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Application of Varisweep technology in 3D Survey over Chinnawala field, Rajasthan (A case history)

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Summary

Correlation noise is a serious problem in many areas with vibroseis system due to dynamic range of more than 60db between the strong first arrival and weak reflection events arriving at several seconds later. A simple and easily implemented method of reducing correlation noise is amplitude tapering (Edepman 1966), but unfortunately tapering induces an increase in main peak width (Berkhout 1984), which is an undesirable effect. Application of tapering minimizes high frequencies caused by the vertical ends; and with deconvolution it can some extent control this noise but cannot cope up always with such a large dynamic range in the presence of noise. So far, Non-linear, Linear sweeps have been employed with varied success for many years. With the approach of Varisweep technique with Non-linear sweep, Vibroseis source spectra were modeled as an objective to broaden /whiten the effective signal bandwidth as received at the geophone, while reducing the ground roll generation at seismic source and correlation.

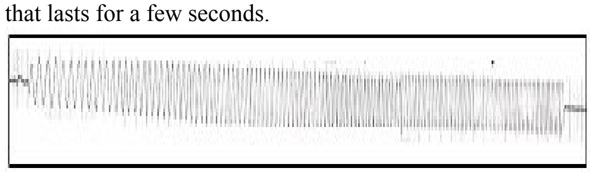
Introduction :

Since 1957, Oil Exploration activities are in continuous strive for search of black gold in the Indian Thar Desert of Western Rajasthan by Oil and Natural Gas Corporation Ltd. In the past, ONGC field parties in different field seasons carried out Geological Surveys, Gravity, Magnetic and 2D Seismic Surveys over the areas of Western Rajasthan. With changing technology, exploration activity strengthened further by carrying out 3D seismic surveys for detailed mapping of sub surface. The Rajasthan sedimentary province forms part of gentle westerly and northerly dipping eastern flank of Indus Shelf. Jaisalmer Basin is one of the four main structural elements of this sedimentary province. It is a late Paleazoic basin with Permian rocks resting unconformity over Phylite and Schists of doubtful Proterzoic age. This basin is covered by steep and linear stand dunes, which has elevations of the order of 120mts from the mean sea level.

Geophysical party 26 of ONGC carried out 3D Seismic exploration In the field season 2006-07 under the SIR-59 putting some special innovative efforts by using vari-sweep technology with vibrators of Nomad-65 of SERCEL to attenuate the correlation noise in the near and far traces and also to attenuate ground roll.

Basic principle:

It is most important to recognize that vibroseis exploration which is based on a single choice of input frequencies. Choice of input i.e. Pilot signal frequency is the support of pilot signal (fig no.01), which is equally important like other parameters such as source and receiver pattern geometry, group interval and total spread length. Vibroseis input pilot signal is typically a swept frequency sinusoid that lasts for a few seconds.



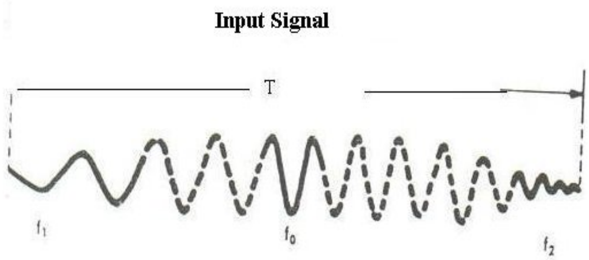


Fig no. 01 (Basic Vibrator Sweep)

Input Sweep:

The input signal is a swept frequency sinusoid of wavelength T. The different parameters of input signal are:

- Length of the sweep : T sec
- Beginning frequency : f_1 Hz
- Ending frequency : f_2 Hz

The frequency of the centre of the signal (f_0) is the average of beginning and end frequency:

$$f_0 = (f_1 + f_2)/2$$

The ends of the signal are tapered to avoid superimposition of beginning and end frequency on the side lobes of the correlogram.

