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Determination of Multiples in Surface Seismic Data Using Zero Offset Vertical Seismic Profiling (ZVSP) Techniques

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Abstract: ***In seismic exploration, one of the major tasks is to construct an image of the subsurface based on a limited amount often obscured and unreliable data. With conventional surface seismic data, we can often only "guess" at the measurements of the subsurface, but vertical seismic profiling (technique of placing the receiver at the depth in the well bore) enables us to measure the behavior of seismic wavelets as they propagate through the subsurface by shortening the path between the seismic source and the receiver. VSP provides a more accurate technique of imaging sub-surface targets with a higher resolution than conventional surface seismic technique. Various processing steps were applied in generating a One-dimensional (1-D image corridor) seismic section of the data, the corridor stack is then shifted to the frequency of the surface seismic data and a tie is generated. Multiples reflections and true primary reflections were then identified on the surface seismic data. From the results obtained using zero vertical seismic profiling, multiples were identified at offset time 1.32ms, 1.59ms, 1.71ms, 1.80ms and 1.82ms respectively across the section while true reflections were identified at 1.20ms. 1.40ms, 1.92ms and 2.19ms respectively. This clearly shows the ability of the technique to differentiate multiples from true reflections in a seismic data or section. Zero-offset vertical seismic profiling survey provide detailed images of the subsurface both around the borehole and ahead of the drill bit which particularly helpful in aiding drilling strategies.***

Keywords: Multiples, Zero-offset, Vertical SeismicProfiling, Borehole, Stacking, Deconvolution, Normalization

1. Introduction

Geophysics is a branch of Physics that studies the science of the Earth, especially its Electrical field, Gravitational field, Magnetic field and the propagation of elastic (seismic) waves within it. A major part of the search for oil and gas is the search for suitable geological features in which hydrocarbon may be trapped; Such features may exist between 1 to 100km^2 in extent and may occur at surface depth of 1 to 10km.Seismic surveys are acquired by the generation of seismic waves and the recording of the travel times of these waves from the source to subsurface geologic horizons and back to the receivers either at depth or on the surface. These surveys allow scientist to map the subsurface distribution of different types of rocks and the fluids they contain.

Seismic surveys can be divided into two main categories which are Surface seismic and Borehole seismic. The principle is the same for both except that in surface seismic, the sources and receivers are positioned on the surface or close to it while in Borehole seismic, sources are typically located at the surface and the receivers are located in the well. A good example of Borehole Seismic Survey is the Vertical Seismic Profiling (VSP).One of the prime purposes of this in-situ survey is to find a rock velocity or travel time as a function of depth; in which velocity is then used in the lithology delineation and mapping process. The surveys can also help in understanding wave propagation in an often complex medium.

VSP data has many properties as surface seismic data. VSP data is dominated by the downgoing wave-field, which is not of direct use to us when we wish to observe the (much weaker) upgoing wavefield. Conversely knowledge of the downgoing wavefield provides us with information that allows us to apply powerful deterministic processes, particularly Deconvolution, during processing. It also provides us with direct information on attenuation and the generation of multiples during transmission of the seismic wavefield.

2. The VSP Concept

Vertical seismic profiling (VSP) is a borehole seismic recording technique that measures the behaviour of seismic wave as they propagate through the subsurface. In conventional vertical seismic profiling, the seismic receiversare positioned at some depth in the earth subsurface, rather than on the surface as in traditional seismic surveys, which make the receiver much closer to the subsurface target. The VSP recording geometry do shortens the target-to-receiver path, thus lowering the energy losses due to absorption (reduced energy loss) and therebyincreases the frequency content (generally higher). Typically, VSP data are recorded down to 5Hz or lower, thus providing superior bandwidth(Features/Events are generally better resolved on VSP data due to superior bandwidth) and the processing sequences applied to VSP data are less inclined to attenuate high frequencies than surface seismic processes (such as stacking). Also, Fresnel zones of recorded seismic waves are smaller in VSP data than in conventional surface seismic (the smaller the Fresnel zone, the more closely spaced two reflecting points can be before we are unable to distinguish between them), however the process of migration reduces the size of the Fresnel zone in surface seismic. Another benefit of the VSP is that both the down-going and up-going wavefields are measured because the receivers are located deep in the subsurface. Knowledge of the downgoing wave allows us to effectively deconvolve the upgoing wave, which provides a broad-bandwidth, multiple-free measure of the earth's reflectivity.

The lateral extent of the VSP imaging is limited since the subsurface coverage created by a typical VSP recording geometry do not usually extend a great distance from the wellbore (with receivers placed in the wellbore). This creates limitations to the illumination of the local subsurface geology that can be extremely varied particularly in complex structures.

The VSP is simply a precision level step change up from the check shot velocity survey, why VSP measures nearly all seismic waveforms in the well bore (up-going and down-going energy), check shot velocity survey measures basically only the down-going energy. Note that a VSP is also a check shot velocity survey but a check shot velocity survey is not a VSP (Robert, 2002). The VSP, like the check shot survey, also measures down-going energy and the basic computed product of the VSP is known as a corridor stack, which in appearance resembles the synthetic seismogram. The down-going wave field is all that a check shot velocity survey records. Another significant limitation of relying only on check shot velocity surveys is that the surface seismic data that they are being correlated with contain almost entirely reflected waveforms. Surface seismic does not measure down-going energy because all the detectors are at the surface.

Because VSP data has a broader bandwidth and contains high frequency events, subtle features like small faults, stratigraphic changes, and amplitude anomalies can be observed in the vicinity of the well bore, whereas they are not discernible on the surface seismic coverage in the same area.Also, angular unconformities, pinchouts, and weakly reflecting interfaces near a well are easily seen more clearly with VSP data from a given well than with surface-recorded data Displaying the VSP/CDP Transform and the seismic section together yields a far more useful product for interpretation.

