Delineating Producible zones in Complex Reservoirs of Western Offshore using Hilbert Huang Transform- Data Driven Approach

Authors: Jadhav Viresh Kumar, Soma Rani, C S Sajith, Soma Chatterjee– ONGC Mumbai*
kumar_jadhav@ongc.co.in

Keywords

Log Decomposition, Hilbert Spectral Analysis, Basement, Basal Clastics, Complex Reservoirs, Data Analytics, Signal Decomposition, Production Log

Abstract

In the quest for tapping more unexplored zones for Hydrocarbons with declining resources, deeper explorations of Basal Clastics and Basements have become major thrust area for exploration in Mumbai Offshore. The recent exploratory success in wells BH-E5, BH-E6 has put up early monetization of Basal Clastics/Basements as major thrust for incremental production. On the contrary, the log features of Basal clastics and Basements display wide range of heterogeneity with sedimentation and tectonic origins, mainly manifest by bedding, inter-bedding, fractures and are complex in nature. Globally, such complex reservoirs (basement and Low permeability basal sandstones) are increasingly becoming targets for petroleum exploration and development because they contain vast resources which were stranded before the advent of modern well logging/ completion technologies. Often this formations (Basement/Basal Clastics) are difficult to delineate with basic conventional techniques/logs, here we try to delineate producible zones by applying Hilbert Huang Transform to Conventional Logs and corroborate them with Production Log data. Hilbert Spectral Analysis (HSA) applied on log data of formations BCL/Basement for wells BH-P, BH-S is found to be an excellent method to find producible zone and also the results go hand in hand with the production log data.

Introduction

Earth's crust is complex and heterogeneous, geophysical well log data manifest these through the multi-scale nature depicted by it. Multi-fold heterogeneity variations in subsurface formation could be mostly due to either tectonics, varying depositional environment, digenesis or other combined factors. Due to this multi-scale and non-linear behavior of well log data conventional techniques are not sufficient enough for analysis or to determine the heterogeneities present. Hilbert Spectral Analysis (HSA) has been applied on Resistivity log data of wells, and prior to HSA application the logs are decomposed into several Intrinsic Mode functions using Empirical Decomposition Technique. EMDT method introduced by (N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H.H. Shih, Q. Zheng, N.C.Yen, C.C. Tung and H.H. Liu, Proceedings of the Royal Society of London Series A, 454 (1998) 903) helps us to quantify the multi scale nature of the well logs. The analysis is performed on Resistivity log data of Basal Clastics/Basement section on few key wells from Mumbai Offshore basin.

Hilbert Spectral Analysis:

The Hibert Spectral Analysis method is widely used as a nonlinear signal processing tool in diverse research areas, such as analyzing seismic data in geophysics (Battista et al. 2007; Loh et al., 2001), analyzing waves and currents in oceanography (Hwang, et al. 2003), biomedical signal processing (Wu and Huang, 2009), power system quality (Senroy et al., 2007), etc.
Hilbert Spectral Analysis and Empirical mode decomposition together can be used to decompose well log signals and isolate the spectral characteristics of hydrocarbons, which can be used to enhance the detection of hydrocarbons in the formation. The HSA was included as a part of HHT to extract the instantaneous frequency, instantaneous amplitude and instantaneous phase from each IMF. In case of well-log data, these instantaneous attributes provide information about the frequencies present in the data, their respective amplitudes and phases with respect to depth. The IMFs extracted by EMDT have a well-defined Hilbert transform and thus HSA of IMFs provides a more meaningful space–frequency–amplitude description of a signal.

Empirical mode decomposition (EMD) is a data-driven, non-parametric method that decomposes a signal into a set of intrinsic mode functions (IMFs) that represents different frequency components of the signal. EMD can be used to extract useful information from well logs by isolating specific frequency components of the signal, such as the spectral characteristics of the rock formation or the presence of hydrocarbons. Here this technique is applied on multiple well log curves and the signal is decomposed into several intrinsic mode functions (IMFs) and then Hilbert Huang Transform is applied on the curves to delineate producible zones.

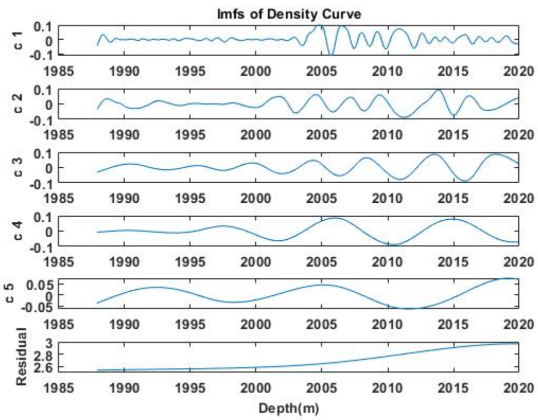

Figure.1 showing Different IMFs (Intrinsic Mode Functions) generated by applying EMD technique on Density Log of Well BH-E5 (basement section).

