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Value Added Imaging through Reprocessing - A Case Study of Basement Mapping in North Mid of Tapti (NMT)

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Summary

Reprocessing of vintage data is generally done with some specific objective e.g. new technology, new approach etc to satisfy. So reprocessing can lead a scope of significant value addition in imaging. While reprocessing of Sea-bed data, one has to face both pros and cons of acquisition technique.

Despite several inherent advantages, the major challenge with Sea-bed data is the noise associated with Geophone data which may lead to inadequate de-ghosting. Vertical component of the geophone provides the major contribution to Sea-bed image. But it is contaminated with noises. Presence of (i) Scholte Wave, (ii) shear leakage, (iii) trapped energy etc can mask the actual advantage of dual sensor summation.

While reprocessing utmost care is taken to (a) make the input data as much as noise free as possible and (b) build an initial model from earlier RMS velocity and considering geological horizon boundaries which satisfactorily account ray bending from top to deeper level. In short, (i) the necessary pre-conditioning of the data before the dual sensor summation to enhance the signal to noise ratio by eliminating the various noises in different domain and (ii) the meticulous velocity analysis produced value added imaging, delineation of basement.

***Keywords**: Reprocessing, de-ghosting, de-noising, automatic residual analysis, basement mapping*

Study Area

In the present study, 3D OBC shallow water seismic data was acquired under the dual sensor OBC seismic acquisition technology using the Sercel 408 UL recording system in 2008. Earlier, the data was processed twice (vintage 1&2) in the conventional way, considering the hydrophone and geophone sum gathers as input. Presently the same is reprocessed with a more appropriate approach: separating the hydrophone and geophone components, application of noise reduction processes to both hydrophone and geophone data separately and summing the two components again for subsequent processing. Objective is to improve the signal to noise ratio before summation and preservation of real amplitudes which can give valuable stratigraphic information.

The present study area (Fig.1) lies in the north-east part of the Surat (Dahanu) Depression, which is thought to be the offshore extension of the Narmada Graben trend. Within the Surat Depression, delta front sands from mainland rivers drape over basement highs and form sandstone reservoirs of Oligocene - Middle Miocene age, which are proven gas bearing sand. The main geological target for present study is to map the sand geometry and bring out stratigraphic plays within Panna, Mahua, Daman Mahim and Basement as well as porosity pods within Diu Limestone for generation of hydrocarbon prospects.

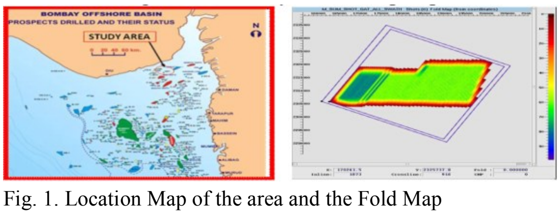

Fig. 1. Location Map of the area and the Fold Map

Like all other OBC acquisition, here also total source points are many fold of total receiver stations. Survey follows cross-line swath (total 37 in no) with each swath consists of two receiver lines and shot line is orthogonal to receiver lines. Average Water Depth is about 5m -18m in

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this area. Bin Size : 25m X 12.5 m. Nominal fold is 42-50 (Fig.1). Fold Offset Distributions **:**

Offset Ranges	Fold Coverage
0 - 1250	7
1250 - 2500	13
2500 - 3750	10
> 3750	12

In order to get a better bin fold coverage in the near offset ranges, two survey designs were shot as follows :

Parameter	Design 1	Design 2
Receiver Station Spacing	50 m	50 m
Receiver Line Spacing	400 m	400 m
Source Station Spacing	25 m	25 m
No. of source per line	192	128
Total channels active	832	840

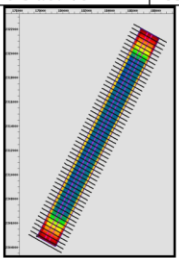

Fig. 2. The second design-improved greatly the fold coverage in the near offsets domain.