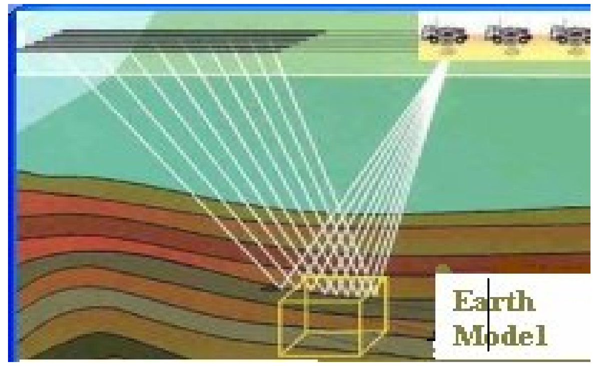
Bandwidth of the input sweep:

Bandwidth of the input sweep depends on the ratio f_1/ f_2 expressed in octaves. Also some authors express bandwidth (Δ) as the difference between f_1 & f_2.
bandwidth(Δ) $= (f2 - f1)$ in Hz.
Octave : Consider the frequencies f_1 and f_2 . Express their ratio as
$f_2/ f_1 = 2^n$
$n = [\log (f_2/ f_1)]/ \log 2$
n represents the number of octaves between the frequencies f_1 and f_2
$n = 1$ if $f_2 / f_1 = 2$

Dispersion:

The dispersion D depends on product of sweep length and bandwidth
$D = \Delta.T$
Dispersion represents correlation power in a collapsed signal.

The signal energy is partly reflected and partly transmitted at each elastic boundary within the earth. The earth model and input signal are shown in Fig. 2.



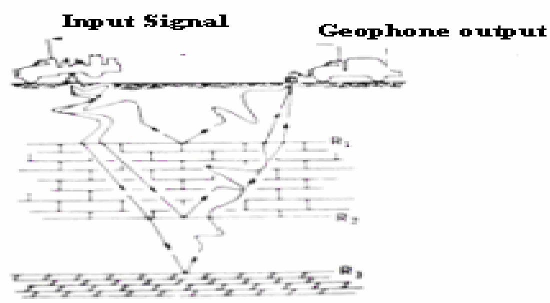


Fig. No. 02 (Sketch of earth model with three Primary reflections of input wave)

This transmitted signal's transmit time is much lower than that of input signal. This unique signal which is longer than the transmit time of the deepest reflection is transmitted into the earth where it is convolved with the earth response to form a geophone output and this reflected signals are compressed by cross correlation into short symmetrical wavelets that are comparable to the wavelets from an impulse seismic source.

Signal Specification:

Simple slide rule shows vibroseis system of seismic mapping is to convolve the autocorrelation of input signal (autocorrelation) with the earth response, i.e. for each spike which represents the reflection coefficient at the boundary between contiguous earth layers that have different elastic properties in the earth response, we can substitute a replica of the autocorrelation pulse with the appropriate amplitude and polarity. That mean, one can get idealized seismic trace by convolving an autocorrelation pulse with synthetic spike trace.

The characteristic of autocorrelation pulse depends on the basic vibroseis pilot signal specification, namely amplitude spectrum and duration of input signal. Thus theoretically we can choose an input signal that will give the best resolution of the desired reflection.

Therefore an important vibroseis tool is the knowledge of the fundamental relation between the input signal characteristics and the autocorrelation pulse shape.

The theoretical auto-correlation of the linear swept frequency signal is called Klauder wavelet.

The shape of the Klauder wavelet depends upon input sweep frequencies. The band width of the input sweep determines the sharpness of the peak.

Klauder Wavelet Chacterstics:

The autocorrelation of waveform is given by Klauder" equation as

$$\Phi_{ss}(\tau) = \frac{A^2 T}{2} \; \frac{\sin \pi (f2-f1)\tau}{\pi (f2-f1)\tau} \; \mathrm{Cos}\, 2\pi \left\{ \frac{f1+f2}{2} + \frac{(f2-f1)\tau}{2T} \right\}$$

A = Sweep Signal Amplitude
Δ = f2 – f1 in hz
Length of the signal = T
Central Frequency f = (f1 + f2)/2
Processed record time = τ

The first factor is the zero-shift (or zero lag) value, which represents the energy in the sweep, the second factor is sine function that defines the envelope. The third factor, (f2-f1)τ /2T can be neglected for sweeps and autocorrelation of usual length: in this case third factor is simply the mid frequency carrier, whose amplitude is then modulated by sync function. **The ratio of the first trough of the auto correlation to the central peak is the squares root of the ratio the end frequencies of the sweep.**

Theoretical Background :

The Vibroseis system gives us two stages for improving Signal to Noise ratio. The first stage is the choice of the input signal bandwidth, terminal frequencies and its duration. The second stage is the cross correlation process which can further improve the signal to noise ratio.