Study Area

Mumbai Offshore Basin is a pericratonic rift basin occupying the central part of the continental shelf. It is the largest and most prominent of all the west coast offshore basins. The basin is contiguous with the petroliferous onland Cambay Basin through the Gulf of Cambay in the north-east. It is bounded in the northwest by Saurashtra peninsula, north by Diu Arch. Its southern limit is marked by east west trending Vengurla Arch to the South of Ratnagiri and to the east by Indian craton. The age of the basin ranges from late Cretaceous to Holocene with thick sedimentary fill ranging from 1100-5000 m.

Deccan Trap forms the floor of the basin for the overlying Tertiary sediments, except in a few areas of prominent paleo-highs like Bombay High, Heera etc. where the basement is granitic. Five distinct seismic reflectors viz. H-1, H-2, H-3, H-4 & H-5 have been mapped in Mumbai Offshore basin. These were correlated on the basis of seismic velocities and regional character with the onshore Cambay basin.

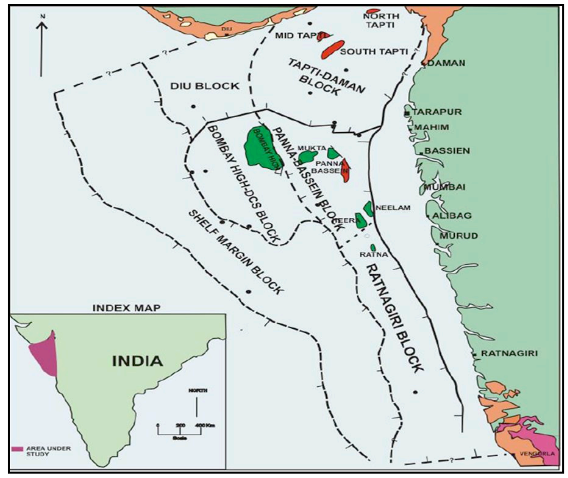

Figure 2, showing Mumbai Offshore Basin

Out of these reflectors, H-5 is confined to the north and north western region and probably marks the top of the basement. The weathered and fractured upper part of the Basement has proved reserves of oil and gas in both the MHN and MHS blocks. Hydrocarbon accumulations in basement are known in the Mumbai High field. The exploratory wells BH- P, BH-Q and BH-R, drilled close to the Mumbai High East fault have produced oil ranging from 464 to 2575 BOPD establishing the hydrocarbon potential in basement, and in the overlying Basal Clastics, which is in hydrodynamic continuity with basement. The weathered and fractured upper part of the Basement has also proved reserves of oil and gas in both the MHN and MHS field. There is no extensive presence of shale beds in between Basement and overlying Basal Clastic sediments. The basement, it seems, is in communication with the overlying oil and gas bearing Basal Clastic sandstone beds. In NWMH Basement is granite gneiss which probably indicates locales of paleo-high during lava flow. In Heera field Minor oil shows are seen in fractured crystalline basement. The Basement encountered in Heera field is granitic as well as metamorphic comprising quartzite/hornblende and granitic gneiss at places.

Application of Hilbert Spectral Analysis to detect Producing Zones in Basal Clastics

Well BH-S was prolific producer of hydrocarbon from both Basal Clastics and Basement. Production Logging was carried out in well to know producing and non-producing zones in well. As mentioned earlier Basal clastics are complex reservoirs with heterogeneous nature, many times in such complex reservoirs it is difficult to determine interesting hydrocarbon zones with conventional basic logs. Here, we apply Hilbert Spectral Analysis on the basic open hole logs and try to detect the hydrocarbon/interesting zones. Hilbert Spectral analysis was applied on all logs (Gr, DT, RT, RHOB, CNCF). It was deduced that Rt (resistivity) logs detects Hydrocarbon and even boundary of zones far more precisely when converted to frequency domain.

