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Simple Processing Sequence to VSP-Seismic data matching in Sindbad oil field, south of Iraq

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Abstract—*The purpose of this research is to get the batter matching between VSP and seismic data after preforming a simple processing sequence on Zero-offset VSP survey. Sindbad oil field is chosen to study goals and it's containing only one well with VSP survey (Snd2) that covering depth from Zubair to Sulaiy Formations and 2D seismic lines of Basrah Survey (2Br & 5Br). In order to get the mentioned information from VSP the main steps of processing sequence (Velocity calculation, Amplitude recovery, wave separation, deconvolution and stacking) has been used to measure (RMS and AVG) velocity and make the corridor stack image of VSP p-waves in Promax landmark software. The principle of VSP and seismic data matching is depended on phase and time shift. The matching filter in Omega software depends on frequency content, phase, locations of the two data and amplitude difference which gives us batter correlation for matching. The final test of these filters shows good matching between Snd-2 VSP and 2Br2 Seismic line.*

Keywords— Vertical Seismic Profile, Zero-offset VSP survey, Processing of ZVSP, VSP to Seismic matching, Lower Cretaceous age- Sindbad oil field.

I. INTRODUCTION

Seismic surveys can be divided into two main categories that are: surface seismic surveys and borehole seismic surveys [1]. Seismic observations in deep boreholes involve some specific requirements of technical and theoretical types, while in surface observations; the sensitivity is usually restricted by the seismic noise level in the region of the recording point [2]. Acquisition, processing and interpretation of VSP data are essential in hydrocarbon exploration because of the important application of VSP in hydrocarbon exploration which is supporting and clarifying the interpretations of the subsurface geology made from surface-recorded seismic data [3].The objectives of most VSPs done today, is the refinements which have come with processing of that data. The most important development has been used of velocity filters to separate the upgoing and downgoing waves, thereby allowing studies of their internal relationships and their relationships to data recorded at the surface [4]. The objective of the current paper is to perform a processing sequence for the better matching of VSP data over 2D seismic line, through utilizing Promax and Omega programs.

II. DATA SOURCE AND LOCATION OF THE AREA

Sindbad oil field is located in Basra city-southeast of Iraq, adjacent to Iraq- Iran border and approximately 16km southwest to center of Basra city as shown in Figure (1). The area has two wells (snd1, snd2). Only (snd2) has VSP data and it will be correlated with log data to seismic line named (2br2). The (snd2) well is drilled to Sulaiy Formation (Lower Cretaceous) and one type of VSP data (Zero-offset) is recorded from 3090m to end depth of the well (4376m).

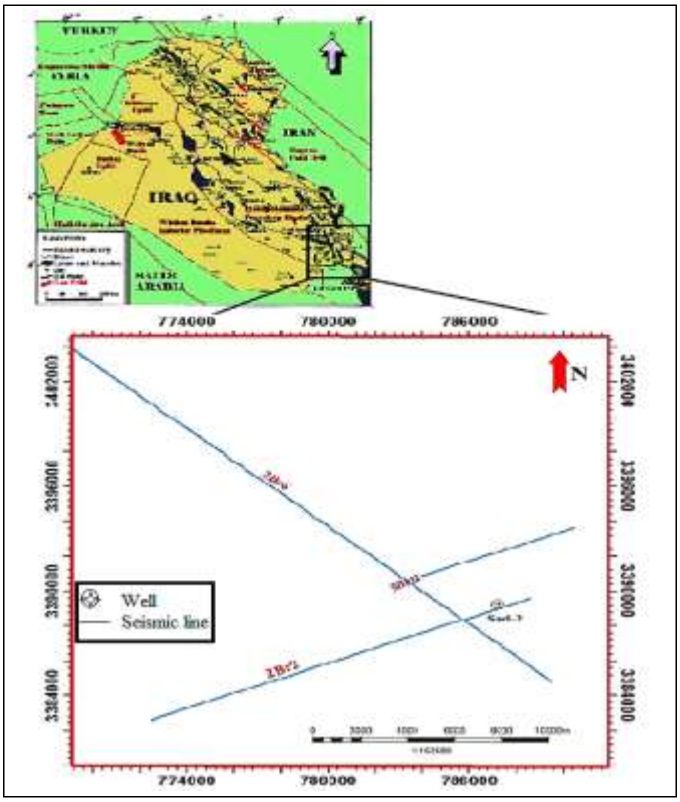

Fig.1: Location map of study area and data of the research.

