Broadband Processing in deciphering Biogenic gas: A case study from Western Offshore Basin

*Premanshu Nandi *, P.K. Satapathy, Dharmendra K. Gupta, Satish Chilaka, Sonu Prasad, Dr. Anand Prakash; ONGC Ltd.*
Nandi_Premanshu@ongc.co.in

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Abstract

Biogenic gas is generated at low temperature due to decomposition of organic matter by anaerobic microorganisms. More than 20% of world's discovered gas reserves are of biogenic origin. Here the strata are identified by seismic reflection anomalies e.g. bright spots and flat spots, reverse polarities, low frequency and shadow zones. Amplitude preservation of the anomalies are the challenging steps in seismic processing.

This paper demonstrates that after the application of de-ghosting, water bottom multiple attenuation techniques, surface related multiple attenuation techniques, denoising in shot domain and CMP domain that anomalies are enhanced, resolved and well preserved.

This seismic data processing project was implemented with special emphasis on establishing shallow Pliocene reservoirs. To improve the resolution of the data, preservation of higher and lower frequency is very crucial. Therefore, the processing project has been designed to broaden the frequency spectrum in low as well as high end of the spectrum. The data was acquired by broadband technology. So broadband seismic processing of data was carried out to demarcate the biogenic activity anomalies.

The broadband processing flow includes

- De-ghosting to attenuate receiver & source ghost and to boost lower frequency.
- Multiple techniques in shot as well as CMP domain to remove the ringing associated with anomalies.
- Denoise to boost S/N ratio.
- Residual multiple in radon domain to enhance the reflection signatures at higher offsets.

The aforementioned processing techniques play major role in deciphering the biogenic gas related signatures. Above mentioned steps were then followed by 3DKPSDM, denoising of migrated gathers, stacking of gathers and post stack processing for better and clear picture of sub surface structures. Processing steps followed here preserves anomalies due to biogenic gas thus helps in identifying gas reservoirs.

Introduction

The current study area is located in Western Offshore Basin, West coast of India. Figure 1 is the location map of the study area. The broadband data was acquired with slant streamer of depth 10 ~ 30 m with sources at variable depth of maximum offset of 8100 m.

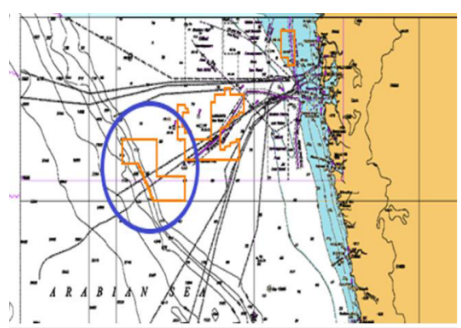


Figure 1. Location map of the area

Biogenic activity generally occurs at shallow depth which is characterized by localized bright amplitude in seismic section. In shallow water environment, shallow part is always contaminated with ghost reflections, multiples of different origin and orders and denoise of various characteristics. Ghost reflections distort the phase of the data and add huge secondary lobes that suppress the strength of main reflection lobe of the useful events. The ringing created by water bottom and other multiples heavily mask the clarity of biogenic reflections at shallow and create many localized high amplitude phenomena which misleads the interpretation. Various types of noise further diminish the standout of the localized shallow biogenic signatures. Therefore, state-of-art broadband processing flow was implemented to overcome the aforementioned challenges and to delineate the biogenic activity regime.

a) Low cut filter, swell noise attenuation and various linear noise attenuation techniques have been followed to preserve of low frequency signal by intense testing and quality control.
b) De-ghosting module was implemented to compensate ghost effects due to source, receiver and the combination of both that potentially fill up notches and retrieve the low frequency of the data. The low frequency strengthens the reflections throughout the data and useful for characterization of these pools.
c) Various types and orders of multiples exist in data due to the complex geology with shallow and deep-water bottom results in complex manifestation with useful primaries which is very challenging for identification and attenuation. The intense ringing effect creates strong false subsurface layers and dominates the actual sub-surface lithological boundaries. Multiple attenuation methodologies to attenuate complex water bottom and surface related multiple (SRME/SRMA) & tau-p domain and radon domain de-multiple in both shot and CMP domain were applied on the dataset.
d) Rigorous QC outputs such as power spectra, autocorrelation function, f-k, f-x, t-f spectra were generated and checked to optimize the processing parameters.
e) In addition to that, noise attenuation techniques in shot as well as CMP domain was applied for further improve S/N.
f) Rigorous velocity analysis from coarser to finer grid was carried to improve the event coherency as well as stacking response.
g) Multi domain velocity smoothing was adopted to remove stripping in the model so as to achieve a gradually varying model.
h) Amplitude variations with offset/angle was adopted as a very important QC tool to optimize post-migrated gather processing.

