Low Frequency Processing - Value Addition to Vintage Seismic Data: A Case Study

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Keywords

Low frequency, broad band, multiple attenuation, spectral balancing.

Summary

Conventional seismic data recording and processing paid less attention to low frequencies (<10 Hz) mostly in view of the high noise content in them, but the importance of having low frequencies is well understood in recent times. Broadband seismic techniques record and process data with frequencies as low as 2 Hz. The term low frequency processing, in general, is still assumed to be associated with high fidelity, broad band recorded seismic data only. Seismic data recorded and processed with conventional techniques often do not express much information in the low frequency bands. With new, deeper targets of seismic exploration and increased costs, better utilization of the already recorded data assumes paramount importance.

Authors of this paper made an attempt to re-process a conventionally recorded seismic dataset, preserving frequencies as low as 3 Hz, by adapting a judicious processing approach and taking advantage of the advanced software options. The preserved low frequency bands resulted in improved imaging of the deeper subsurface (~2 to 4 sec) and facilitated clear mapping of a highly dipping trap, which were missing in the previously processed seismic sections.

Introduction

The high amplitude seismic noises like ground rolls, anthropogenic noises etc. usually fall in lower frequency ranges (<10 Hz). Added to this was the limitations of the earlier generation acquisition equipment and processing software in recording and handling low frequencies. Because of these reasons, conventional seismic data acquisition and processing generally disregarded lower bands of the data. But the industry now realizes the importance of low frequencies better. Since low frequencies are affected by lesser attenuation and scattering, and provide more accuracy and stability to inversion processes, they assume a major role in modern imaging solutions, especially for deeper targets, sub-basalt mapping etc. Lot of studies have gone into developing acquisition technologies and processing algorithms/methodologies towards this purpose. But broadband data acquisition is a costly affair and increasing logistics is one major hurdle in re-occupying already surveyed areas. Hence re-processing of available data for new objectives and with newer perspective becomes unavoidable for the industry. It was felt if vintage data could be reprocessed preserving low frequencies, which was given least importance in earlier years, it could be an immeasurable value addition.

Vintage 3D seismic data from an area of Cambay Basin in Gujarat was taken for this study. Analog geophones were used in acquisition, without applying any low cut filter in recording.

The Cambay basin is an intra cratonic rift basin with narrow elongated graben running approximately NNW-SSE direction, takes a swing in southern part and aligns along NNE-SSW direction. During Late Cretaceous, major volcanic eruption activities took place and Deccan trap formed the technical basement of the basin, subsequently different units came into existence in differential depositional environment. The structural pattern of the study area typically depicts horst and graben tectonics with several faults controlling the sedimentation.

Structural complexity of the area, presence of coal layers in Oligocene formation, strong inter bed multiples etc. contributed to the inferior quality of earlier processed seismic sections. The deeper and dipping portions of the trap also were not properly mapped. The two-way times to the trap varied from nearly 600ms to 3600ms in the survey area. The regional geologic setup of the area is shown in Fig-1. Data of three different seismic campaigns were used for this study. Location map of the acquisition areas were shown in Fig-2. Salient acquisition parameters of the three campaigns are given in Table-1.

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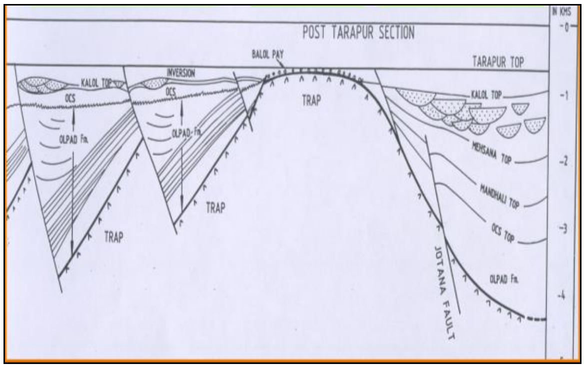