Sindbad exploration vertical well (2) which drilled by the Iraqi national oil company are reached to a depth 4376m that cover all the thickness of interesting Formation (Yamama) (Lower Cretaceous) in this study. The drilling process is end at September 2013 and gives a remarkable note about oil shows in Zubair and Yamama Formation (Lower Cretaceous).

Vertical seismic profile is executed to get detailed information about the velocity and seismic response in the field. The recording parameter and field tools used in the survey is shown in (Table 1).

Table.1: Shows the field parameter of Sindbad (VSP) survey.

Design, recording and source parameters of VSP Snd2 survey	
Specifications	**Parameters**
Survey type	Zero offset
No. of Receiver per shot	6
Receiver interval depth	10m
No. of record for each depth	3
Receiver type	3-component hydrophone
Kelly bushing elevation	11.7m
Surface elevation	2.6m
Source type	Vibrator
Offset between well and source	70m
Natural frequency record	6-90 Hz
Sample rate	1msec
Fluid density	1.55
Type of hole	Cased hole
Minimum recorded depth	3085m
Maximum recorded depth	4345m
Sweep length	12sec
Taper length	300-500msec
Total recorded time	5000msec

III. METHODOLOGY

The (VSP) surveys have some special advantages over surface seismic reflection surveys. One key advantage is the ability to separate the downgoing (direct) and upgoing (reflected) wavefields that enable the calculation of the true reflection amplitude or seismic impedance [5].

For the processing, the ProMax (VSP) Data Processing Software which relates to Halliburton Company has been used. The geometry of the survey demands the use of the Zero-Offset (VSP) processing flow of the particular software. The flow diagram in Figure (2) shows analytically the processing steps.

3.1 Data load and Editing

As described in the acquisition section, the receivers in the borehole contain two horizontal components and one vertical component. The two horizontal components are named X and Y while the vertical component is named the Z component [6].

The X and Y components rotate randomly in the borehole since there is no control over their direction. These component trace loaded in the Promax software with Segy format where each level or depth have the X, Y and Z trace combined with one or two auxiliary traces.

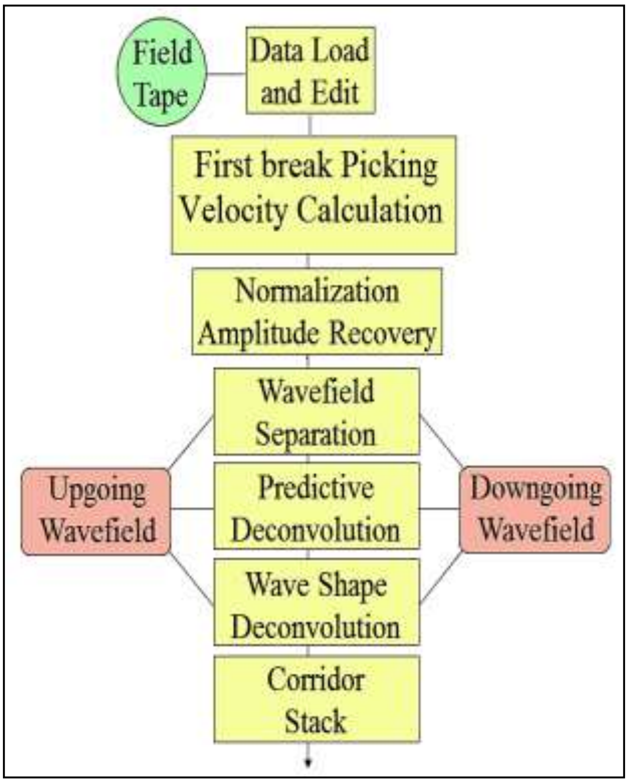

Fig.2: Illustrate the processing sequence of zero-offset (VSP) data Snd-2 well.