Seismic Data Processing

There is no single algorithm that can remove all types of noise in seismic gathers. It is rather the combination of a number of different techniques, each adapted to the specific problem at hand that will lead to optimal de-noising results. Again different type of noise manifest differently in different domain. In present study, hydrophone and geophone data are processed separately in shot, receiver, CMP and again in shot domain to eliminate noises and then summed to produce good quality noise & receiver ghost free data.

Velocity analysis consisted of (i) horizon velocity analysis along five horizons: Mahim, Daman, Mahua, Panna & Basement. (ii) Vertical velocity analysis to map the deeper reflector below the supplied basement interpretation and finally (iii) residual move out analysis twice on conditioned PSTM gather to update & finalize. The result obtained was very encouraging, specially in delineating deeper horizon.

Pre-conditioning of data

Various types of coherent and random noise are present in both hydrophone data and geophone data. These includes Scholte Wave, trapped energy, guided wave, noise bursts, spikes, shear leakage (converted), cable noises etc. The general approach of almost all de-noising methods is that they transfer the data to a domain where the signal and the noise component can be separated. The observed noise is subsequently removed, before the data component is transformed back to normal physical x-*t domain*. Thus, the challenge is to find a domain where the noise and the signal are well separated. Below we will briefly describe some noise elimination procedure adopted in different domain for present 3D OBC survey.

Shot domain de-noising

The first data example from the survey in Fig.3, shows a raw geophone gather in shot domain contaminated with noises, mainly shear leakages. Reflections are not detectable at higher offsets.

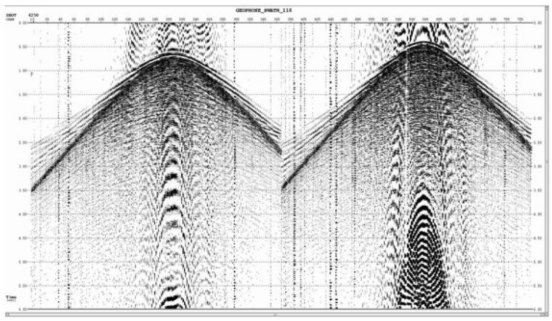

Fig. 3. Raw geophone gather in shot domain.

The data were de-noised by means of the de-spiking (using noise suppression by amplitude scaling), surface wave generated linear noise removal and 2D f-x domain dip filter to remove transverse dipping noises and the result is shown in Fig.4.

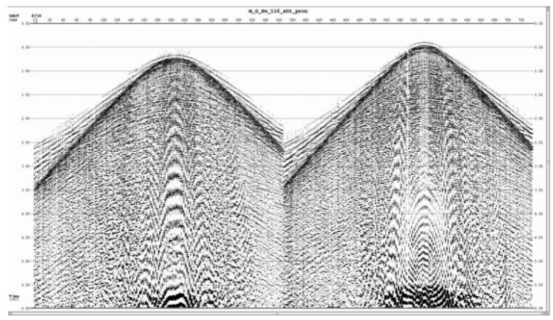

Fig. 4. Shot domain processed geophone gather.

Major noise part is cleaned and reflections at higher offsets start to appear. But the data is still contaminated with shear wave leakage due to poor coupling at sea floor in the OBC survey. This leads to take the advantage of processing in receiver domain, where trace sampling is simply double than that of the shot domain.

Receiver domain de-noising

This data when seen in shot domain appears as random noise but in receiver domain it appears as semicoherent to coherent noise. When such data is used for PZsummation before de-noising, it deteriorates the summing process and the resulted output. The objective of the reprocessing is to improve the signal-to-noise ratio of these records such that they could be used to de-ghost the hydrophone records. After applying same de-noising procedure in receiver domain, dataset with better quality is achieved as shown in Fig.5. Hyperbolic events manifest in complete offset range. Restoring the primaries over the full offset range is the main advantage of de-noising in this domain.

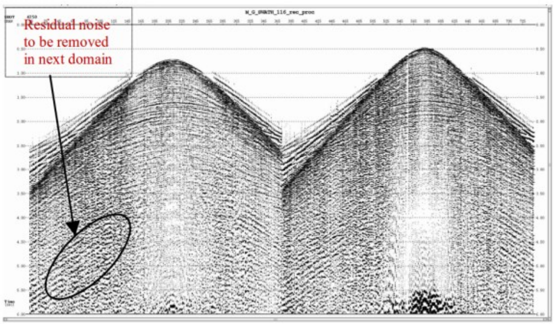

Fig. 5. Receiver domain processed geophone gather.