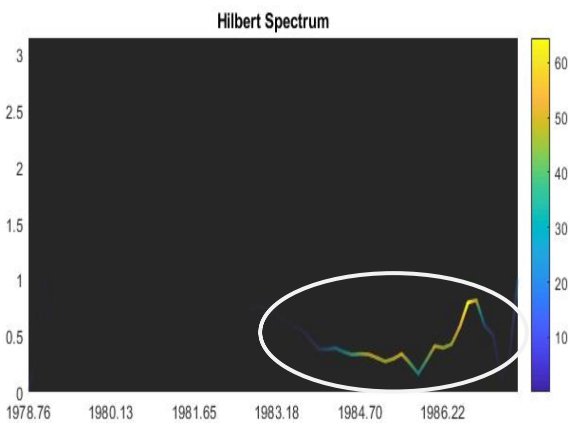

Figure 3 showing Hilbert Spectrum of Imf of RT log in Well BH-S

Hilbert Spectrum of well BH-S is shown in figure 3, it can be seen that high energy amplitude observations are seen in IMF in interval 1983.5 to 1987 depicting interesting zone, when we corroborate the results with production log data (shown in figure 4) we see that from temperature log and density log deflections seen in basal clastics are in interval 1983-1987. Fluid density of ~0.65g/cc is seen interval 1983-87 m (Basal clastic) is indicating mixture of oil & gas and also Cooling anomaly is seen in Temperature log in above mentioned interval.

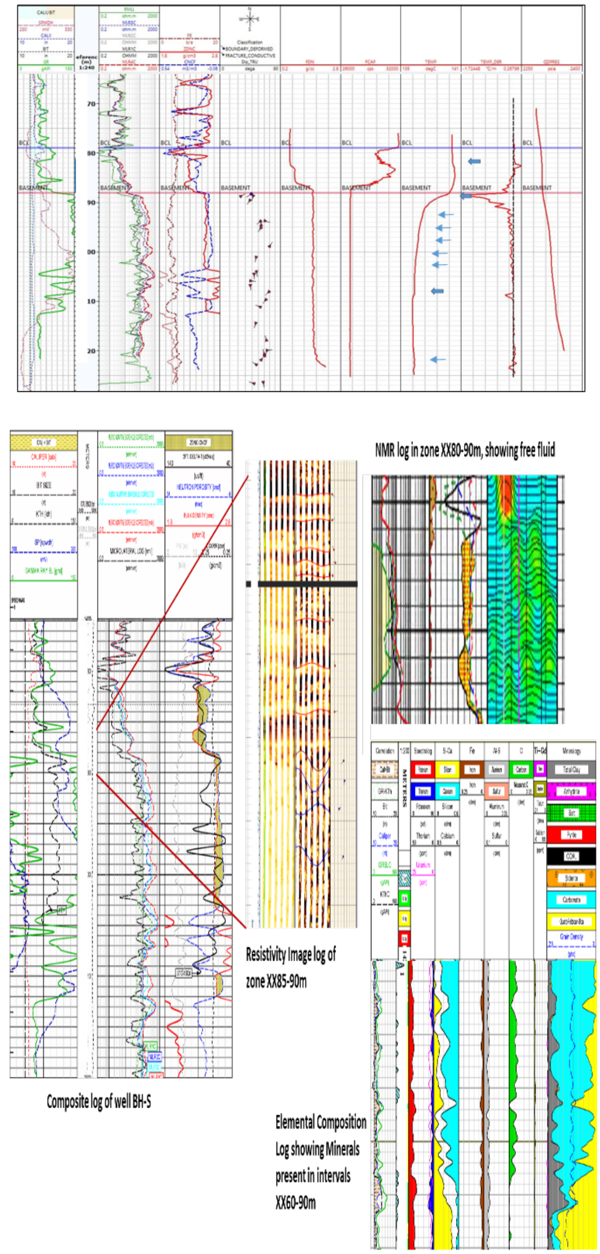

Figure 4 showing production log data in well BH-S and also other advanced logs recorded in well.

Similar HSA Technique was applied on RT log of well BH-P. Hilbert Spectrum and production log data of well BH-P is shown in figure 5, it can be seen that according to Hilbert spectrum interesting intervals are 2084-85.5 m, 2096-99 m and the interval 2087-96 m which was also perforated shows low energy in Hilbert spectrum which corroborates with production log data which showed that interval 2087-96 was silent. Production log data showed production was from interval 2097-99 and 2084-85.5 m.