Each of the raw data wave-field has a characteristic Trace-ID Code or Trace type in the header of the Segy file. Specifically, the Raw X file has a Trace-ID Code equal to 14, the Raw Y file equal to 13 and the Vertical file equal to 12. This is the way that software can recognize the separation among the three components in the raw data and so the division of the Trace-ID Code is a fundamental aspect as shows in Figure (3). After killing or eliminate the bad trace data will be ready for the separation of its component. The dataset will be sorted on the type number of trace or Field files number with Trace ID for separation the three components Figure (4).

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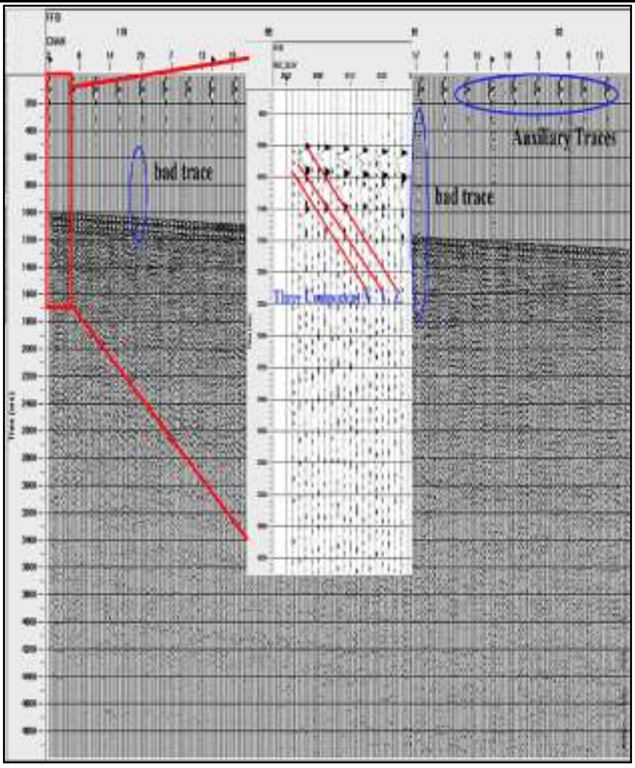

Fig. 3: Illustrate the raw VSP data with three components of Snd-2 well.

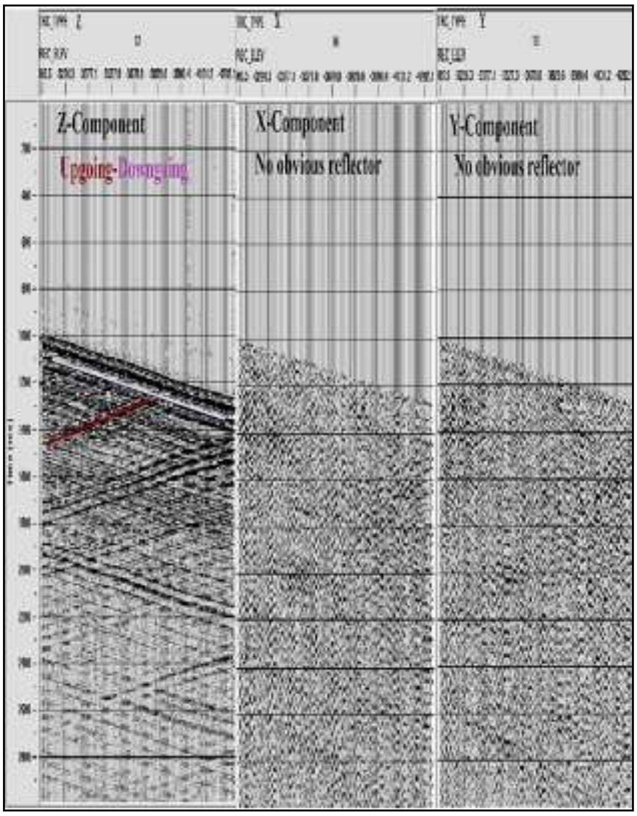

Fig.4: Shows the separated three components Z, X & Y data of Snd-2 well.