Fig 1: Regional Geologic Setup of study area

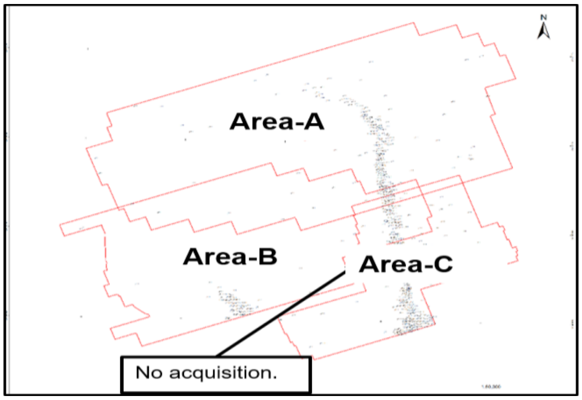
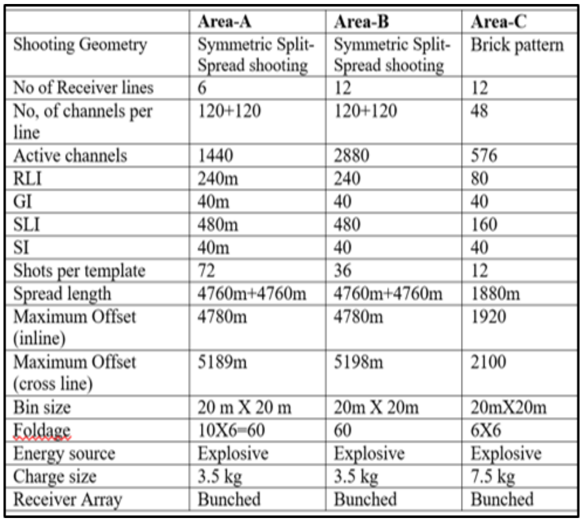


Fig 2: Acquisition area



	Area-A	Area-B	Area-C
Shooting Geometry	Symmetric Split-Spread shooting	Symmetric Split-Spread shooting	Brick pattern
No of Receiver lines	6	12	12
No, of channels per line	120+120	120+120	48
Active channels	1440	2880	576
RLI	240m	240	80
GI	40m	40	40
SLI	480m	480	160
SI	40m	40	40
Shots per template	72	36	12
Spread length	4760m+4760m	4760m+4760m	1880m
Maximum Offset (inline)	4780m	4780m	1920
Maximum Offset (cross line)	5189m	5198m	2100
Bin size	20 m X 20 m	20m X 20m	20mX20m
Foldage	10X6=60	60	6X6
Energy source	Explosive	Explosive	Explosive
Charge size	3.5 kg	3.5 kg	7.5 kg
Receiver Array	Bunched	Bunched	Bunched

Table 1: Acquisition Parameters

Methodology

Raw data was merged with SPS information and thorough quality checks were done. Field statics and spherical spreading corrections were applied to data.

Noise attenuation and filtering are two stages of data processing where major loss of frequencies could happen. Noise attenuation of the data set was done taking utmost care to avoid any data loss. The high amplitude noises were removed in decomposed frequency bands, by using frequency dependent and time variant amplitude threshold values in trace neighborhoods. The data was infested with strong ground rolls and linear noises. The ground rolls and back scatters were removed using adaptive ground roll attenuation methods in FX domain. Linear noises other than ground roll were attenuated in radon domain. By analyzing the difference between input and noise attenuated gathers, it was ensured that no signal frequency was lost (Fig-3).