Method

The broadband processing flow is mentioned below in following Figure 2

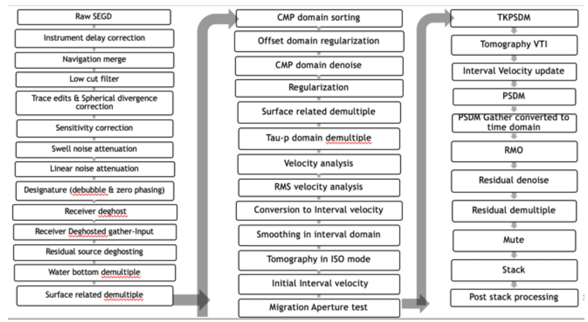
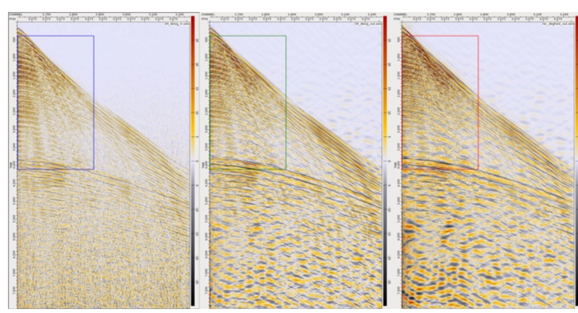


Figure 2. Processing sequence

The data was also corrected for low cut filter, trace edit, sensitivity correction, spherical divergence correction, swell noise attenuation, liner noise attenuation, ship noise attenuation, de-signature, de-bubbling, tidal statics, source and receiver datuming. Figure 3 and Figure 4 shows input to de-ghosted data and its output along with frequency spectrum. After application of de-ghosting, the frequency spectrum gets widened in the lower end which helped in imaging of complex structures and also the ghost notches were removed. In this process anomalies were not affected but notches due to ghosts were removed. Figure 5 shows the study area of anomaly after de-ghosting.



Input After De-Signature After De-ghost

Figure 3. Gathers of Input, de-signature and De-ghost

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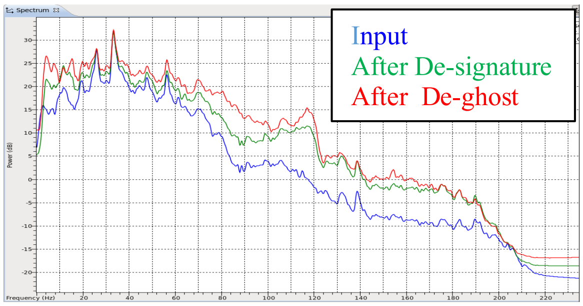

Figure 4. Spectrum of Input, De-signature and De-ghost

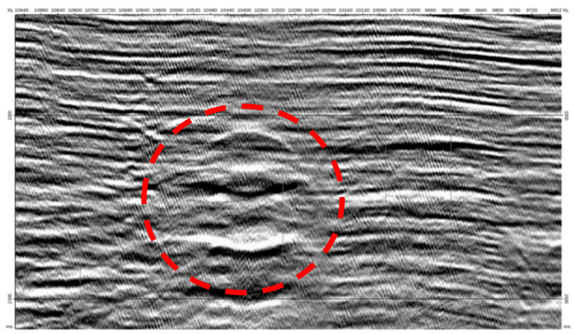

Figure 5. Anomaly after De-ghost

Wave equation-based water bottom multiple attenuation was applied which performs multiple modelling by downward continuation of the receivers to the multiple generating water bottom and upward continuation of the receiver field by the same amount. This was followed by adaptive subtraction of multiple model from data in the shot domain. The additional ringing associated with the anomaly was removed which further improves the clarity as shown if Figure 6.