Correlation:

The correlation process for varisweep is illustrated in figure 03, it consists of 10 sweep segments (A, B, ---, J) each one length of 12secs.
Auto correlation of the combined sweep would be

$$Z' = Z'_A + Z'_B + Z'_C + Z'_D + Z'_E + Z'_F + Z'_G + Z'_H + Z'_I + Z'_J$$

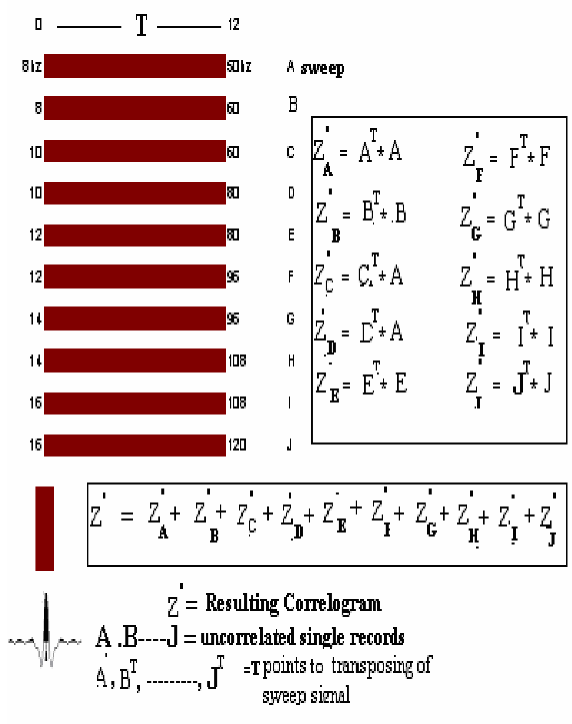


Figure : 03 (Correlation Process)

Auto correlation pulse is indicated in the beneath the correlogram (Z')

Combination of different sweeps will result attenuation of technical noise, which inherent in the vibroseis method.
The technical noise is
A . The near correlation noise described by
the ration of a2/a1
The far correlation noise Asymmetric correlation ghost which are generally caused by harmonic freq.

Near correlation noise is defined as the amplitude of the first and sometimes also the second side lobes which precede and follow the main peak of a signal. Quality of signal is expressed as a 2 /a1. The amplitude of a2 and a1 is nothing but the ratio of the first trough of the auto correlation to the central peak is the square root of the ratio the end frequencies of the sweep.
As in our experiment the final parameters of vari-sweep are : 08-50hz,08-60hz,10-60hz,10-80hz,12-80hz,12-96hz,14-96hz,14-108hz,16-108hz, and 16-120hz for which a2/a1 for the first sweep segment is 0.4,second was 0.36

Like that the amplitude ratio of a2 /a1 for remaining sweep segments are 0.40, 0.35, 0.38, 0.35, 0.38, 0.36, 0.38, and 0.36 , if it combined we get a single auto correlated plot with a2/a1 is **0.372**. By suitable combination of sweep the ratio of a2/a1 shows quality of signal. Combined autocorrelation wavelet is appended below which is obtained from real data. Sample of nine records are shown in fig. 04

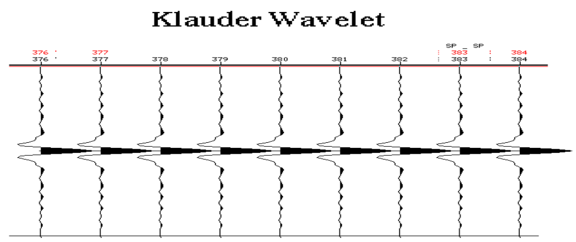


Fig no. 04 (Klauder Wavelet of 9 records)

Far Correlation noise is defined as the oscillation of a correlation pulse at a greater distance from the main peak. Theoretically far correlation noise lasts as long as sweep exists. Its amplitude decreases rapidly with increasing time from the main peak.

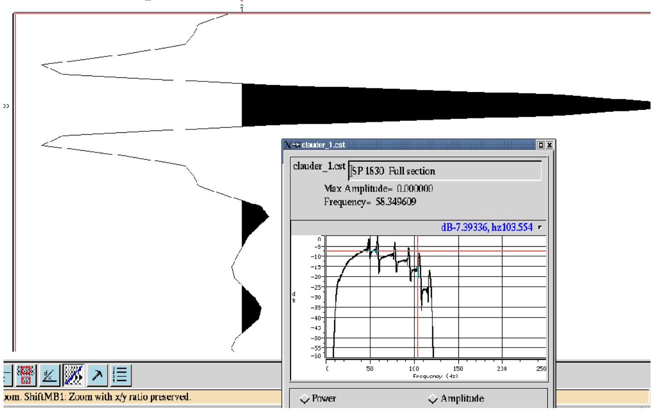


Fig no. 05 (Auto correlation wavelet and it spectrum)