The Z component show mainly downgoing P wave and the signature is consistent with no character variation with increasing depth, except the reflector of depth 3980-4020m which have a distinct amplitude. The X and Y components recorded weaker first P arrivals and the signature has no character variation also the phase of the first P arrivals doesn't show any appearance with continues depth of well. In this Study X and Y component didn't show any signal so that, no process will be operate on them.

3.2 First break pick and Velocity

If a seismic receiver is positioned at the depth of a known geological interface in the well, then the traveltime, from a seismic pulse emitted at surface to that interface of two geologic layers, can be measured directly [1].

Traveltimes are then used to determine velocity, which is calculated using the time difference at which the seismic pulse arrives at the geophones and the distance between receiver points. In the case of dynamite source, this requires picking the time of the first energy arrival at the geophone. For vibrator data, in which the embedded wavelet after cross correlation is assumed to be zero phase, it is necessary to pick the peak of that wavelet as the first arrival as shows in Figure (5).

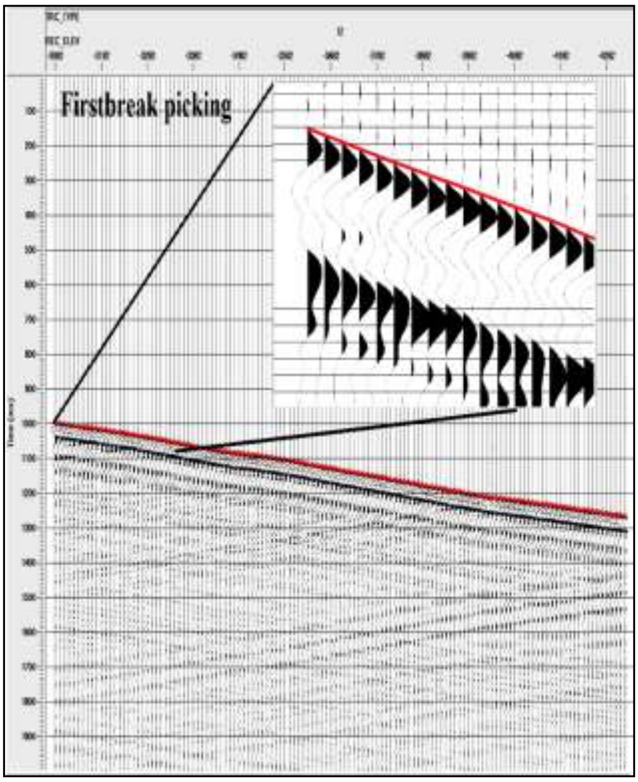

Fig.5: First break picking (red line) on vertical component of VSP data on the first peak amplitude, because of vibrator source.

A fundamental use of VSP surveys is to determine the variation of seismic velocity with the depth [7]. Thus, the interval velocities, the average velocities and the root

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mean-square (RMS) velocities for the P waves were calculated. The average velocities, Vavg, were calculated directly by dividing the true vertical depths by the picked first-break times at each depth level with consider of 70m offset Figure (6).