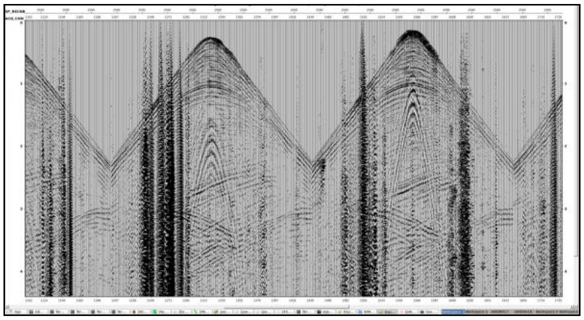


Fig 3(a): Input Gather

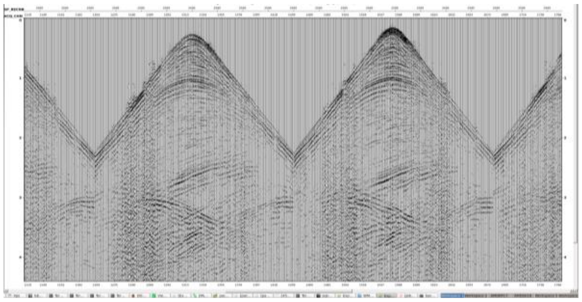


Fig 3(b): Noise attenuated Gather

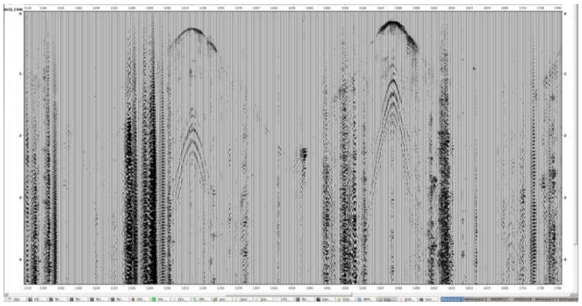


Fig 3(c): Difference

Fig 3: Comparison of input and de-noised Gathers

Exhaustive testing was done both on gathers and stacked data to select a filter ensuring no loss of signal frequencies. A band pass filter, 0-2-90-120 Hz was chosen. Surface consistent amplitude corrections were applied to the noise attenuated gathers. After sufficient testing, predictive deconvolution was applied to data with a prediction gap of 12ms and operator length of 280ms.

Since the data used were from three different seismic campaigns, the acquisition geometries, equipment and field conditions were different. These resulted in amplitude and phase differences between the datasets. Proper matching filters were designed and applied to the data.

Residual statics were calculated and applied to the data. Four dimensional regularization of data was done. Since the acquisition geometries were of narrow azimuth, azimuthal regularization was not attempted.

Data was infested with lot of multiples, both short and long periods. The long period multiples were attenuated mainly in radon domain. Residual long period multiples were attenuated by stacking. The short period inter bed multiples were more difficult to identify in gathers, but were clearly visible in stack sections, cutting across reflection events. These were attenuated in the final migrated stacks, by filtering in spatio-temporal gates in the F-X domain, under the assumption that the multiples pertaining to a flattened reflector exhibit similar spatio-temporal patterns as the primary reflector (Fig-4).

In a structurally complex area, the determination of velocity is very crucial and at times tricky too. Velocity analysis was done multiple times before running test migration. Test migration was done with percentage velocity scans, facilitating structural velocity analysis for RMS velocity. In this method selected in-lines of the data were migrated with different percentages of the input velocity. The different outputs generated were analyzed to choose the velocity which had properly migrated the data. The velocity so picked was input to automated high density velocity batch picking to generate a high density velocity volume. The final RMS velocity volume generated was showing very good structural consistency (Fig-5a & 5b).

Kirchhoff pre-stack time migration was carried out. Residual random noise attenuation was done on stacked data. Coherency filters were applied to enhance the coherent events. Spectral balancing of the data was done within the bandwidth of the data, using the wavelet domain. The processing sequence followed is shown in Figure-6.

Results

Fig-7(a), 7(b) and 7(c) shows same inline stack from the final processed data with different filters applied.

The section shown in Fig-7(a) was applied with a low cut filter and do not contain frequencies below 8 Hz. Fig-7(b) shows the same section without applying any filter and contains frequencies as low as 3 Hz. The dipping flanks of the horst were properly mapped in the second section, whereas in the first section, which was devoid of low frequencies, the flanks of the horst were almost missing. Fig-7(c) shows the same stack with a limited frequency band, i.e. from 3-7 Hz. It shows very clear imaging of the trap and an amplitude maximum around 5 Hz.