CMP domain de-noising

Dataset is then conditioned in CMP domain and the result is shown in Fig.6. Here the residual noises, as shown in receiver domain output (in Fig.5) are removed. Shear leakage is also removed.

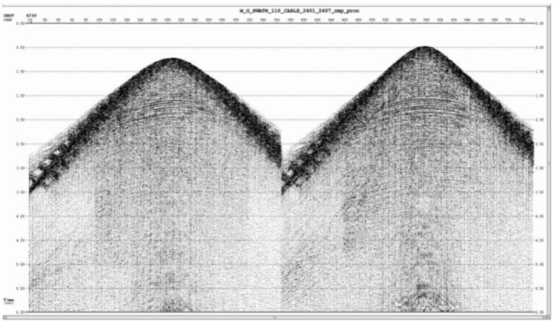

Fig. 6. CMP domain processed geophone gather.

Shot domain de-noising

Final de-noising is done in shot domain again before summation and the result is shown in Fig.7. Frequency spectrum of raw & processed gather is shown in Fig.8.

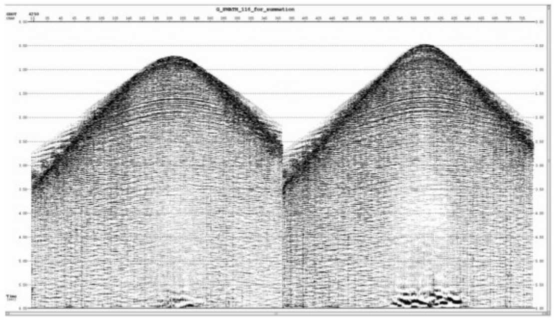

Fig. 7. Final shot domain processed geophone gather.

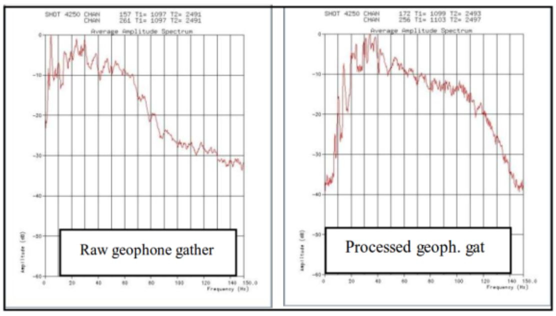

Fig. 8. Geophone gather frequency spectrum comparison.

In final shot domain dataset, all hyperbolic events are clearly visible. Signal-to-noise ratio improves substantially as evident from the frequency spectrum. Considering the data is of proven gas-bearing field, utmost care is taken for parameterization of conditioning in three domains. After removing the random noises and coherent noises from hydrophone and geophone, the data is summed.

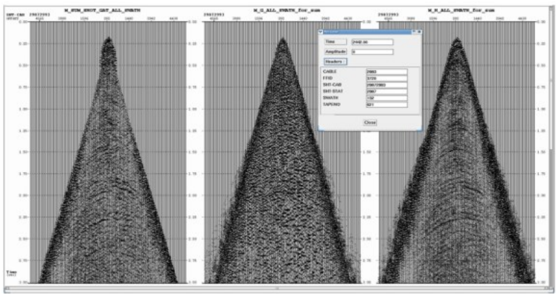

Fig. 9. Shot gather comparison PZ SUM-Geophone-Hydrophone.

Thus after de-noising in different domain, vertical component geophone dataset looks comparable to its compatible hydrophone counterpart. The summed dataset of the two is free from all kind of receiver-side ghosts. Here lies the supremacy of sea-bed acquisition over towed streamer hydrophone only dataset. Better resolution, continuity & frequency content is visible in time section also as shown in Fig. 10 below.