An autocorrelation with its spectrum shown in fig.05

Methodolgy:

Field Application:

Initially the experimentation was carried out for fixing the parameters to achieve the
assigned objectives.
Parameters were as follows:
Sweep length of 12sec.
The correlated record length : 5sec
Sampling interval : 2ms
Shot interval :80mts.
Preamp Gain : 12db
Taper Length : 400ms

The acquisition configuration was a split spread of 144channel (72 channels on both side) with group interval of 40mts and near offset 40mts on one side and zero offset on other side so that to achieve the foldage of 45.

Drive force kept most of the time 70%, except the area where hard formation in which non-linear coupling of the vibrator to the ground appears and to avoid harmonic distortion on the signal and to protect the life of Vibrators, drive force reduces to 40 –50%.

To improve further in the vertical resolution, it was selected Non-linear mode of sweep throughout survey to control the shape of spectra by playing the frequencies as per requirement for suppression of ground roll energy.

Vari-sweep technique allows each sweep in a set of composite for a single source point to have different sweep parameters, each of which has a widely varied frequency range and bandwidth.

In the experimentation, combination of different set of sweeps of different bandwidth was selected which concentrates source energy into frequency ranges. In the first experimentation, FT analysis for Ten and Eight different vari-sweep selected. as shown in the fig 06 ,fig: 07 ,Fig.09 and Fig.10. Initially eight sweep Signal were taken with different end frequencies as shown in (Fig.06), and these were stacked. Then without moving to any further station, another set of ten different sweep parameters as shown in fig.07 were selected and were stacked. Like that this experimentation continued, in locations of such as in-line and cross line and with 2/3/4 vibrators in stationary positions.

Placing an equal emphasis on all frequencies within the recorded signal bandwidth maximizes effective resolution potential.