3. The VSP Configuration

Normal seismic sections are recorded by moving the detectors (geophones) and seismic source horizontally along the ground or, in marine surveys, the sources (airguns) are set in place and the receivers (hydrophones) are places on the streamer near the surface of the water. But in Vertical Seismic Profiles (VSP), the receivers are run vertically in a wellbore by activating a seismic energy source on or near the earth's surface. The down-going and up-going seismic wave-fields are recorded with receivers positioned at closely spaced depths in a well to obtain detailed seismic response near the wellbore. After correcting for the very different geometry of such a survey, the results are presented in seismic section format which can be correlated with conventional seismic data.

4. Background of Study

The borehole seismic data (Vertical Seismic Profiling - VSP) is acquired by firing the seismic source on the surface and recording the times the signal takes to travel from the source at the surface to the receivers or detectors positioned downhole within a wireline tool. Multiples which are reflections that have been reflected from more than one boundary or interface are masked with the true primary reflections in the seismic section. Vertical Seismic Profiling (VSP) provides one of the best tools for identifying these multiples. The technique is based on the joint analysis of VSP wavefield processed using different types of deterministic Deconvolution. This technique provides insight into the origin of residual multiples in surface seismic data, and helps in understanding the contribution of surface and interbedded multiples to the total multiple wavefield contaminating the primaries at target intervals. VSP data also act as a QC tool for the surface seismic multiple removal procedures. The work is aimed at using the Zero offset vertical seismic profiling (ZVSP) to correlate with surface seismic survey in identifying multiple reflections and true primary reflections presence in the given surface seismic data.

5. Methods

There are different techniques or processing steps applied when carrying out Zero Offset Vertical Seismic Profile (ZVSP) data processing. The processing sequences applied for the case of this project are highlighted below.

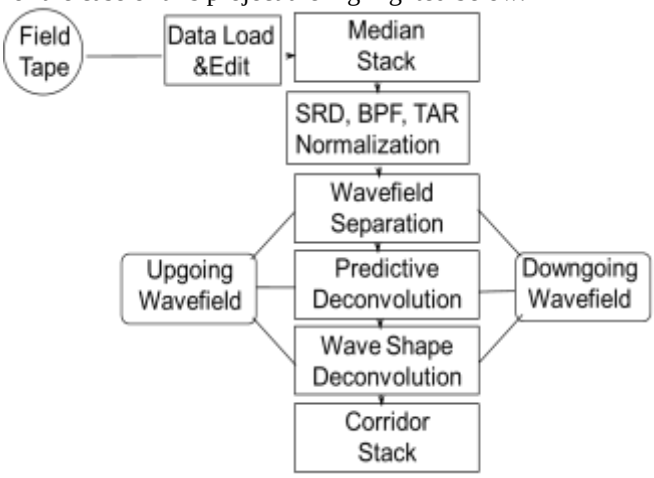


Figure 1: A schematic Procedure for Multiples identification in Seismic Data using ZVSP technique

Schlumberger software Geoframe is used to process the data. The software can be applied to process data from all facet of the upstream cycle of the exploration and production industry i.e. (Geology, Geophysics, Petrophysics and Reservoir Engineering). The data gotten from the field are loaded into the system and are converted from Log Depth Format (LDF), which is the field format to Clusters which is accepted to runs in Geoframe. The loaded dataset are then viewed where bad traces highlighted, identified and removed with the following processes:

- **Stacking**

The data set is stacked to give a better alignment of the traces and reduces noise, thereby improving the overall data quality. Traces from different shot records with a common reflection point, such as common midpoint (CMP) data are then stacked to form a single trace.

- **Time Picking**

The arrival timeof direct seismic waves are then picked on an amplitude extremum of the signals. Based on this

picking, the seismic components are then oriented in a unique reference frame anda time window is defined on either side of the picked arrival times, while the azimuthal direction is determined by maximizing the energy of the horizontal components within this time window. Also, the time shift calculation in the frequency domain is used to improve the predicted first break. Finally, the up-going waves are suppressed in order to eliminate its influence on the down-wave, allows us to obtain more accurate first arrivals.

- **Normalization and Time Varying Gain**

The variations in the first arrivals amplitude are generally compensated for by computing the RMS amplitude value over a window covering the first arrival at each geophone location and then normalizing each trace so that all the first arrival amplitudes are the same. This can also compensated by applying a time variant amplitude recovery factor proportional to time.

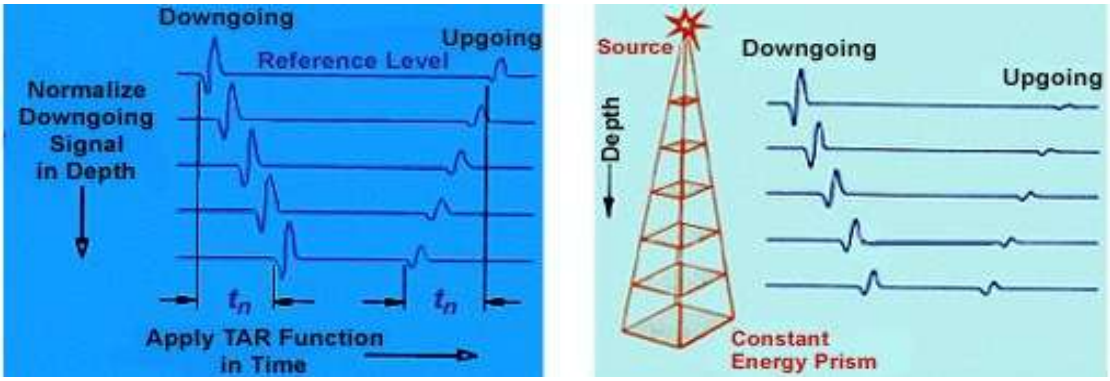


Figure 2: Principles of Normalization and Time Varying Gain (Hardage, 1975)

- **Wavefield Separation Technique/Velocity Filtering**

In order to retrieve detailed geological information from the data, the down-going events must be separated from the up-going events, which are superimposed in VSP field data. F-K velocity filtering is applied to the dataset, thetechnique preserve the proper amplitude, phase, and timing relationships among all of the individual events in both the down-and u-going wavefields but distinguishes between down-and up-going events using the differences in their apparent velocities.