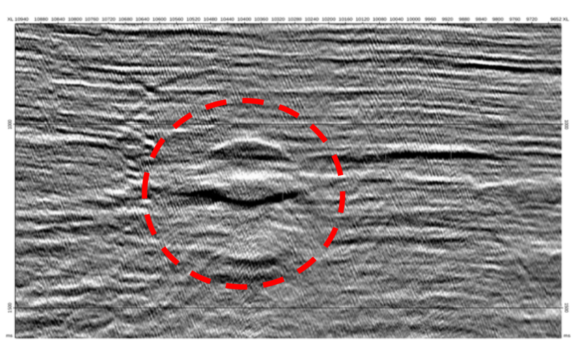

Figure 6. Anomaly remained unaffected after water bottom multiple attenuation and multiples were removed

To remove remaining multiples, SRME was applied which attenuates all kind of surface-related multiples. SRME is entirely data driven and needs no subsurface or any other information, since the multiples are completely predicted from the data itself, which is accomplished by 2D auto convolutions of the input data in time and space. Figure 7. shows SRME on the anomalies which were remained unaffected while removing the multiples.

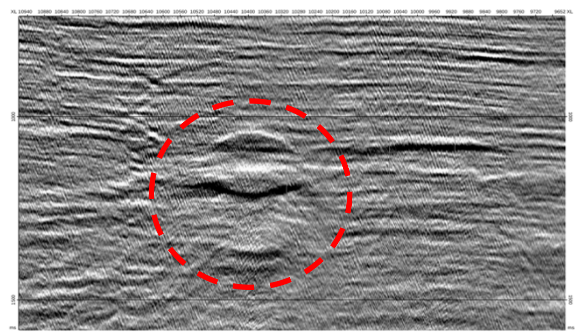

Figure 7. Surface related Multiple elimination removed multiples which results much clear picture

Then residual linear noise and other random noises was removed which enhanced the S/N ratio of the data. Figure 8 shows that after applying linear noise attenuation, anomalies were not hampered.

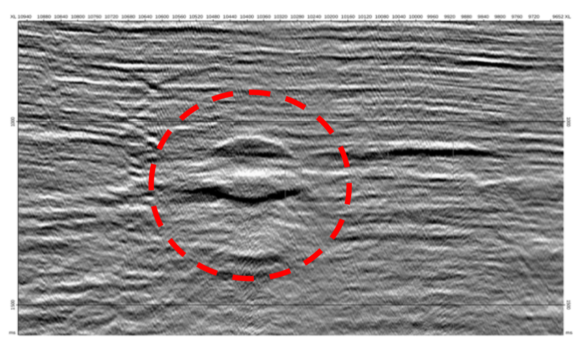

Figure 8. Linear noise removal results clarity of anomaly

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Proper care was taken during data regularization in CMP domain. The anomaly remained unaffected by optimal parametrization and QC as displayed in Figure 9

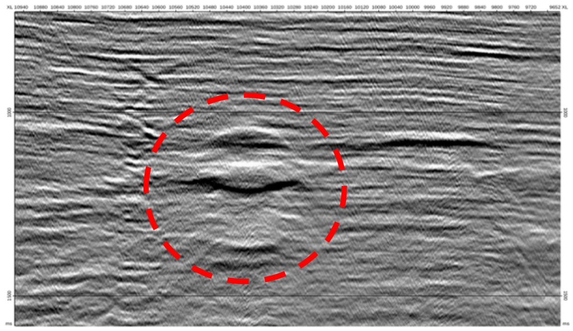

Figure 9. Unwanted offsets were dropped and regularized without affecting the anomaly

Remnant multiples of sub-surface generated were also seen in the data after shot domain de-multiple techniques. The SRMA multiple attenuation technique predict the multiple model from CDP gather and adaptatively subtracted from the data. Figure 10 shows that after SRMA anomalies were unaffected and only the multiples associated with it were removed.