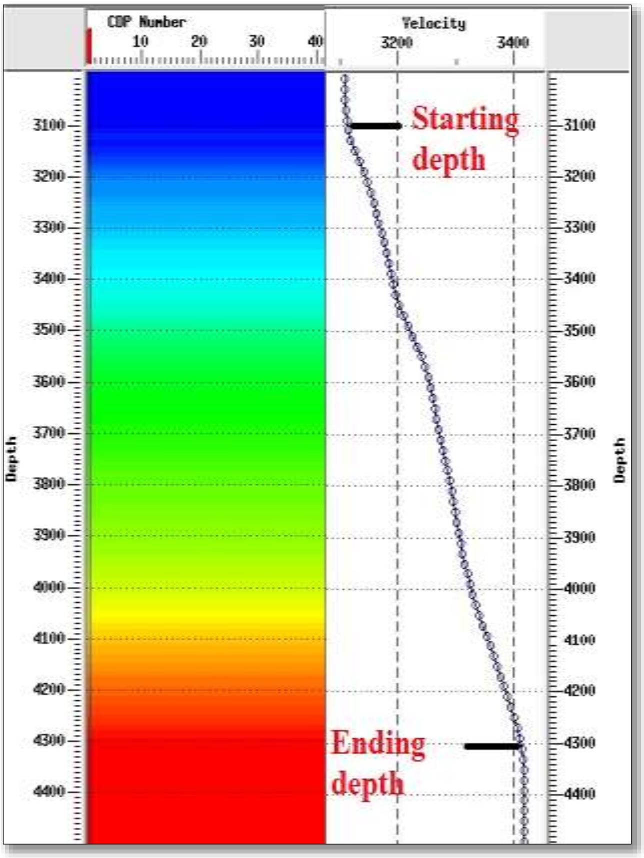

Fig.6: Shows average velocity curve and spectrum for the recorded depth of VSP Snd-2 well.

3.3 True Amplitude Recovery (TAR)

This step is required by signal processing theory for the later steps to work correctly. A point acoustic source generates a spherical expanding wavefront with the energy decaying inversely as the square of the distance travelled.

$$E \propto 1/(d)^2$$

Therefore the signal decays both as a function of recording depth down the borehole and with time along any trace [8], as in the Figure (7). A further complication concerning the signal amplitude is the variability in coupling between tool and formation. In addition to this, the source energy level itself is not necessarily constant.

All of these signal strength factors, if unattended to, would create serious problems in the subsequent processing of the data, especially the velocity filtering. Therefore, it is required that the energy in the direct downgoing waves should be equal at whatever level they are observed. This is simply done by normalizing each trace with an individual gain.

The test of VSP True Amplitude Recovery processes is an appropriate dB/Sec correction combined with spherical divergence. The spherical divergence correction uses the velocity function that was generated by converting the average velocity function into an RMS function. The produce of a comparison of 10,8,6,4,2 and 0 dB/Sec test value combined with 1/distance spherical divergence correction, gives many result of TAR and the best Correction for Snd-2 well was 4 dB/Sec Figure (8).

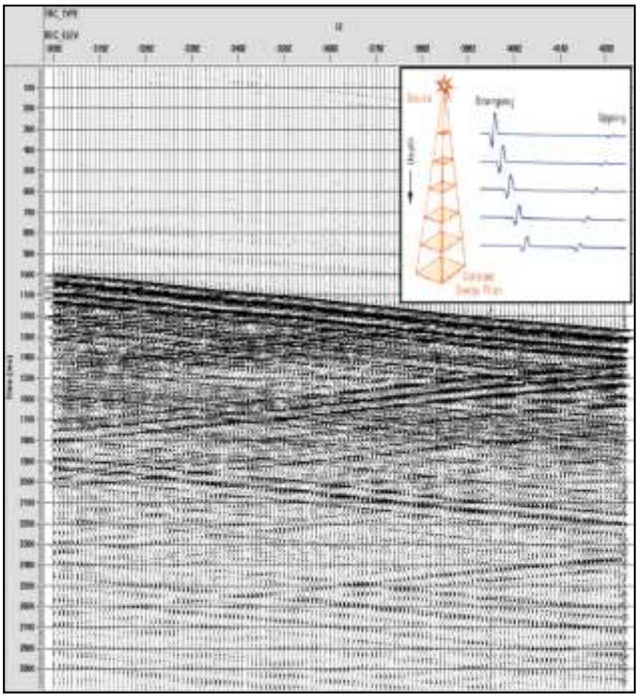

Fig.7: Shows the concept of amplitude decay with time and depth in Snd-2 well vertical traces of VSP data.

3.4 Wavefield Separation

Velocity filter used for Wavefield separation of Sindbad well data to separate upgoing and downgoing waves. The raw Z component is considered the input to the f-k analysis domain. This raw Z component is then flattened to a 100 ms datum by subtracting the first break times from each trace. The flattened raw Z component is shown in Figure (9A).