- **Deconvolution**

This is a step in seismic signal processing to recover high frequencies, attenuate multiples, equalize amplitudes and produces or converts the wavefield to zero phase wavefield, this process is also known as **inverse filter**. Deconvolution is used to remove reverberations which are recorded in seismic data, its removes the adverse effect of convolution which occurs naturally as the seismic signal travels through high frequency filter (earth).

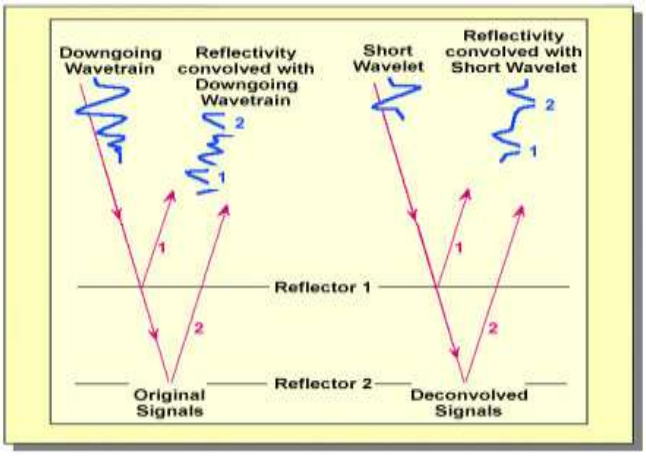
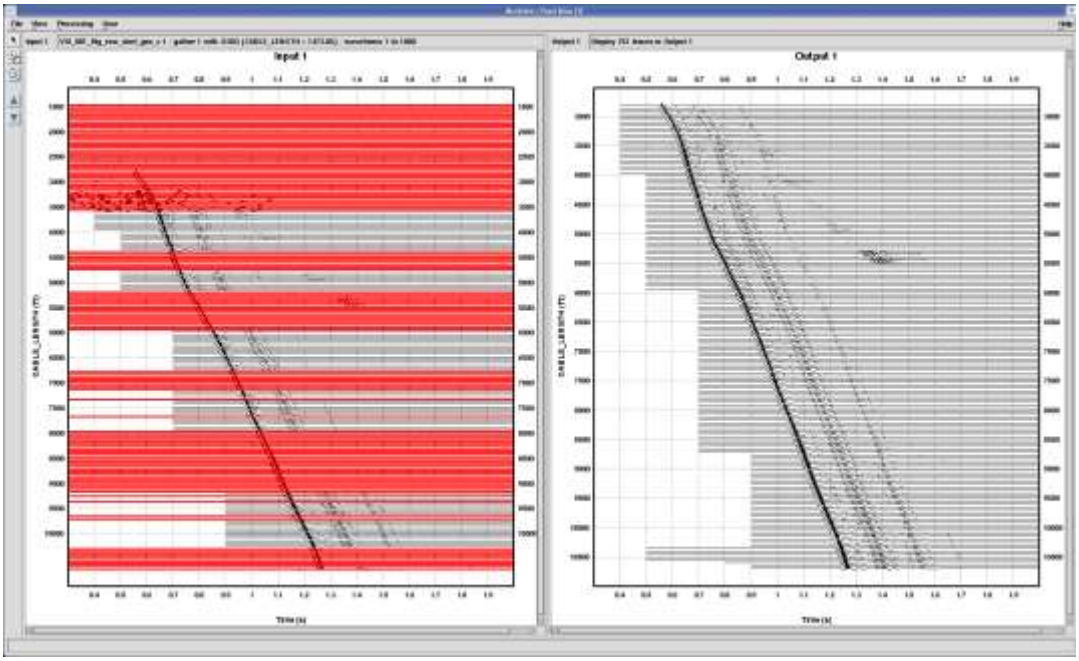


Figure 3: VSP Deconvolution diagram

6. Results

The seismic dataset obtained from field were loaded into the software and a plot of the raw dataobtained is shown in Figure 4a. All observed bad traces (highlighted as red flag) were subsequently removed during the data editing stage by applying Normalization by trace icon on the software, the resulting output of the edited traces is displayed in Figure 4b. The corrected dataset were then stacked using median filter (odd number of shots), NMO corrected times, transit time sensor or One Way Times (OWT). This help to sum up traces from the same common depth point (CDP) known as stacked traces (Figure 5), thus reducing the amount of the data by a factor called fold.



a **b**

Figure 4: Data Loading and Editing

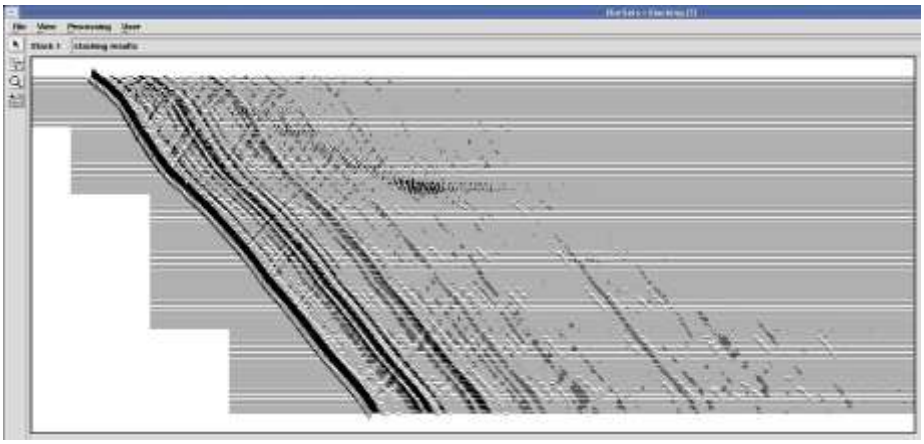


Figure 5: Stacked Traces

After stacking the dataset, the downhole geophones first arrival times were then picked using parameters like geophone break, inflection point tangent, threshold of 0.1 and vertical z-axis (VSP Level). The pick will highlight any gross errors in a transit time pick of a level. Source consistency is examined for quality control (QC). The time pick dataset is shown in Figure 6.