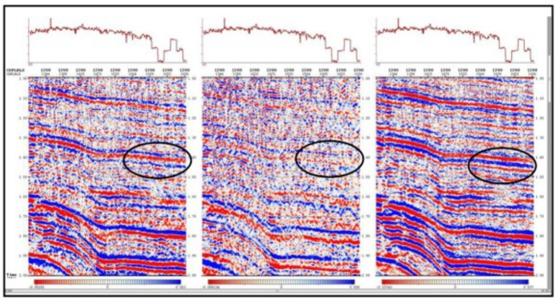
Hydrophone Geophone PZ-Sum

Fig. 10. Time section: Hydrophone-Geophone-PZ SUM

After summation, offsets as well as fold within the gathers are regularized both in subline & crossline mode. Data is corrected for Q-phase and wavelet is converted to minimum phase. Finally noise suppression in timefrequency domain is done which operates on different frequencies without affecting nearby trace and/or sample. To improve deeper reflectors, a mild parabolic radon demultiple is applied to attenuate secondary events, as shown in Fig. 11 (with proper muting).

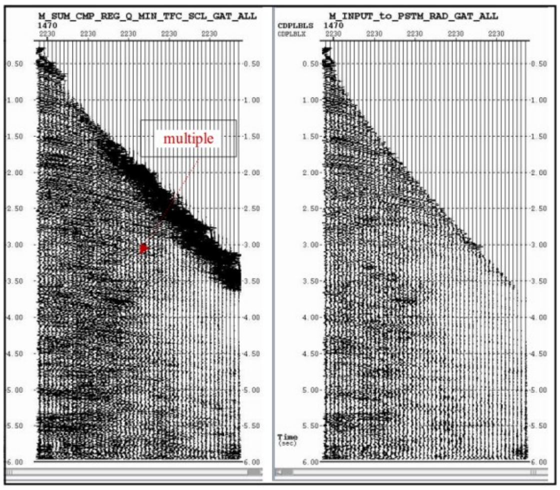

Fig. 11. CMP gather before & after (with mute) multiple removal.

Velocity Analysis

Using five interpreted horizons in Time Migrated domain: (i) Mahim, (ii) Daman, (iii) Mahua, (iv) Panna and (v) Basement, (Fig. 12) horizon velocity analysis is done taking 'vintage 2' RMS velocity (as shown in Fig.13) as initial model.

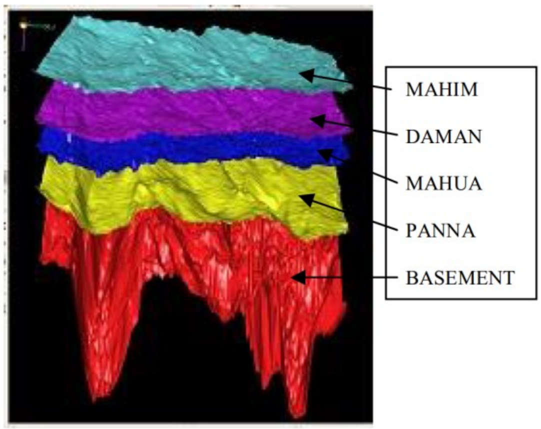

Fig. 12. Five Horizons in Time Migrated Domain.

Curved ray Kirchhoff Migration with 6km X 6km aperture is done using this Interval velocity in TM domain (as shown in Fig.13). To map properly the deeper reflector below the supplied basement interpretation imaging out after PSTM, vertical velocity analysis is done manually & precisely to built up refined RMS velocity model. With this velocity, straight ray PSTM is run with 7km X 7km aperture. Lastly, automatic residual move out analysis is done twice on conditioned migrated gather, restricting maximum velocity updation to 5%. In this way, Final updated RMS velocity model is built up as shown below in Fig. 13.

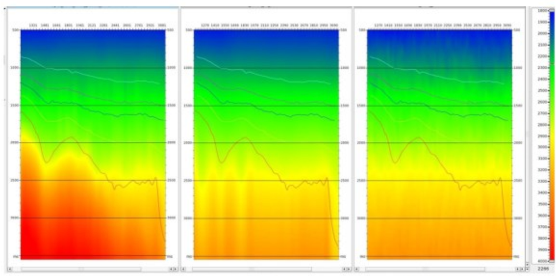
Final Updated, Int. vel in TM Vintage2

Fig. 13. Velocity Model: Final Updated (RMS), Int vel in TM & Vintage2 (RMS)

Summary of complete processing sequence is listed below.

