 3Hz responds from deeper hydrocarbon layer relative to peak at 5Hz.

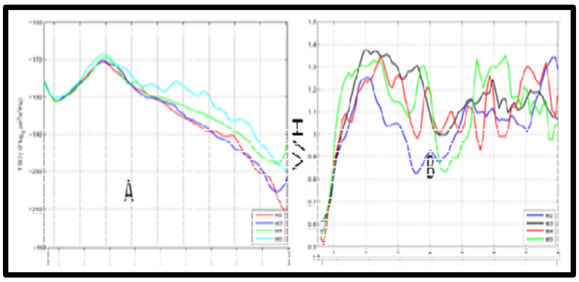


Figure: 12 (A, B) PSD & V/H attributes of stations 2 to 5.

Further, V/H attributes for stations 2 to 5 and 11 to 13 in Figure 11 also supports the anomalous spectral behavior within 2.5 to 3Hz.. Similar observations are noticed in Figures 12 (A,B) and (C,D) when a cluster of stations are plotted separately to locate the anomalous zone.

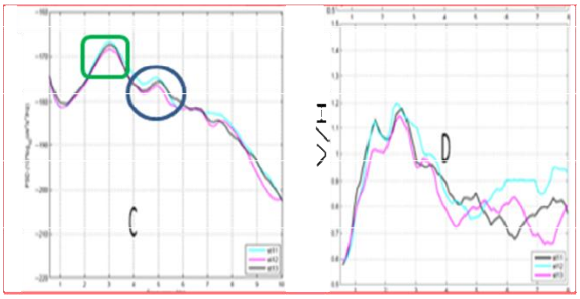


Figure: 12 (C, D) PSD & V/H attributes of stations 11 to 13.

The presence of two simultaneous peaks both in Figure 10 and Figure12C of PSD spectrum suggest that apart from existing oil pool (near station 5 & 6), an additional pool may be expected within the survey area . The location of additional oil pool is reflected further in Figure 12 (G&H) where area under curve of PSD and V/H are plotted against survey stations. Conspicuously, both the spectrum in Figure 12 (G&H) depict same high trend in the same survey locations (marked with circles).

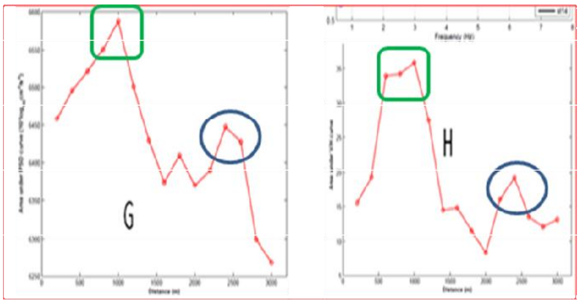


Figure 12.(G, H) Area under curve of PSD & V/H vs Survey Stations.

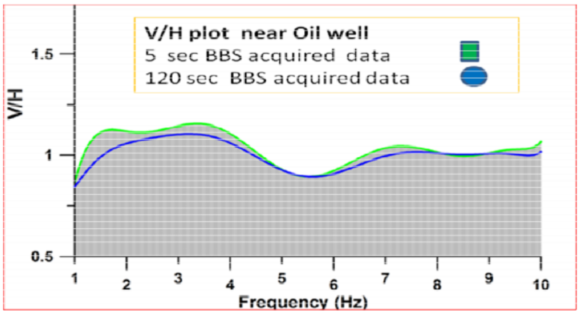


Figure: 12 (E) V/H attributes of stations 5 & 6

To ascertain the spectral anomaly over / near Oil pool as shown in Figures 10 , 11, 12 (A,B) ,(C,D) and (G,F), further analysis are carried out which is depicted in Figure 12E . The same spectral anomaly (peak at 3 Hz) is noticed when additional data acquired over / near the oil well with a 120sec BBS as a reference point, contrary to existing 5sec BBS.

The results supports the theory that low frequency anomalies are related to the presence of hydrocarbon reservoirs and can be used as supplementary information to seismic imaging to reduce drilling risk and assist well positioning.

With exceptional cases where acquired data of Earth Omnipresent Seismic background noises (signal in this case) are extremely noisy and spectral analysis is difficult, passive seismic outputs may be erratic .In other words, Passive low frequency seismo acoustic spectroscopy (Geospectra IPDS) has proven more than 90 projects worldwide to be a reliable information tool for the direct identification of hydrocarbon reservoirs. In this case also, Passive Seismic has indicated hydrocarbon pool over the oil well as shown in figure 12(G&H) and supported by Figure 12E with a peak anomaly. However, to ascertain the depth of the reservoir, a close grid data to be acquired followed by Reverse Time Migration and meticulous interpretation. The interpretation of the recorded signals is very complex and the key factors for the analyses are: Spectral Power, Appearance of Spectral Lines and Dynamic Behavior of the Signal.

Conclusion

The acquired 2D profile data is processed with Matlab software and interpretation is carried out with our own understanding on the literature available in the industry .An anomalous spectral response (both PSD as well as V/H) were observed over the known oil pool in Wavel oil field,Gandhinagar area ,Gujrat pertaining to low frequency band of 2.5 to 3 Hz .This has already been reported by many authors and is being practiced by many oil companies.

The other important aspect is the extension of the oil pool beyond the producing area which has been visualized by the spectral analysis as discussed above is yet to be proved. Here passive seismic analyses need to be corroborated with surface seismic and log data to arrive at the final evaluation of the reservoir findings and further drilling to avoid risk.

Acknowledgements

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