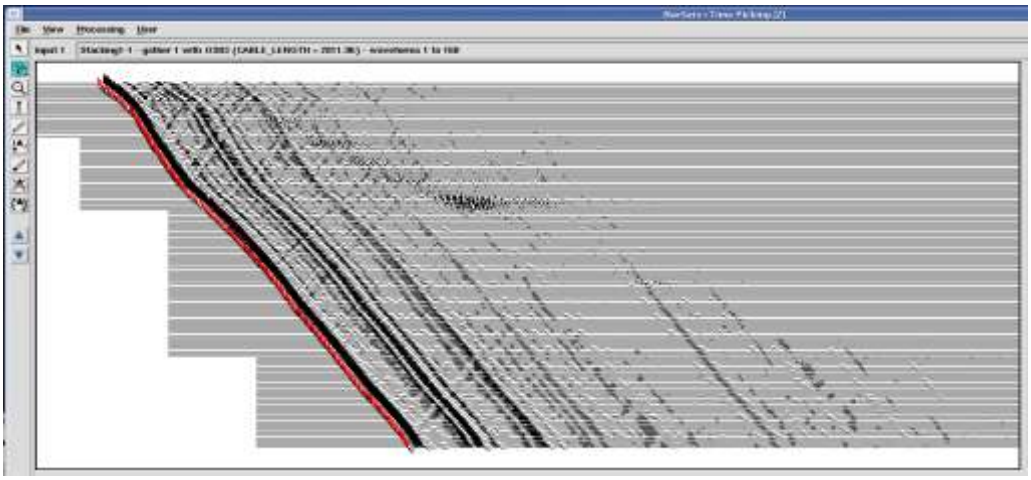
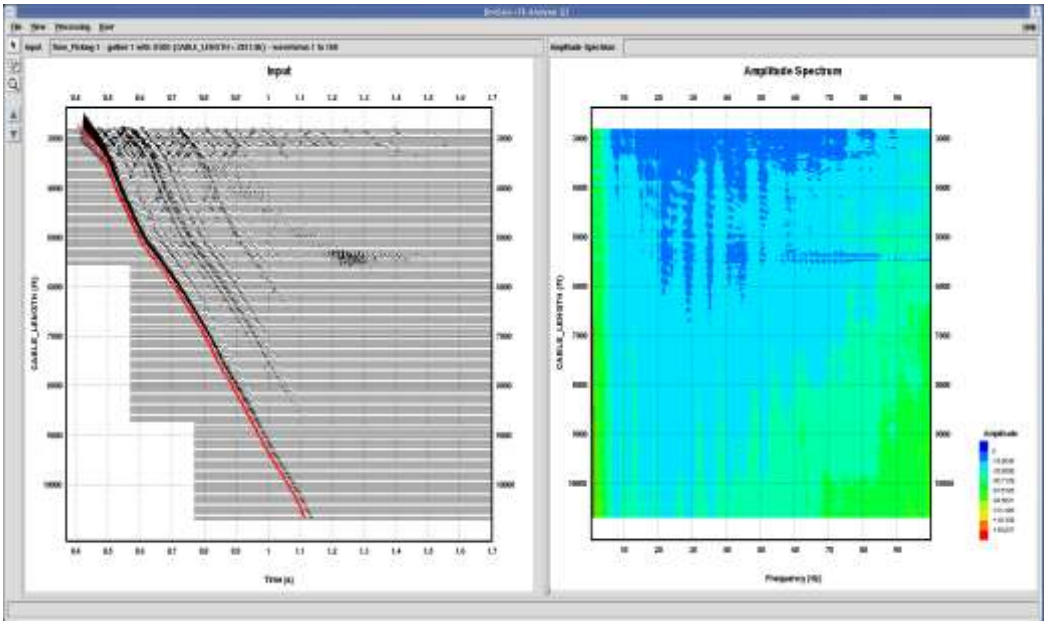