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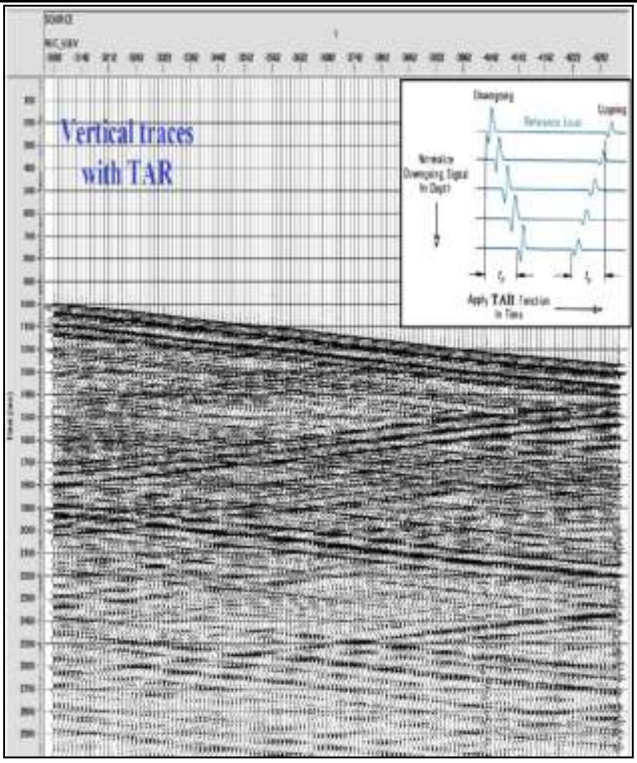

Fig.8: Vertical traces of VSP data Snd-2 after True amplitude recovery process.

The f-k filters are applied to the entire dataset (Z-component data). Separating waves by velocity pass and reject filters is based on the following concept: waves which desired are signal and everything else is noise [9], [10] & [11]. So signal is passed by the time-correcting it for moveout and applying velocity pass filters that are centered about zero moveout.

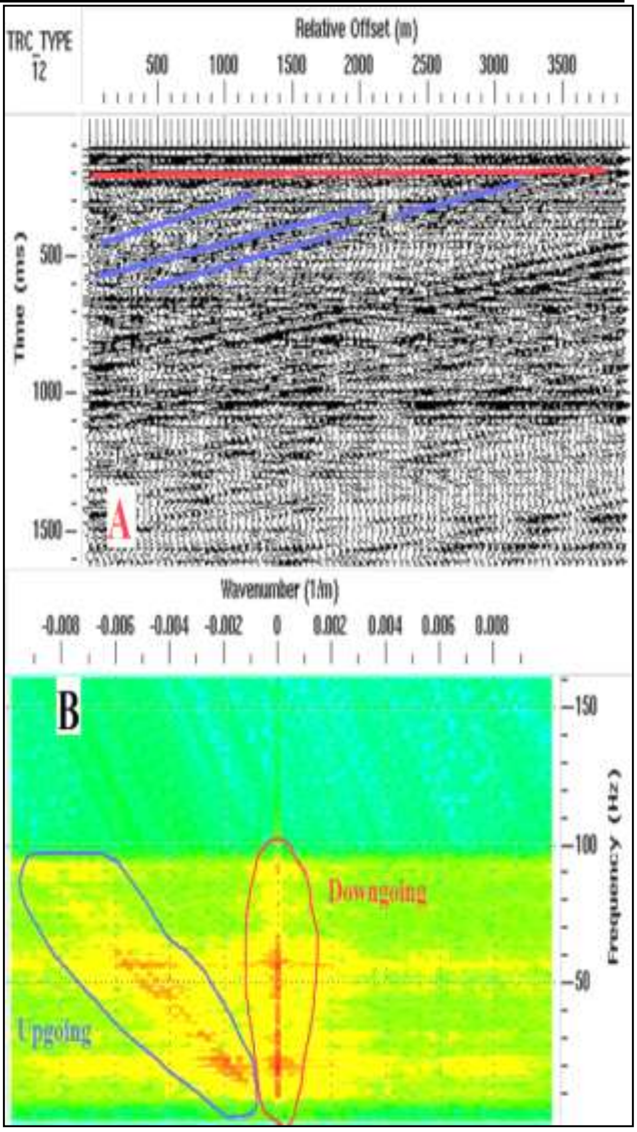

Fig.9: (A) Flatten of Z component VSP data after TAR. (B) f-k domain analysis to select windows for separate up and downgoing waves.