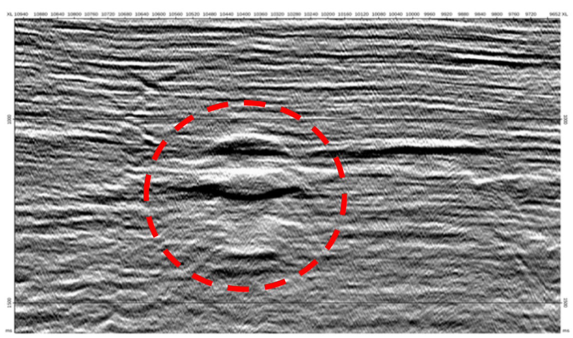

Figure 10. Surface related multiple attenuation eliminates multiples without disturbing the anomaly

Short period multiples were attenuated in tau-p domain by keeping large Predictive Distance (about 100ms) to preserve the basic wavelet of the data. Figure 11 shows the results after application of tau-p domain de-multiple.

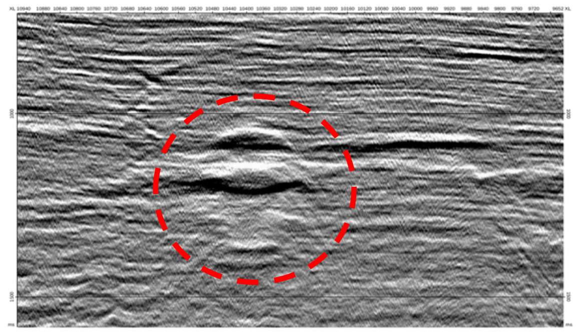

Figure 11. Tau-p deconvolution removed short period multiples which results better clarity of anomaly

RMS velocity used in Pre-Stack Time Migration was used to derive initial velocity in depth. Smoothing was applied in the Interval velocity volume in time domain. The Interval velocity in time domain was converted to depth domain. Tomography was run to update velocity in isotropic mode. VTI grid-tomography was run to update the anisotropic velocity which updated layer parameters. Figure 12 shows final Interval velocity in depth for depth migration.

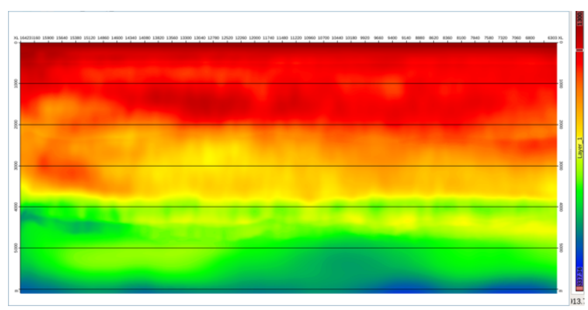

Figure 12. Interval velocity in depth for 3DKPSDM

The data was migrated in depth domain by suitable interval velocity prepared from velocity model building workflow through travel time tomography.

Eta corrections were applied on PSDM gathers scaled to time to improve the flatness of gather at higher angles. Residual de-multiple and denoise techniques were applied to further enhance the coherency as well continuity of events. Figure 13 shows 45° angle mute on PSDM gather scaled to time.

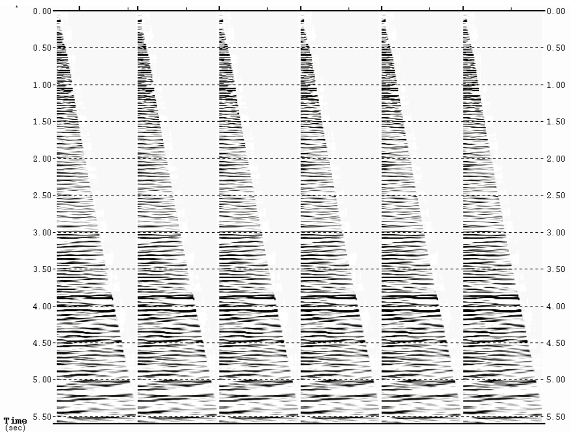

Figure 13. PSDM gather scaled to time at anomaly location

Denoised PSDM gathers scaled to time was muted to have initial raw stack. Structural Guided Seismic Enhancement was applied over raw stack to remove the noise in 3D domain which provides the principal strengths and directions of subsurface geological features and enables to design filters that smoothens along linear and planner features, but that do not smooth across them. This results an enhanced seismic image which preserved the subsurface discontinuities and augment S/N. Figure 14 shows stack after structural guided seismic enhancement.