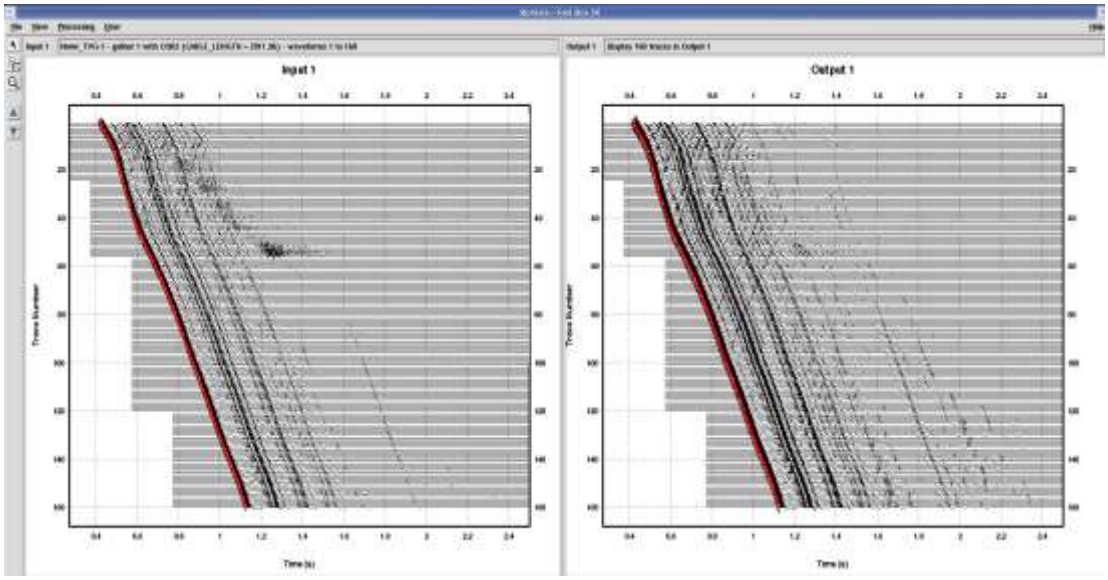
Figure 6: Time Picked Traces



a **b (Amplitude spectrum)**

Figure 7: Amplitude Frequency Analysis

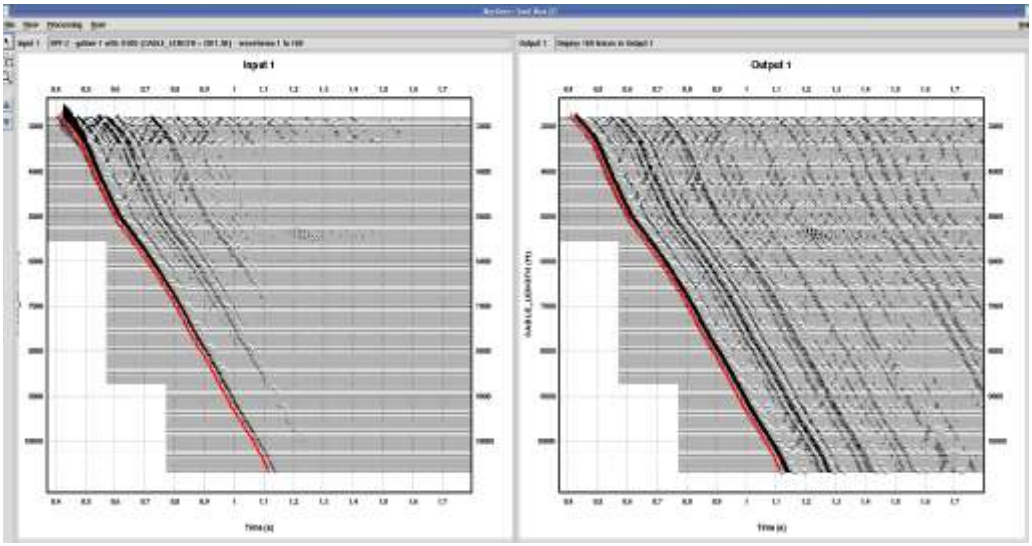
The time picked dataset are then loaded into an F-K analyzer (Figure 7a), which gives a frequency amplitude spectrum (Figure 7b). The frequency bandwidth of the time picked dataset is observed and the frequency band is selected for quality data check. A bandpass filter is set using frequency bandwidth of 5Hz – 75Hz, the filter helps to remove some of the inherent very high or low noise in the dataset (Figure 8).



a (Before filtering) **b (After filtering)**

Figure 8: Band Pass Filter Applied

Due to the effect of the earth being a high frequency filter, a normalization filter is applied on the bandpass to equalize the amplitude variation (amplitude loss) of the dataset with depth (Figure 9) using Check shot parameters, transit time, gate length of 0.2sec and travel time from 1.2seconds.



A (Before normalization) b (After normalization)
Figure 9: Normalization and Time Varying Gain

After normalizing the dataset, a median filter is applied to separate the wavefield based on their polarities (positive or negative polarities). The upgoing wavefield are separated from the downgoing wavefield and the residual noise. Figure 10 shows the downgoing wavefield and the residual noise, while Figure 11, the upgoing wavefield and residual noise separated.