The above example very clearly establish that the better imaging of dipping and deeper reflectors in the second section was contributed solely by the preserved low frequencies in the band of 3 to 7 Hz.

The preserved low frequencies brought clear cut improvement in imaging of dipping and deeper events compared to the earlier conventionally processed data (Fig-8).

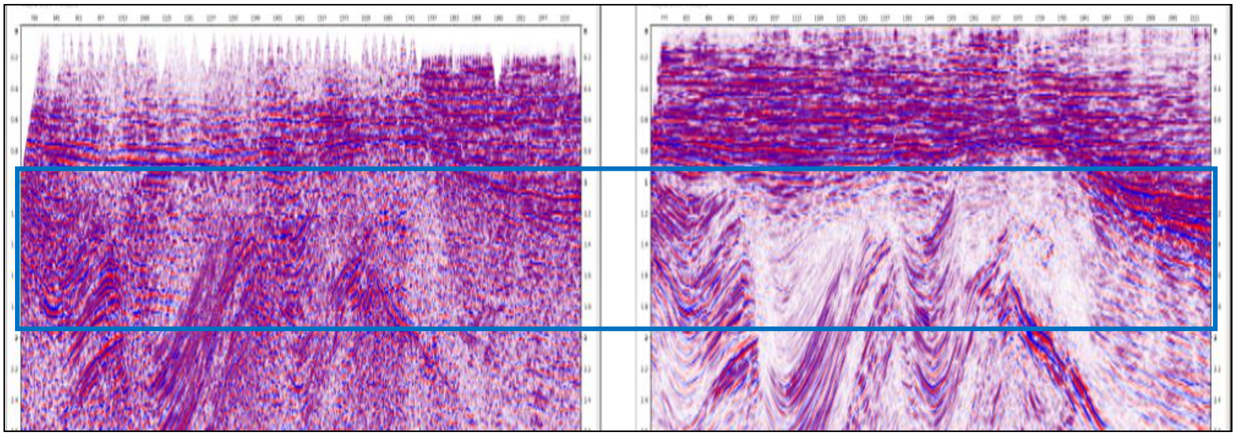


Fig 4: Strong multiples seen in the earlier processed data (Left) were attenuated

