trough and minimum ringing. Low frequencies are also important for imaging the deeper formations because of less absorption in comparison to higher frequencies. In actual seismic data higher frequencies always have low strength due to more absorption of these frequencies depending on the Q value of the medium. Generally, attempts are made to compensate for this loss of frequency though combination of Q compensation and deconvolution. Figure-2 shows the shape of wavelet as well as spectrum with low and high frequencies.

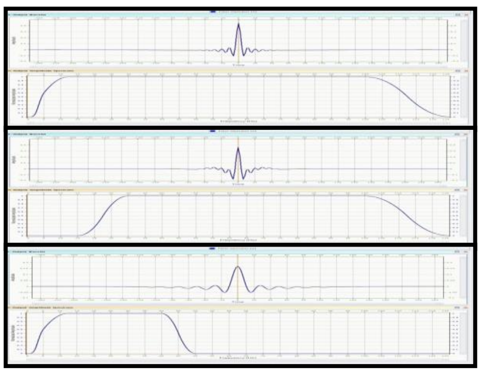

Figure2: Wavelet of broadband spectrum (top), wavelet without low frequencies (middle) and wavelet without high frequencies (bottom)

In conventional streamer data acquisition, ghost energy associated with source and receiver results in the notches in the amplitude spectrum. The notch frequency is governed by the depth of the airgun/hydrophone, which is given by the relation:

$F_n = n(V/2D)$,

Where n=1,2,3……..,fn is the notch frequency, V is the velocity of seismic wave in water and D is the depth of airgun/hydrophone from the water top.

Because of the presence of the notch, usual processing steps of improving the bandwidth have limited capability. Broad band processing of conventional streamer data involves, application of de-ghosting technique to remove the effect of ghosts from the data, thus improving the signal strength of notch frequencies.

Input data challenges

Reflection strength was very poor at deeper time zones especially from Mesozoic sequences. Strong multiples were present in the data and they were completely masking the deeper events. Raw data also had strong swell noise.

Processing sequence

Format Conversion
↓
Trace header updation
↓
Swell noise attenuation
↓
Linear noise suppression
↓
De-bubble, De-signature and De-ghosting
↓
2D-mode SRME & Q-compensation
↓
Bulk shift and Velocity analysis
↓
Offset class regularization
↓
Target line PSTM
↓
RMS velocity analysis
↓
Final Kirchhoff PSTM
↓
Parabolic radon de-multiple
↓
Stacking of PSTM gathers
↓
Random noise attenuation

Table 1: Processing work flow

Broadband processing of Kutch offshore data

(1) De-ghosting

With the given acquisition geometry, first notch related with receiver ghost was expected to be at about 108Hz, which was a major concern because of sharp drop in the strength of lower as well as higher frequencies. Second notch related with source ghost was expected to be about 150Hz, which was beyond the frequency of processing interest.

An operator was designed for removing the ghost effect and tested first on the ghosted gun signature itself as shown in figure-3. Figure-4 shows the amplitude spectrum of ghosted gun signature (blue) and after de-ghosting (red). There upon, the tested operator was applied on the data set. Shot gather before and after de-ghosting process and amplitude spectrum before (red) and after (blue) de-ghosting process is shown in figure-5 & figure-6 respectively.

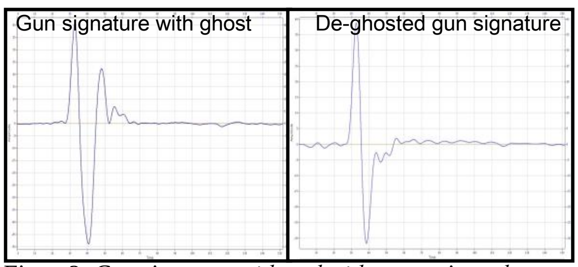

Figure3: Gun signature with and without receiver ghost

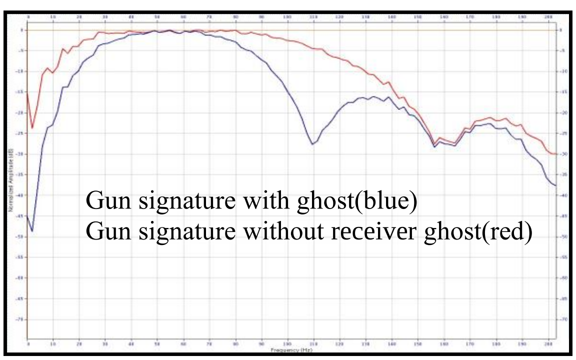

Figure4: Amplitude spectrum of gun signature with source and receiver ghost (blue) and after receiver deghosting (red)