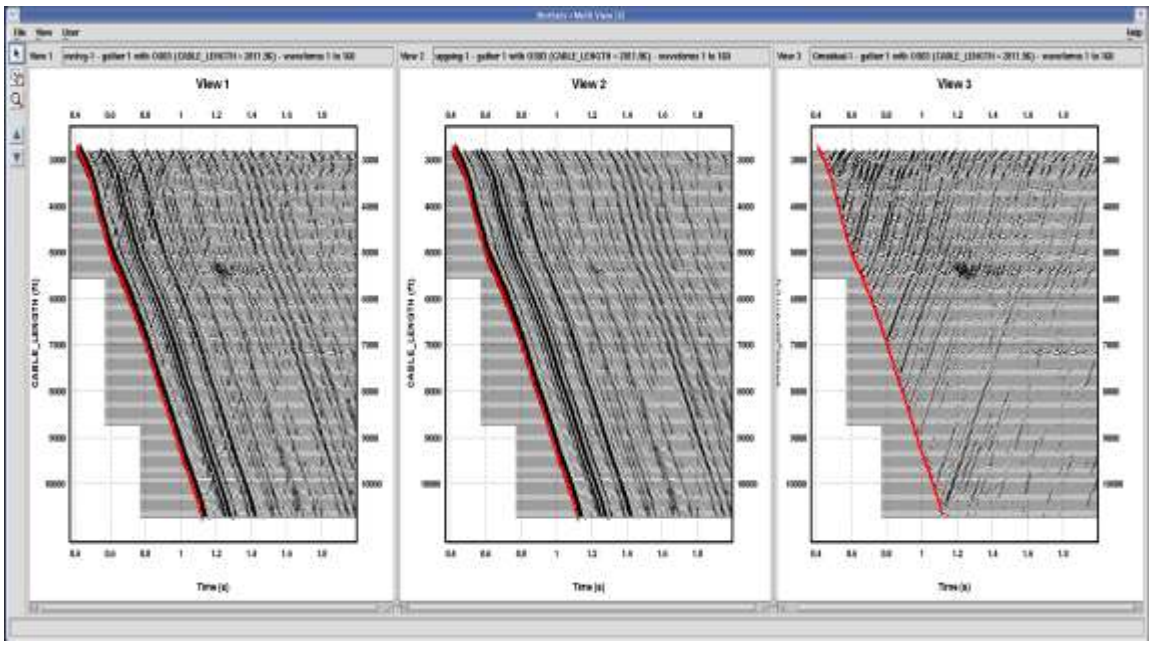


Figure 10: Downgoing Wavefield Separation

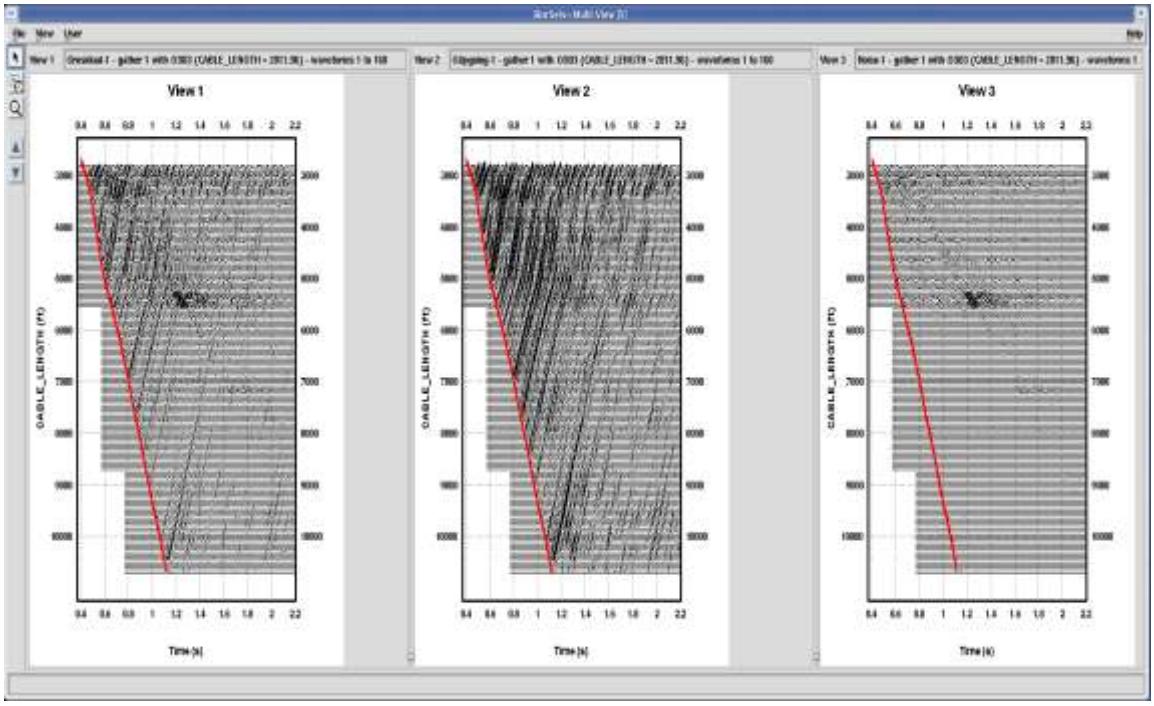


Figure 11: Upgoing Wavefield Separation

Separating the wavefield into its various groups gives an idea of their different travel times and the Deconvolution operator needed. A Deconvolution operator is extracted from the downgoing wavefield (Figure 12) and this is applied to the upgoing wavefield. Applying the Deconvolution operator to the upgoing wavefields helps to attenuate multiple events and generates upgoing wave shaped primary events in two way time (Figure 13).