The coherent noise is rejected by time-correcting it for moveout and applying velocity reject filters that are centered about zero moveout This principle is used to pass signal (upgoing P-waves) and reject noise (downgoing P waves and tube waves) Figure (9B), so the filter will apply two times once for passing the red circle and reject all velocities while the other is passing the blue circle and also rejecting all the surrounding velocities. After several tests of selecting pass and reject window for f-k filter, here in Figure (10) the best separation of VSP data of up and downgoing waves.

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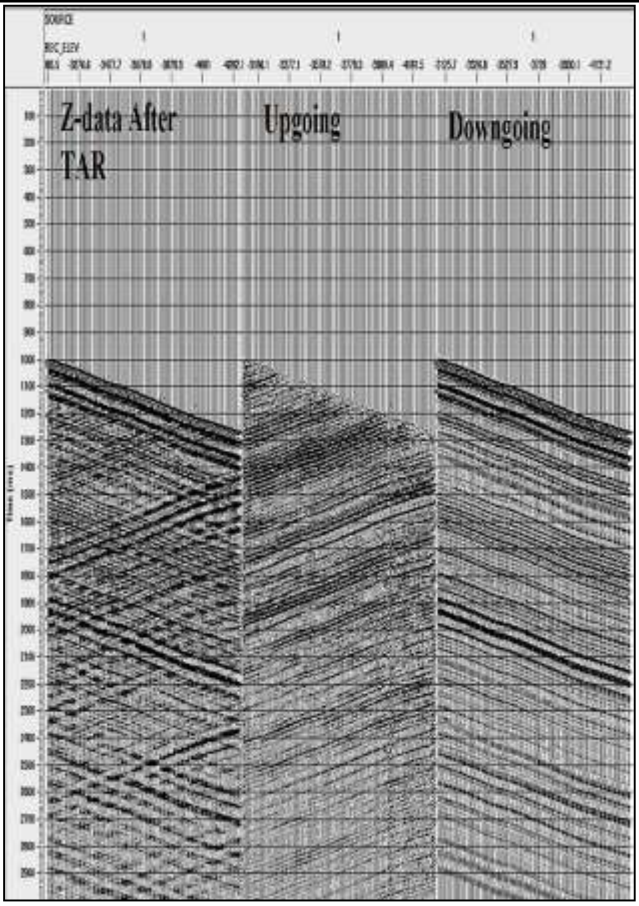

Fig.10: Shows the Input and Output of the Wavefield separation processes.

3.5 VSP Deconvolution

Deconvolution process will be a combination of two types (predictive and Waveshape) by using the inverse filter. The input wavelet is commonly extracted from the separated downgoing wave energy. A filter is designed to compress this energy into a zero-phase wavelet centered on the first arrival time of primary waves [12]. This filter is then applied to the upgoing data to remove the source signature from the reflection energy and output a zero phase wavelet at the actual time of the reflection generation interface also without multiple interfaces.

Some design gate determination is commonly performed to isolate the wavelet from which the inverse filter is designed. This design gate generally starts at zero time, covering the first arrivals and progresses in time for hundred milliseconds. The maximum time gate typically comes immediately after the last consistent reverberation or the main obvious multiple of the first arrival. The best design gate in Snd-2 VSP data on downgoing waves was (100-500ms) after shift the first break by (100ms) so the flatten waves will be full with energy and has no cycle of first break multiple. The zero phase of this wave, on 109ms so that the operator of the inverse filter will be at a time representing zero time on 109msec and the operator length best tested on data was1000ms. The applied of deconvolution process on downgoing made it free of multiple reflectors and more resolution as in Figure (11).