1.	REFORMATING (SEGD to Internal format)
2.	SPS MERGE, DELAY CORRECTION
3.	SEPARATION OF HYDROPHONE AND GEOPHONE DATA
4.	SPHERICAL DIVERGENCE CORRECTION

5. DESPIKING, LINEAR NOISE REMOVAL & FX-DIP BASED FILTERING IN SHOT, RECEIVER & CMP DOMAIN
6. SUMMATION OF HYDROPHONE & GEOPHONE IN SHOT DOMAIN
7. OFFSET REGULARIZATION BOTH IN SUBLINE & XLINE MODE
8. INELASTIC ATTENUATION COMPENSATION
9. MINIMUM PHASE CONVERSION
10. NOISE SUPPRESSION IN TIME-FREQUENCY DOMAIN
11. TRACE EQUALIZATION
12. RADON DEMULTIPLE
13. HORIZON BASED VELOCITY ANALYSIS
14. PSTM (KIRCHOFF'S CURVED RAY): APER 6KM X 6KM
15. VERTICAL VELOCITY ANALYSIS
16. PSTM (KIRCHOFF'S STRAIGHT RAY):APER 7KM X 7KM
17. NOISE SUPPRESSION IN TIME-FREQUENCY DOMAIN
18. DECONVOLUTION (TWO WINDOW)
19. TIME VARIANT ATTENUATION COMPENSATION
20. RESIDUAL VELOCITY ANALYSIS
21. MUTE & STACK
22. BP & DIP FILTERING, TRACE EQUALIZATION
23. FKPOWER, SPECTRUM BALANCING, FXY
24. TVF

Fig.14. Summary of processing sequence

Results

PSTM stack response of the present data indicates the improvement over the vintage data sets. The efforts made on noise attenuation have also helped in better velocity analysis and both of these factors together have helped in bringing out better image. The improvement in stack response for two different Inlines are shown in the following figures from Fig.15 to Fig.20