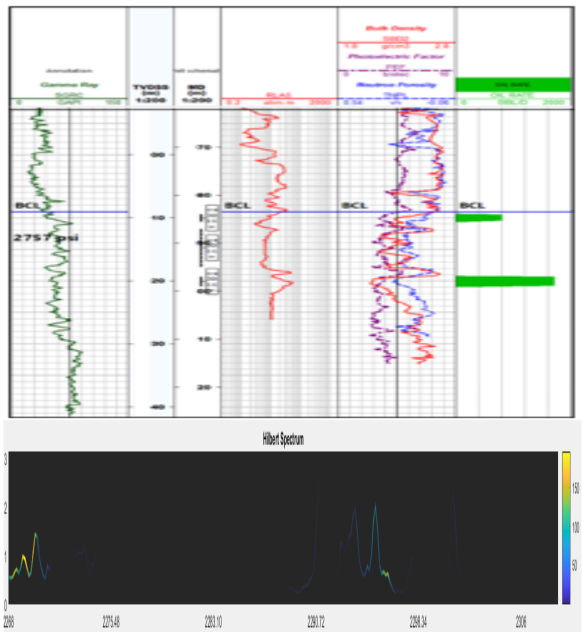

Figure 5 showing Production log analysis and Hilbert Spectrum of well BH-P

Hilbert Spectral Analysis to detect Producing Zones in Basement

Similar approach was applied on Basement interval of well BH-S and BH-T to see whether same delineation of producing zones can be made and corroborate it with production log data. In figure 6 and figure 7 Hilbert spectrum and production log data of basement is shown of well BH-S, it can be seen that much of the high energy amplitude seen in Hilbert spectrum match well with the temperature anomaly and density anomaly showing hydrocarbon contributing zones.
In well BH-T we can see that Hilbert spectrum(shown in figure 7) shows high energy in interval 2268-72m and 2290.5-97m, whereas in production log(figure 7) we can see that temperature anomaly is seen in interval 2268-72m but there is no production log data in interval 2290.5-97 m.

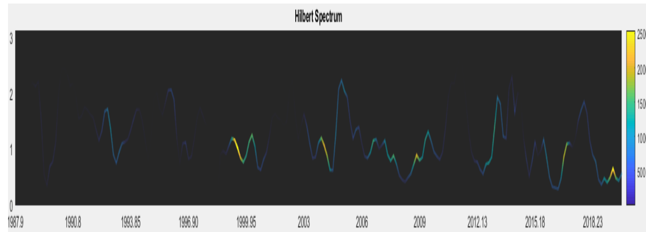

Figure 6 showing Hilbert spectrum of well BH-S

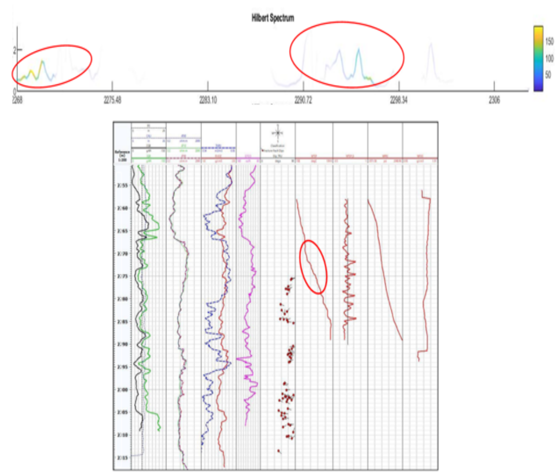

Figure 7 showing hilbert spectrum and production log data of well BH-T

In well BH-S when we see the hilbert spectrum shows high energy in interval 1997-2006 m which corroborates with production log data where temperature anomaly is seen same interval indicating producing zone and also presence of fractures can be seen in this interval. Hilbert spectrum to a certain extent is able to identify producing zones in Basements in study area.

Conclusion

- A novel approach is attempted to delineate producing zones in complex reservoirs with signal decomposition and processing techniques.
- Hilbert Spectral Analysis applied along with EMD on Rt logs in Basal Clastics helps us to find interesting zones/hydrocarbon zones in complex reservoirs which also correlates with the production log data of wells BH-S and BH-P.
- Hilbert Spectral Analysis applied on Basements helps to find interesting zones to a greater extent which also corroborates with production log data.

Delineating Producible zones in Complex Reservoirs of Western Offshore using Hilbert Huang Transform

References

N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H.H. Shih, Q. Zheng, N.C.Yen, C.C. Tung and H.H. Liu, Proceedings of the Royal Society of London SeriesA, 454 (1998) 903.

Heterogeneity analysis of geophysical well-log data using Hilbert–Huang transform Gaurav S. Gairola, E. Chandrasekhar

Acknowledgement:

The authors are grateful to Shri S K Singhal ED-Chief Logging Services- ONGC Mumbai and senior officers for their support during this work.