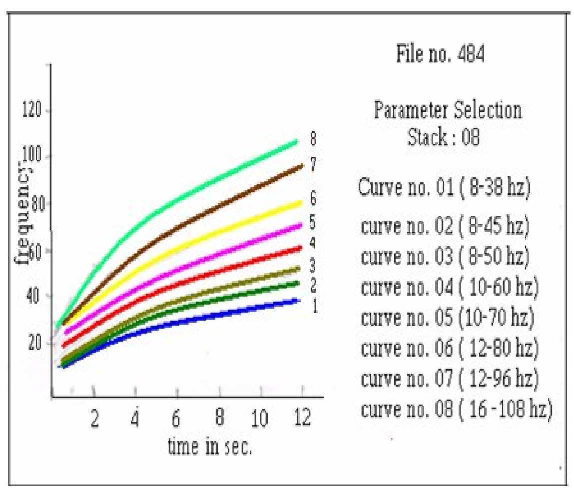


Fig . 06 FT Analysis

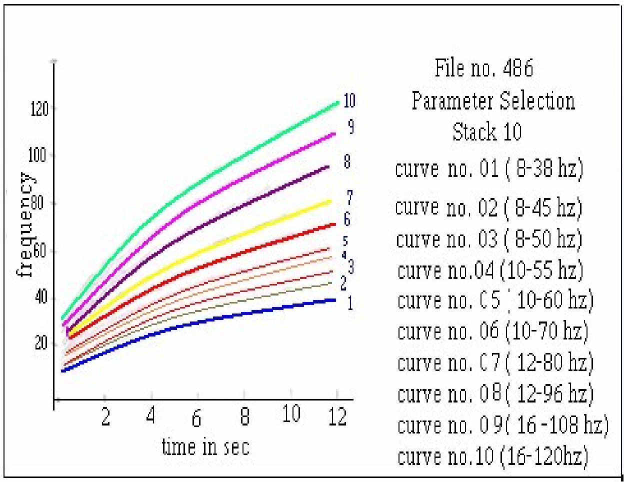


Fig .07 FT Analysis

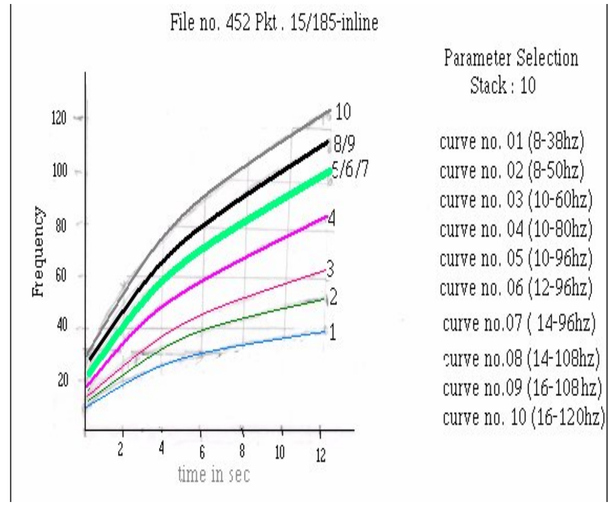


Fig: 10 FT Analysis

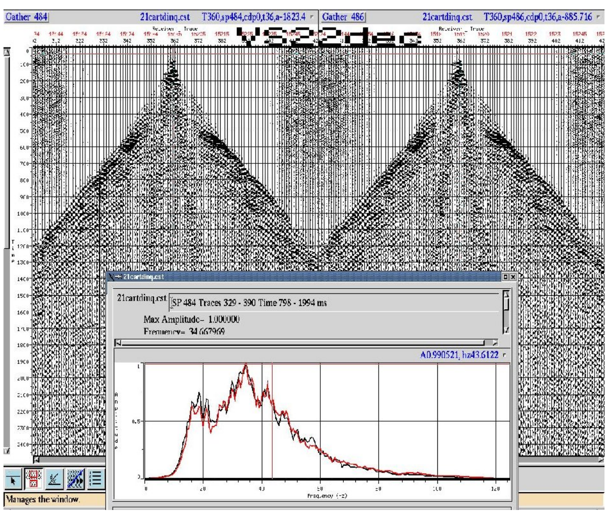


Fig: 08

Fig : 11

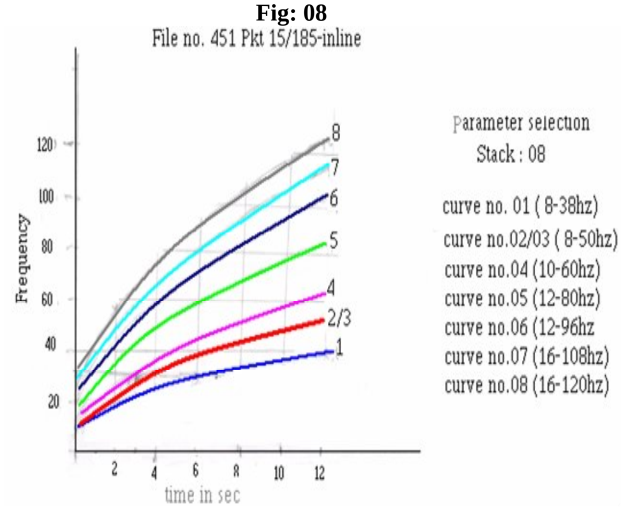


Fig: 09 FT Analysis

Power Spectra analysis was carried out with through Field processing unit on the acquired signal and comparison studies carried. Figure 08 shows frequency spectrum of fig06 and fig7 where peak frequency achieved 34.6 Hz and whereas from the parameter of fig09 and fig10, peak frequency obtained as 24.6 Hz which is shown in Fig11.

By combining this two exercise, a separate parameter selection with varying different low end and high end sweeps were tested as a separate FT analysis carried out and shown in Fig.12 , initial sweep parameter for the first sweep kept as 08-50hz, in respective stages as 08-60hz,10-60hz,10-80hz,12-80hz,12-96hz,14-96hz,14-108hz,16-108hz, and 16-120hz.