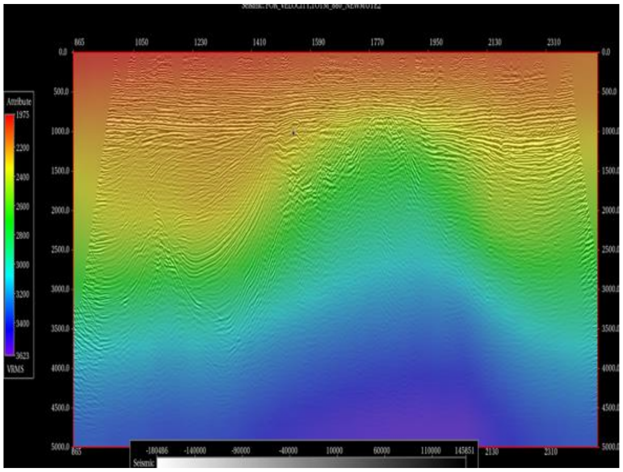


Fig 5(a): RMS Velocity overlain on an Inline

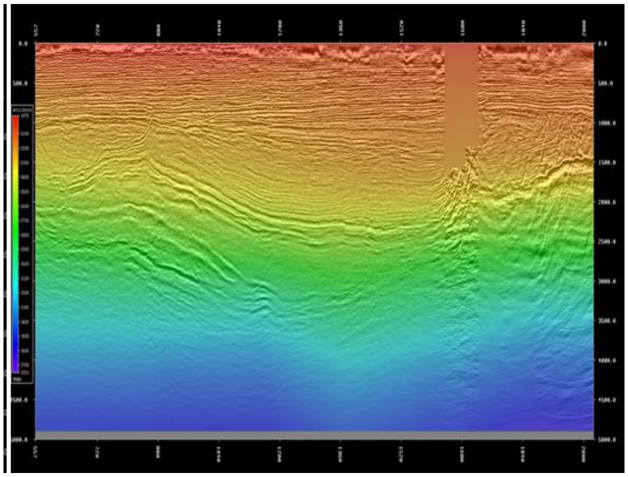


Fig 5(b): RMS Velocity overlain on a Cross line

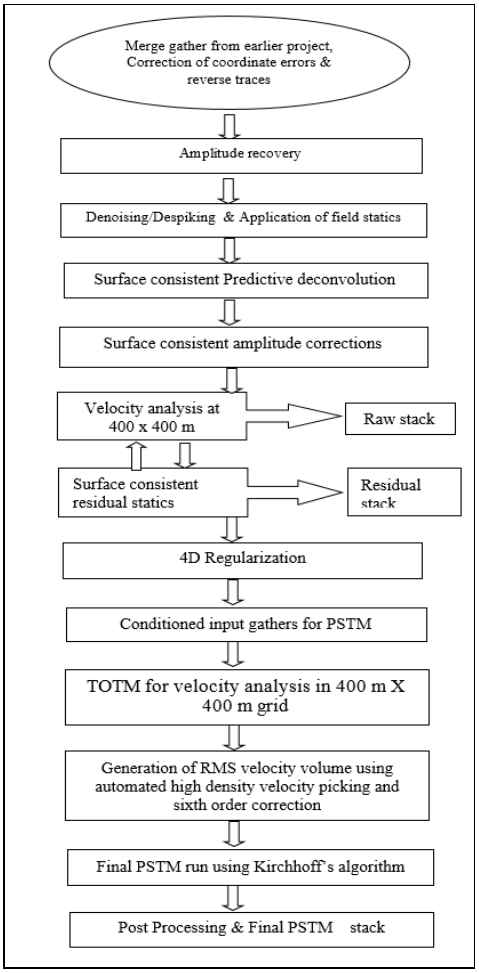


Fig 6: Processing Flow chart

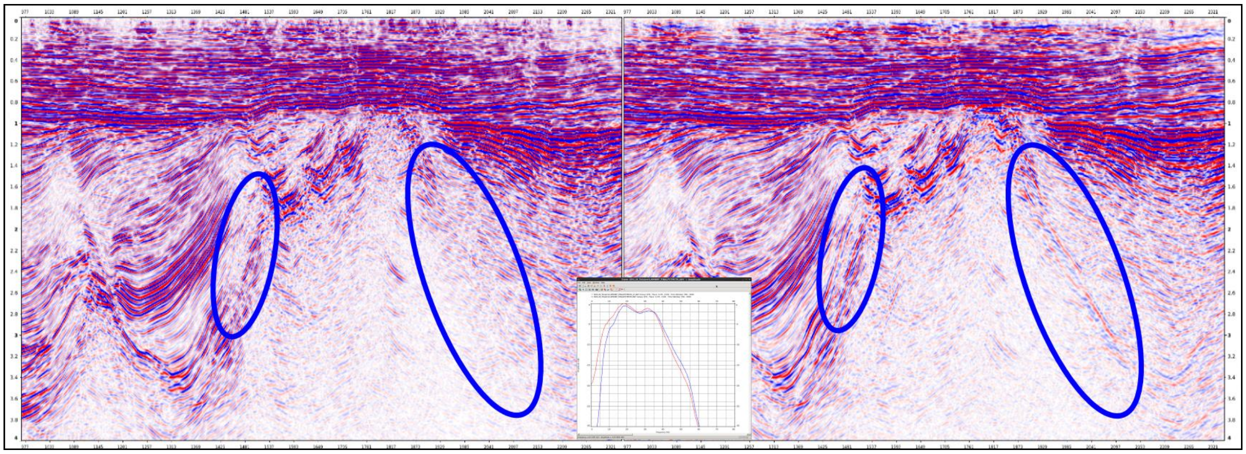


Fig 7(a): Inline stack with frequency 8-45 Hz Fig 7(b): Inline stack with frequency 3-45 Hz