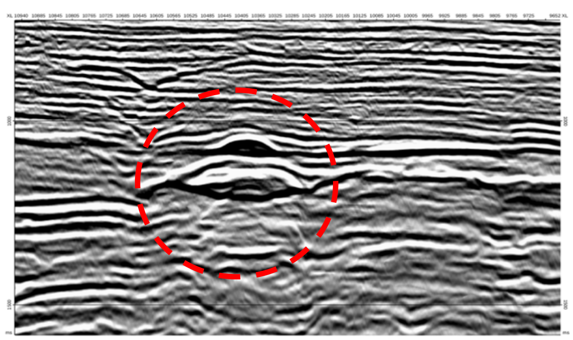

Figure 14. Structural Guided Seismic Enhancement enhanced anomaly removing dip noises

The output was further enhanced by applying coherency filtering in two passes along inlines and xlines which results in final output as shown in Figure 15.

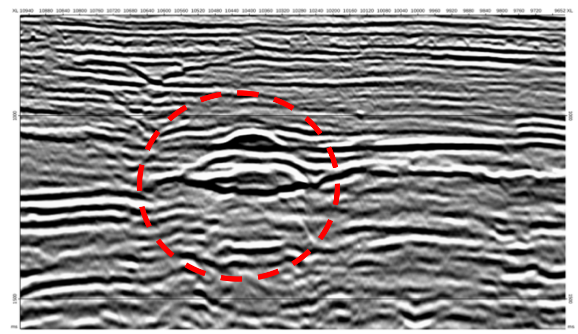

Figure 15. Final Stack at anomaly location after all denoising steps

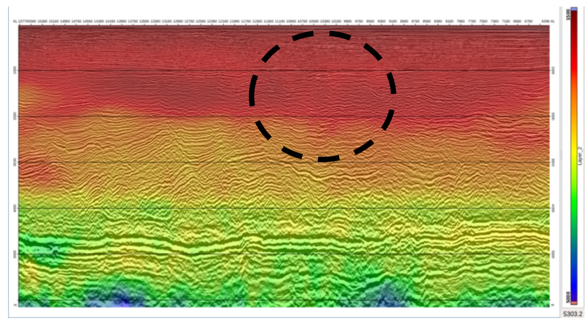

Figure 16. Interval velocity laid over depth stack at anomaly position

Figure 16 shows that interval velocity laid over depth stack which shows the validity of sturctures over the area.

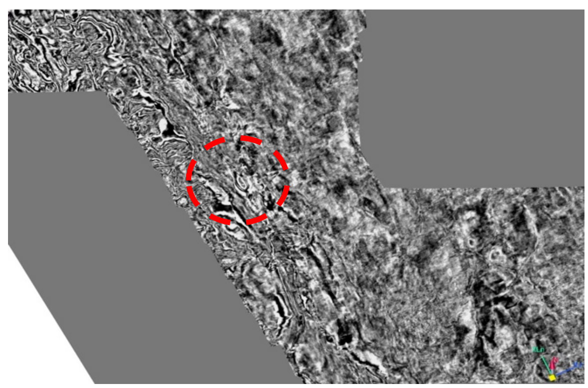

Figure 17. Time slice at time 1150ms over anomaly (zoom)

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Time slice of Figure 17 at time 1150ms corresponds to the anomaly and the Pliocene horizon. There are lot of faults in this area as manifested in time slice also.