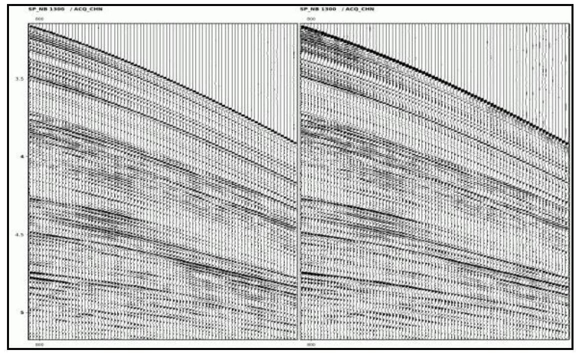

Figure 5: Representative shot gather before and after de-ghosting

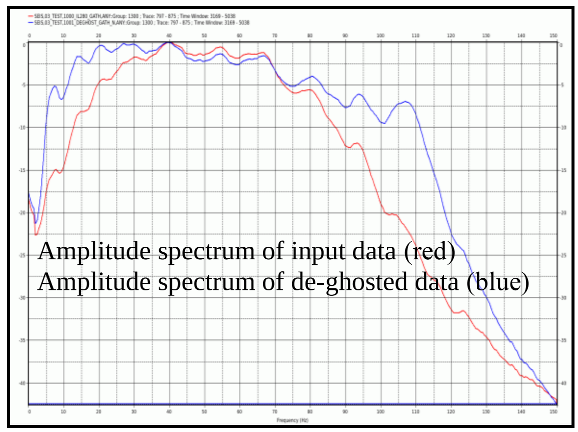

Figure 6: Amplitude spectrum of the shot gather before (red) and after de-ghosting (blue)

(2) SRME and Q-compensation

Seismic data had strong multiples and reverberation. They were masking the primary reflections. Multiple present at larger offsets can be easily removed by parabolic radon de-multiple but at near offset it cannot be handled by it because the small move out difference of primary and multiple energy. This type of problem can be handled by SRME technique.

SRME was carried out in 2D mode, considering each streamer as a 2D sequence. Figure-7 shows the stack before and after SRME application. It was observed that the strength of surface related multiples was reasonably attenuated.

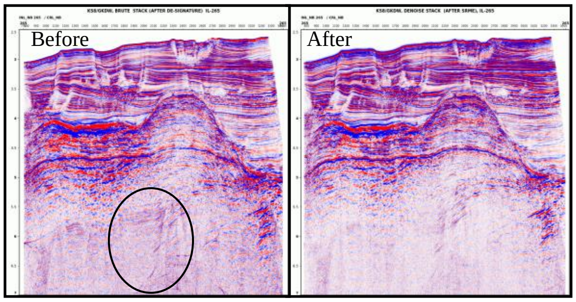

Figure7: Before and after SRME result

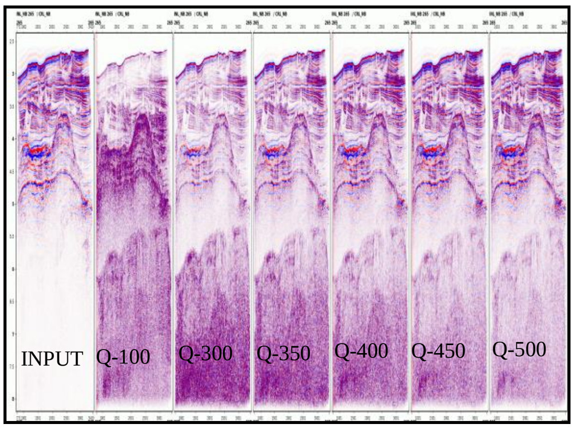

Figure8: Comparison of Q- compensation (amp & phase) test results with different Q values

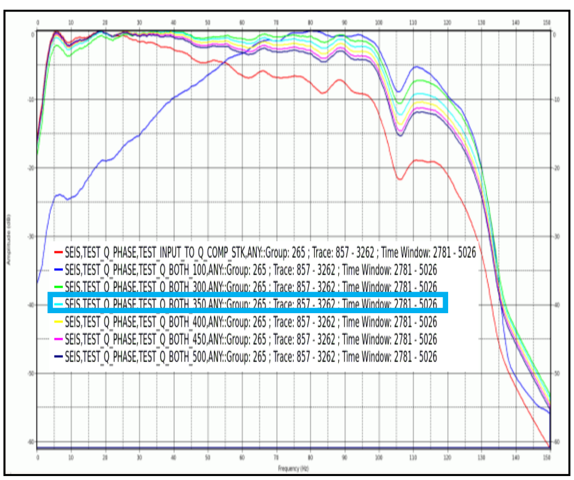

Figure9: Comparison of spectrum of test result with different Q values

Seismic attenuation affects both amplitude and phase of seismic signals. The effects of attenuation are dispersive with frequency which results in reduced stack coherency and subsequently reduced spatial resolution from the stacked image.

Two different approaches were adopted for estimation of Q-value, one using panel test and other using stack section. After thorough study of different Q panels, 350 value of Q factor was found to be optimum. Figure-8 to figure-10 show the test result of Q-estimation using two different approaches.