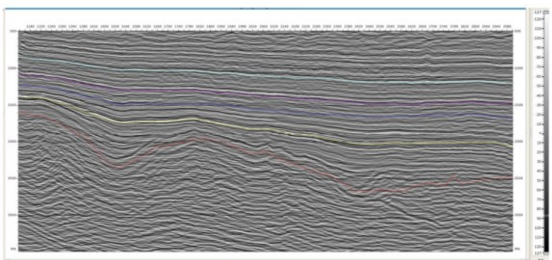

Fig. 15. PSTM Stack response of vintage1 : IL – XXXX

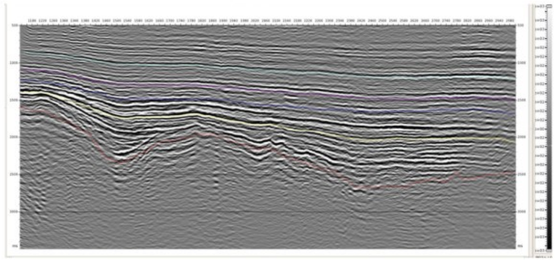

Fig. 16. PSTM Stack response of vintage2 : IL – XXXX

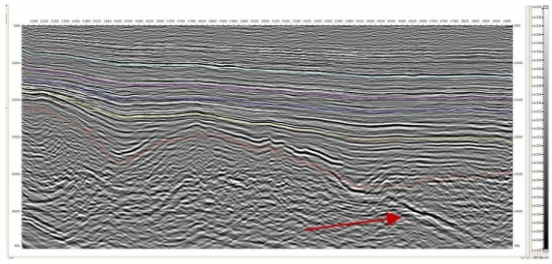

Fig. 17. PSTM Stack response of present processing : IL – XXXX

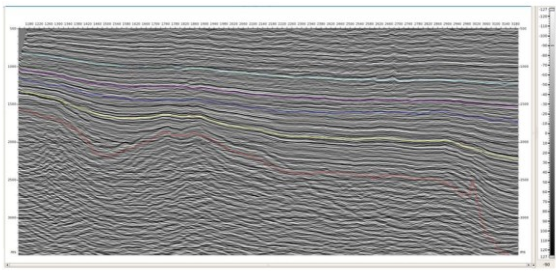

Fig. 18. PSTM Stack response of vintage1 : IL – YYYY

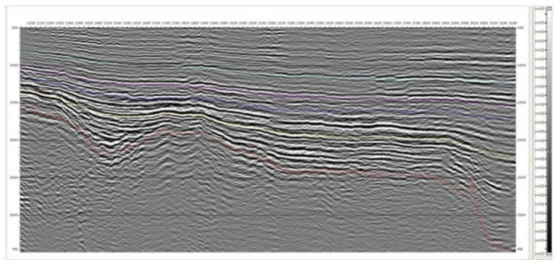

Fig. 19. PSTM Stack response of vintage2 : IL – YYYY

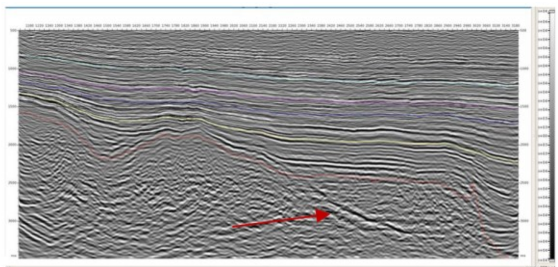

Fig.20. PSTM Stack response of present study : IL – YYYY

Sharpness and resolution of events are remarkably improved in the present study. Reflector below basement interpretation is clearly visible as shown by red arrow in Fig.17 & Fig.20. This may add value in basement interpretation. Let us now compare time slices of present study with that of vintage2 in Fig. 21 & Fig.22, at two different levels depicting both shallow & deeper reflectors.

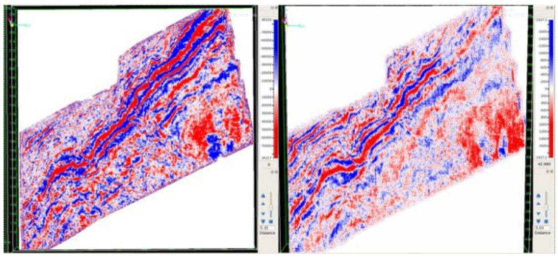

Fig. 21. Time Slice (1s) : Present & Vintage 2.

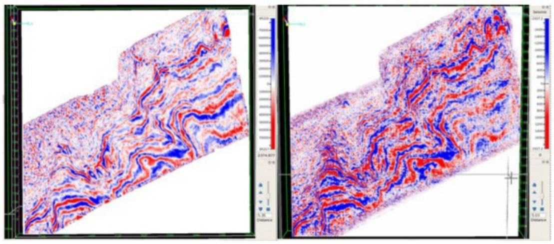

Fig.22. Time Slice (2s): Present & Vintage 2.

Substantial improvement in noise elimination, enhancement in frequency content and sharpness of events are clearly visible at all levels.

Conclusion

The result after de-noising hydrophone and geophone data separately for all possible noises in different domains and then summing the data has tremendously improve signal to noise ratio in the gather. With efficient noise reduction, data driven velocity guided by the geological interpretation enhanced imaging at all levels of interest. Improvements are seen in the time slices at various levels. Events are better focused. A deeper reflection (possible basement) has been imaged, which is a significant value addition. In last word, main advantage of present study are,

- **Restoring the primaries over the full offset range.**
- **Crucial lead : Basement**

Acknowledgement

Authors wish to thank Mr. P. K. Bhowmick, EDCOED, Basin Manager WOB, MR, ONGC & Dr. S. Viswanathan, the then Head, Geophysical Services, MR, ONGC for providing us the opportunity to work on this study area. We also commend members of ONGC for the various roles they played during the course of this study, especially to Mr. Anil C Naithani, DGM (Geol)-Acreage Manager, Mr. Subhankar Basu, CG(S) and members of SPIC processing Centre, ONGC.

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