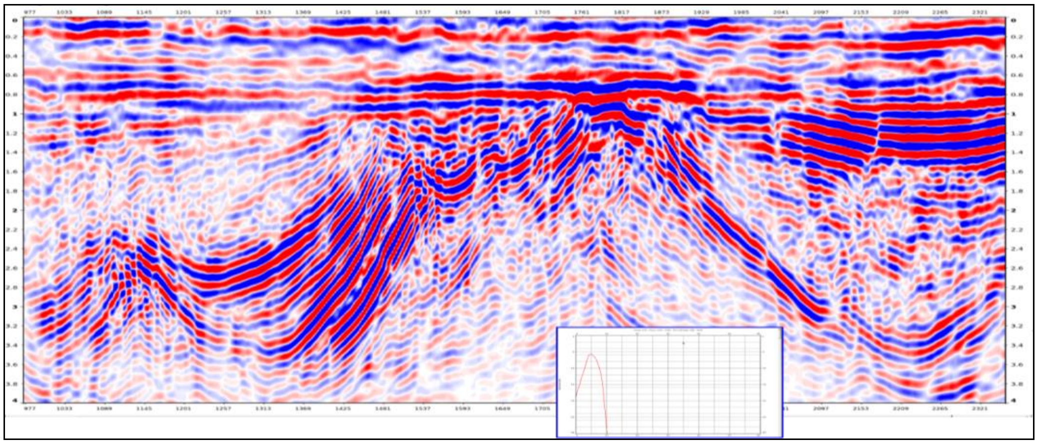


Fig 7(c) Inline stack with limited frequencies - 3-7 Hz

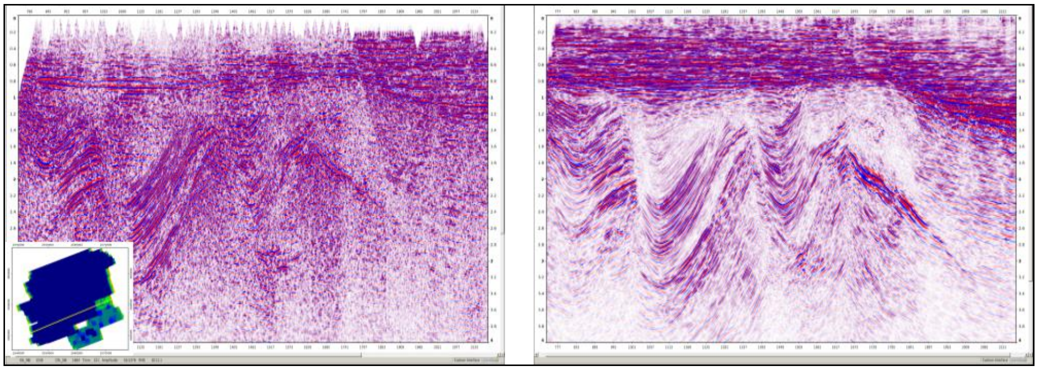


Fig 8(a): Conventional processing (Inline stack) Low frequency preserved

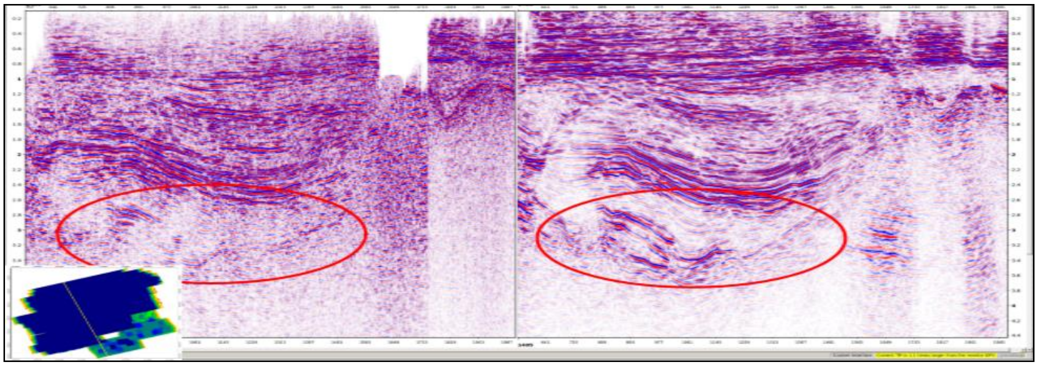


Fig 8(b): Conventional processing (Crossline stack) Low frequency preserved

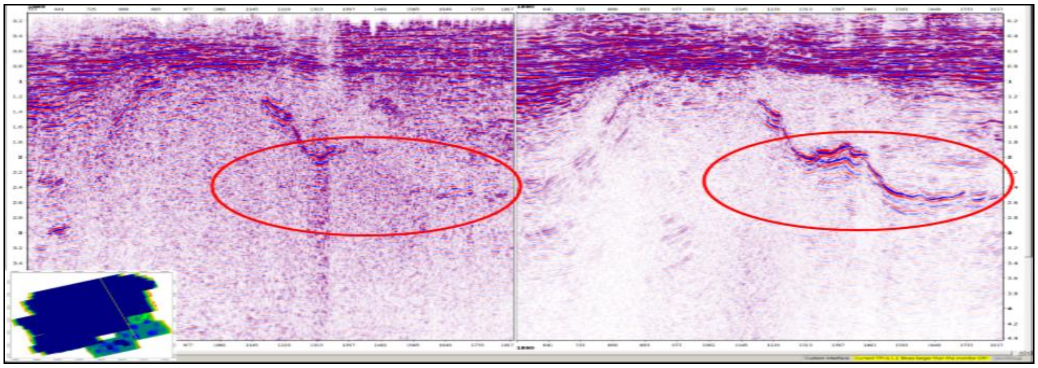


Fig 8(c): Conventional processing (Crossline stack) Low frequency preserved

Conclusions

The results emphasized the importance of preserving low frequencies in seismic data during both acquisition and processing. The imaging of dipping flanks of horst and deeper parts of trap could be improved to a great extent by preserving and boosting the lower frequency bands through processing. The improvement in low frequencies may also facilitate better results in inversion studies.

Noise attenuation, filtering, deconvolution and spectral balancing are stages where special attention needs to be paid in preservation and boosting of low frequency data. Proper utilization of modern algorithms for residual static calculations, data regularization, velocity analysis etc. also help in getting better results from vintage seismic data.

The prospect of adding more value to vintage data sets by adapting astute processing approaches becomes crucial in the current scenario of increasing operational costs and logistics in data acquisition.

N.B: The views expressed here are those of the authors only and may not necessarily reflect the views of ONGC Ltd.

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Acknowledgments

The authors wish to express sincere gratitude to Dir.(E), ONGC, India for permission to publish this work.

Thanks are due to Shri. Puneet Suri, ED-Basin Manager, Jorhat and Shri. H Madhavan, GGM-Basin Manager Vadodara, ONGC for the support and encouragement provided.

Thanks are due to Shri. Matibar Singh, GGM, Head Geophysical Services, Vadodara and Shri. H N Garg, CGM, Head Geophysical Services, Jorhat, ONGC for encouraging us and giving valuable inputs during processing & compilation of this paper.

Thanks are due to all seniors & colleagues of Processing Centres, ONGC, Vadodara & Jorhat for their kind cooperation and valuable suggestions.