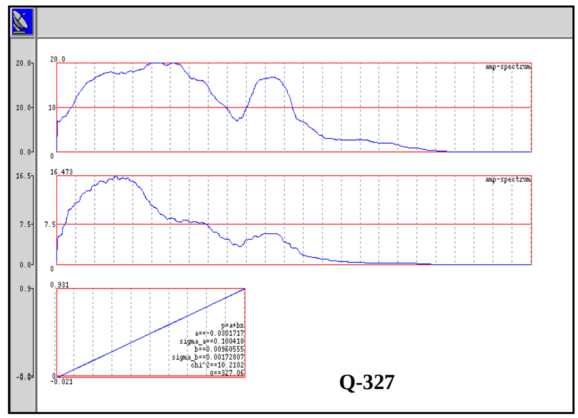

Figure10: Q-value estimation using stack section

(3) Data regularization

In the data, fold varied from 1-169, in place of the nominal acquisition fold of 60. To reduce the possible artifacts that might arise during migration process owing to data irregularities, data needs to be regularized over the processing grid for each offset class that would go into migration process.

Considering the fold variation, it was decided to keep 100m offset classes for migration. The entire offset range from 200m to 6300m was consequently split into a total of 61 offset class. Offset classes were regularized using 3D Fourier decomposition algorithm and regularization was done into a bin size of 12.5m X 25m. Figure-11 shows the fold map before and after data regularization. Figure-12 shows the stack section before and after data regularization

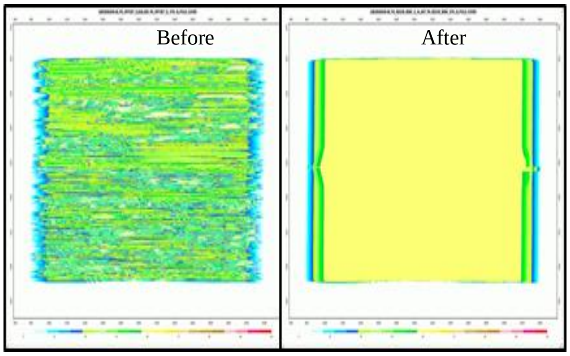

Figure11: Fold map before and after data regularization

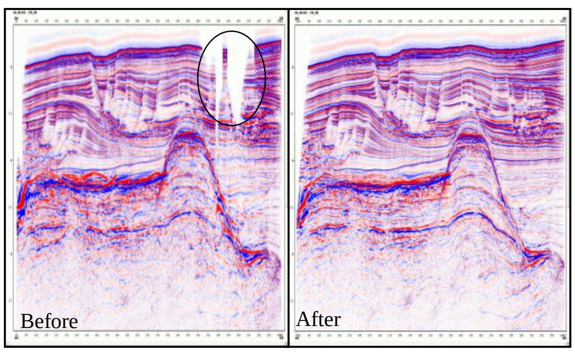

Figure12: Stack before and after data regularization

(4) Pre-stack imaging

Proper RMS velocity analysis was carried out in a 1000m X 1000m grid. Smoothed RMS velocity volume was used for final PSTM of the data. Minor residual move-out observed in the PSTM gathers was taken care by high density velocity and eta picking and application. Subsequently, parabolic Radon de-multiple was applied on the PSTM gather to remove the far offset multiple, before generating the final PSTM stack

Multichannel spatial filtering using projection filters for random noise attenuation and acquisition footprint suppression using f-kx-ky was carried out on PSTM stack. Figure-13 shows the comparison of vintage PSTM stack and newly processed PSTM stack image.

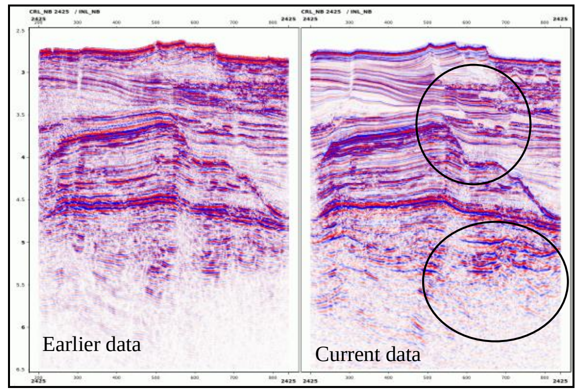

Figure13: Comparison with Earlier and Current PSTM stack

Conclusion

Processing steps included De-ghosting, proper noise suppression, signal processing and RMS velocity analysis followed by Pre-stack time migration. Broader bandwidth gives the better texture, higher resolution and clarity in sequence boundaries in the seismic image.

Broadband processing has resulted in reduced ghost effect and broadening of the bandwidth. Tertiary and Mesozoic image was enhanced significantly by added low frequency as well as high frequency in the signal.

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