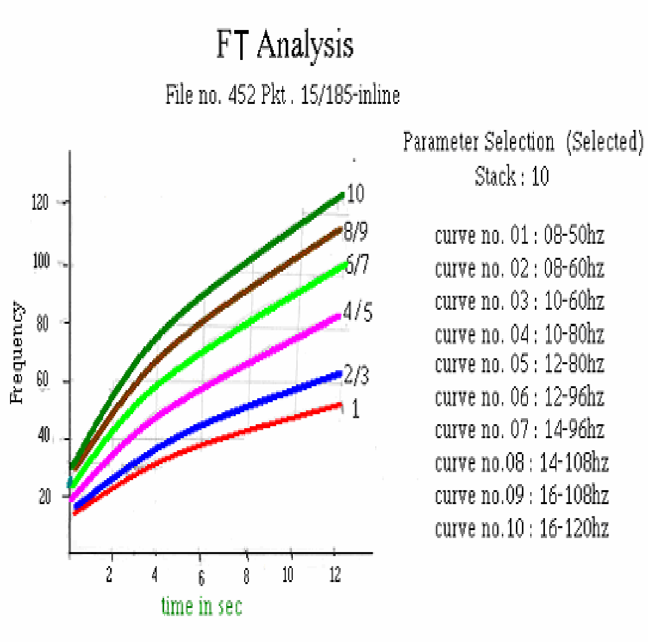


Fig : 12

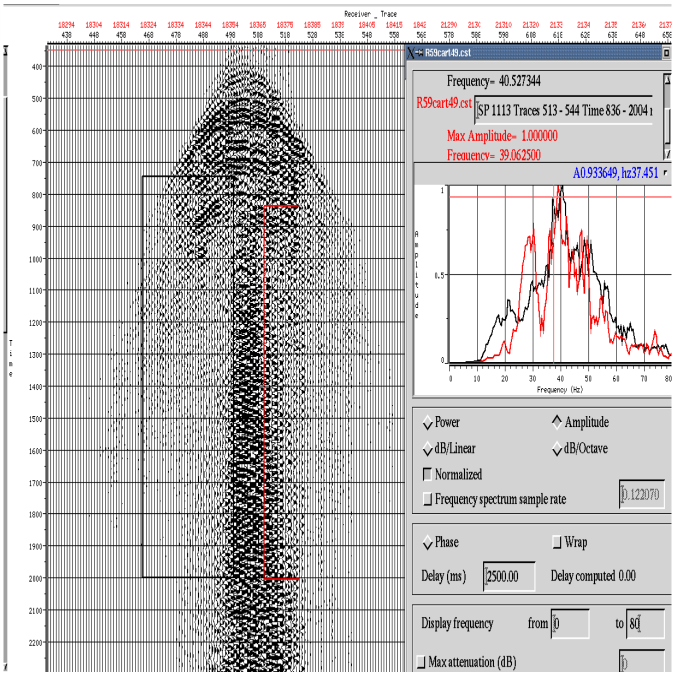


Fig: 13

Power Spectral Analysis carried and results shown in Figure 13 and observed good frequencies and achieved a peak frequency of 39.0625 Hz as. This combination of 10 different set of vari-sweeps were used throughout survey. In this way, specified bands of frequencies are combined in real time in weighted fashion to obtain a resultant wide bandwidth signal.

Certain composite focus on the low frequency generation yields good penetration while other components are high frequencies giving good resolution and correlation without interference of low frequency ground roll.

Entire data with static's was sent to processing center and processing was immediately taken up on the data of Swath01, consequently test processing carried out with refraction static's and results were very impressive. A processed section on swath 01 of one in-line is shown in Fig 14, however it is still in the initial stage.

Brute Stack -Line 428 -R59

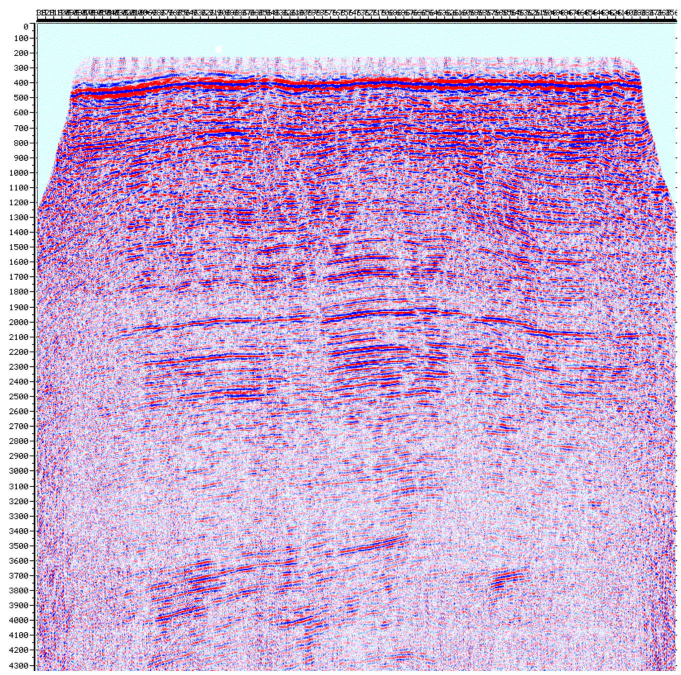


Figure : 14

Conclusion:

Significant data quality improvement was seen through increased resolution, coherent noise attenuation, and reduction of correlation noise resulting in improved S/N ratio.

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