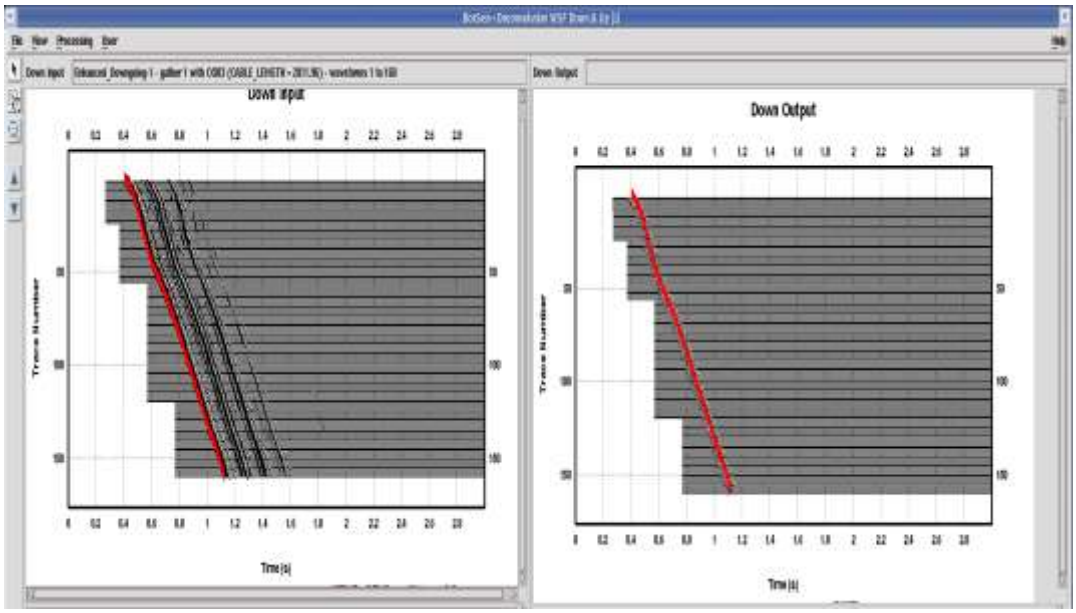


Figure 12: Deconvolved Downgoing Wavefield

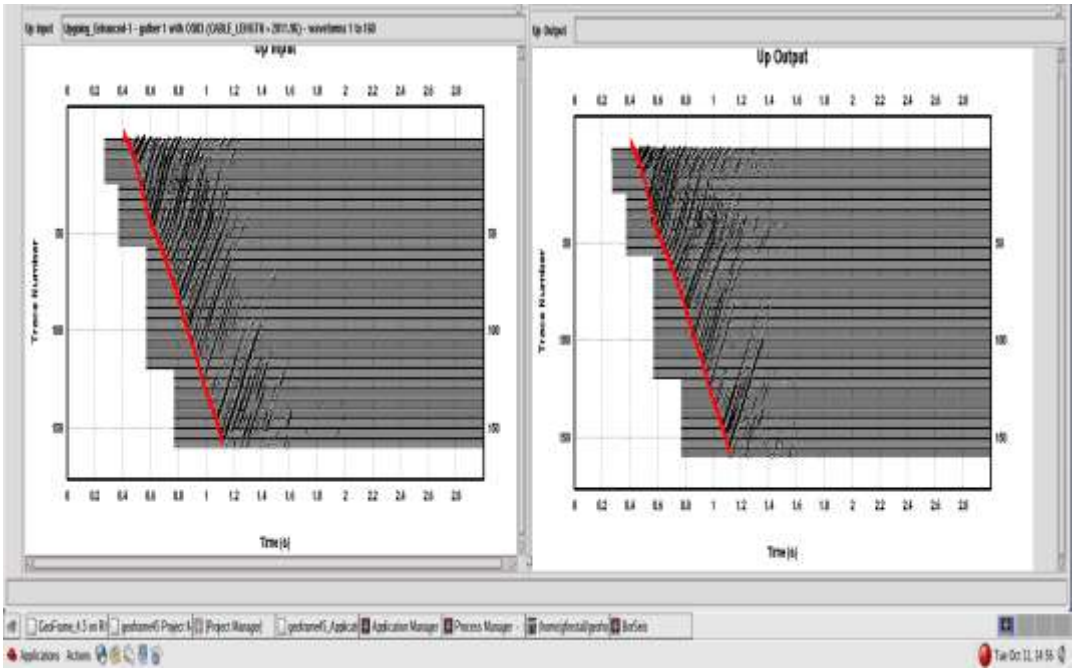


Figure 13: Deconvolved Upgoing Wavefield

The obtained section (display) is now compared directly with the display of surface seismic, it is observed that short order multiples generated in layers transverse by the VSP survey can easily be identified on both wavefields. Also, higher frequencies are enhanced on the VSP for better bed resolution while time to reflecting events beneath the bit can easily be determined from the output display.A corridor stack from the ZVSP dataset (Figure 14) is plotted in two-way time using SEG normal polarity. Try comparing minimum and zero phases, normal and reverse polarities corridor stacks.

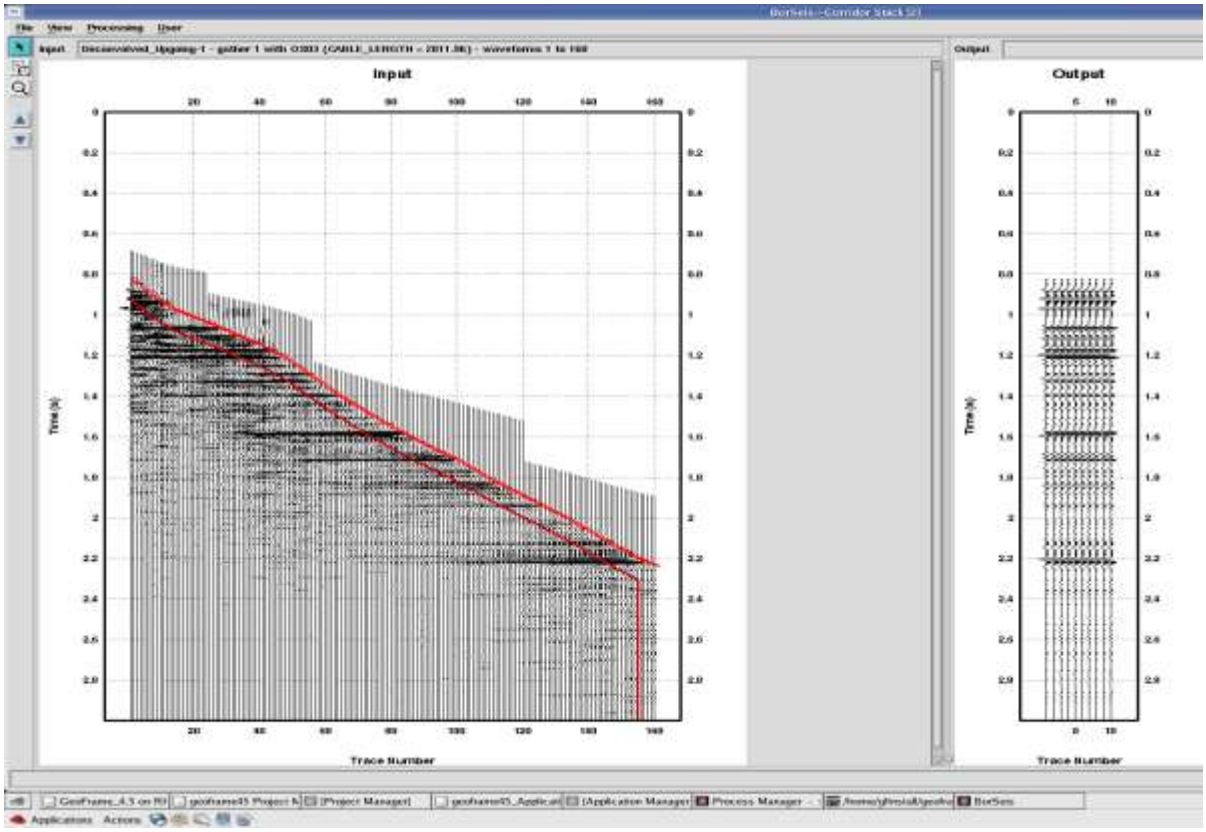


Figure 14: Corridor Stack of ZVSP dataset

Thecorridor stack of ZVSP data is used to tie surface seismic data (section) of the area. From the seismic match or correlation of the ZVSP data section and the surface seismic data, reflections appearing on the surface seismic section which do not appear or seen on the ZVSP section are regarded as multiples reflections (Figure 15).