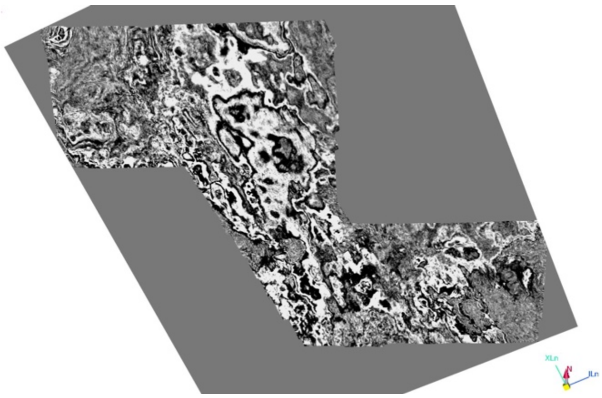

Figure 18 Time slice at time 4000ms showing structural features

Time slice of Figure 18 at 4000ms which corresponds to Mid Eocene horizon containing carbonate deposits at deeper portion of the area.

Reservoir characterizations has been carried out in this area which establish gas reservoir through pre-stack inversion. Figure 19 shows P Impedance volume generated at Pliocene 1 horizon having low values over the anomalies over proposed well no. 1 can be the indicator for the presence of biogenic gas.

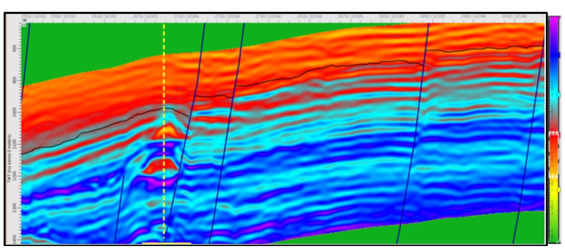

Figure 19. P Impedance volume after pre-stack seismic inversion having low value over anomaly

Figure 20 shows low Vp/Vs value of the extracted horizon Pliocene 1 shows at the top of anomalies over well no.1 suggesting the presence of biogenic gas.

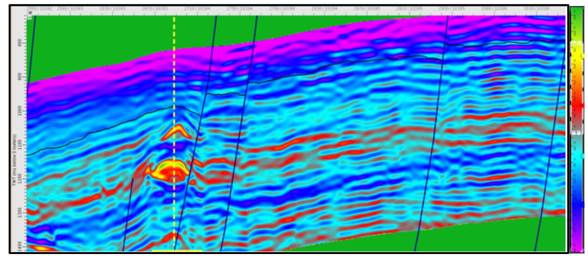

Figure 20. Vp/Vs volume having low value over anomaly

Results

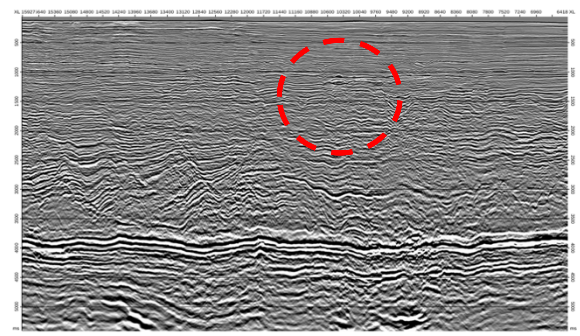

Figure 21. Final PSDM stack in time along inline of anomaly

Figure 21 is the PSDM stack along the inline of the anomaly which is discussed above. Here the entire exercise of preserving the anomalies was successful as the anomalies were not affected by different parameters which were used in processing the data. Only the noises were removed from the data leaving behind the signal in shot domain, CDP domain and in post stack processing.

Conclusions

The broadband processing flow such as deghosting, demultiples and denoise preserved the biogenic gas anomaly as bright amplitude signatures. The unwanted energies were attenuated in subsequent stages to enhance its presence. It was observed that at different broadband processing stages, standout of the anomaly improved without affecting the inherent characteristics of the anomaly. The entire processing flow was developed through intense testing and multi-phased quality control (QC) so as to overcome the challenges to image biogenic gas reserves. The velocity model updated in depth that resulted in flattened gather more than 45°. The low frequency enriched data from broadband processing along with large angles flatten gather tremendously which improved the reservoir characterization results. The biogenic gas anomaly is being characterized by P-impedance and its occurrence is ascertained by Vp/Vs ratio after prestack seismic inversion.

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