7. Discussion

The comparison show clearly that ZVSP can easily identify multiples in the seismic section as shown in Figure 15, traces in the seismic section mark **R,** are the true reflections identified while traces marked **m,** are the multiples identified in the seismic data. Although in some cases discrepancies between the two sections can cause a great deal of concern, the most common discrepancy are often seen as bulk time shift. Though small, this can be significant for anyone trying to do time to depth conversions. The ZVSP Corridor stack is matched with the Surface Seismic section, the results shows true primary reflections (identified) at 1.20ms, 1.40ms, 1.92msand 2.19ms, while multiples reflections are identifiedat 1.32ms, 1.59ms, 1.71ms, 1.80ms and 1.82ms respectively which are not seen on the ZVSP Corridor stack.

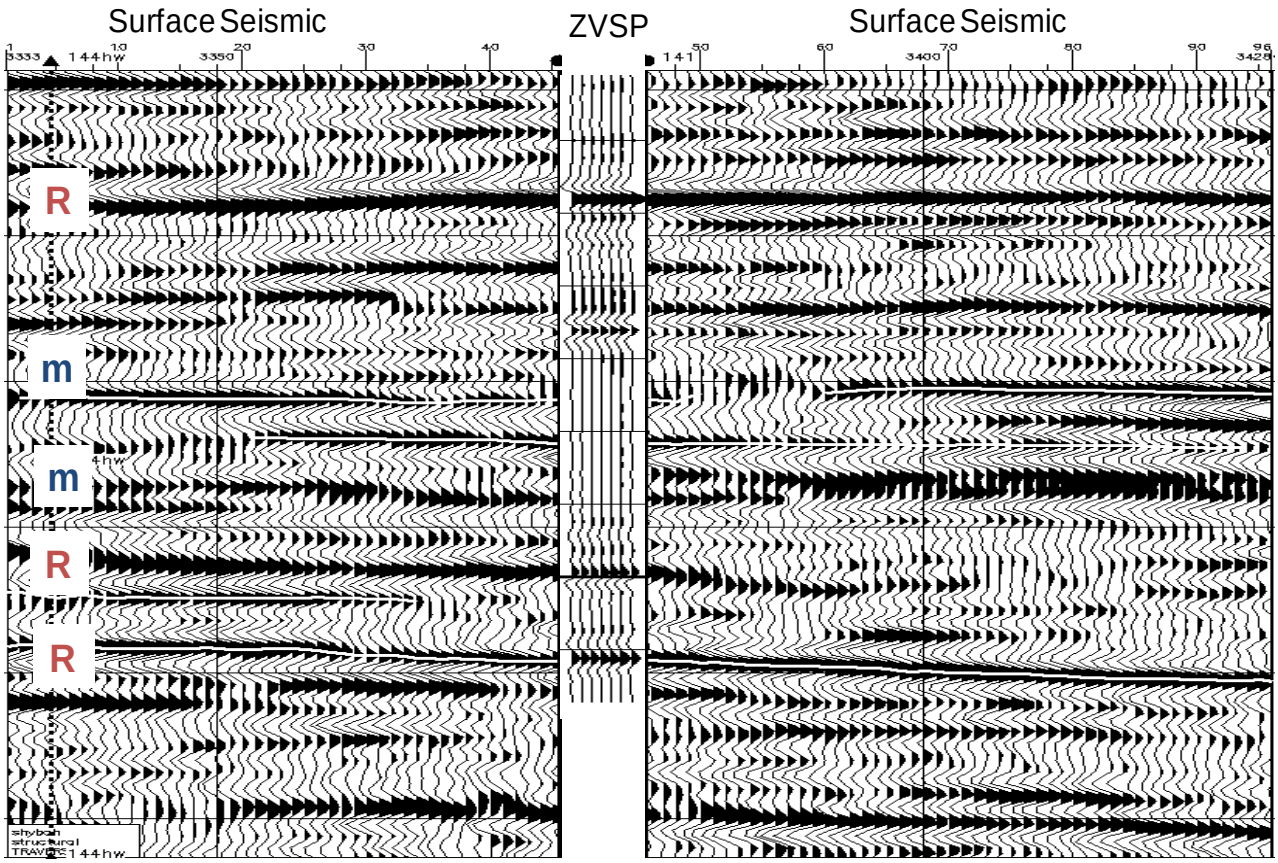


Figure 15: A Match of Corridor Stack from VSP and Surface Seismic Data

8. Conclusion

The study has investigated multiples reflection identification on surface seismic data using Zero-Offset Vertical Seismic Profile (ZVSP) technique. The ZVSP dataset acquired from a drilled well where the surface seismic was acquires is processed to generate a ZVSP Corridor Stack. The Corridor stack is matched with the Surface Seismic section and true Primary reflections are identified at 1.20ms, 1.40ms, 1.92ms and 2.19ms respectively, while multiples reflections are seen at 1.32ms, 1.59ms, 1.71ms, 1.80ms and 1.82ms respectively are identified as reflections on the surface seismic but are not seen on the ZVSP Corridor stack.

9. Recommendation

Natural reserves and Sustainable development are the drives which make people utilize recent technology to search for subsurface features. These subsurface features stores Hydrocarbon.It is recommended that the ZVSP though expensive but more accurate be run alongside other well logs when evaluating subsurface formation properties for hydrocarbon exploration.

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