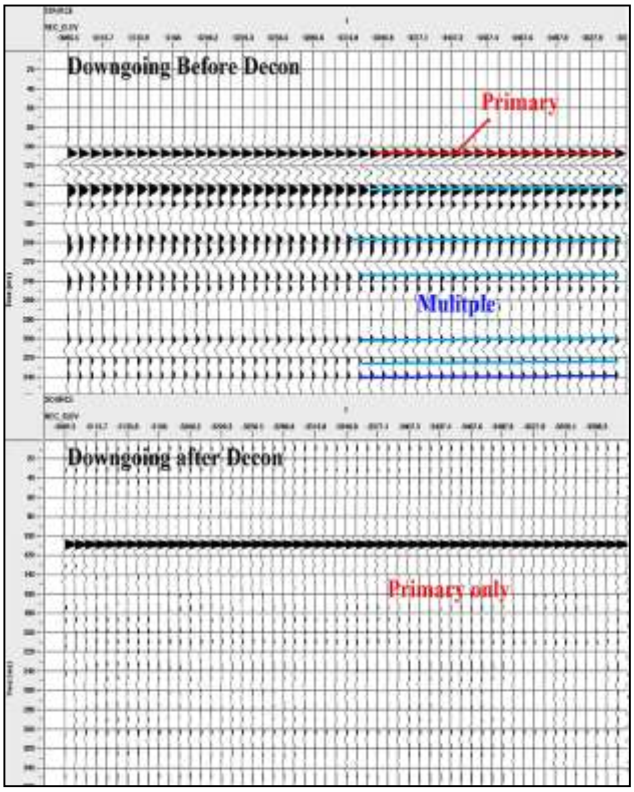

Fig.11: Illustrate the downgoing wave before and after deconvolution process.

After the success of deconvolution process or inverse filter operator on the downgoing waves, same parameter of this filter should apply on upgoing waves, that's what executed on the Sindbad VSP data and shows a good result with amplitude spectrum as in Figure (12) which shows the enhancement of amplitude with high frequency content.

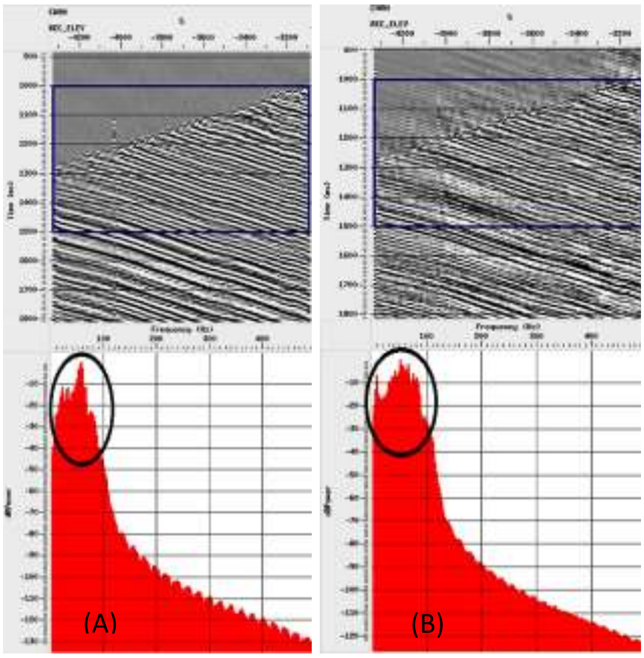

Fig.12: (A) Upgoing waves with amplitude spectrum before deconvolution (B) Same waves after deconvolution.

3.6 Corridor Stack

After deconvolution, the VSP wavefield is multiple free, of a known wavelet shape and contains only reflected energy. It can now be compared with the surface seismic of the same wavelet shape. A more convenient way of doing this is be using a corridor stack [13], As its name implies, we stack data contained within a specific window of the upcoming VSP wavefield and display the data as a number of vertical traces. This is more convenient to lie alongside the surface seismic data than the wavefield itself.

The data closest to the geophone is of the best quality and the most reliable; because we know the position of the geophone and the location of the well on the surface seismic we can put the corridor stack in the right place; the corridor stack will therefore contain these multiples provided that the window is small enough.

Therefore, by looking at only a window of data, say 100 ms Figure (13A), after the direct arrival, a dataset can be extracted that conforms closely to the assumptions used in the processing.

As noted earlier, upgoing multiples never extend to the direct-arrival curve; therefore, the window automatically excludes any multiples that might have been inadequately collapsed by deconvolution. Typically, this data window is then stacked to form a single trace, which is repeated for clarity the reflectors Figure (13B). This trace, known as a corridor stack, can be thought of as the measured, multiple-free, zero-phase, normal-incidence seismic response at the well. It is the best normal-incidence response that can be obtained at that point.

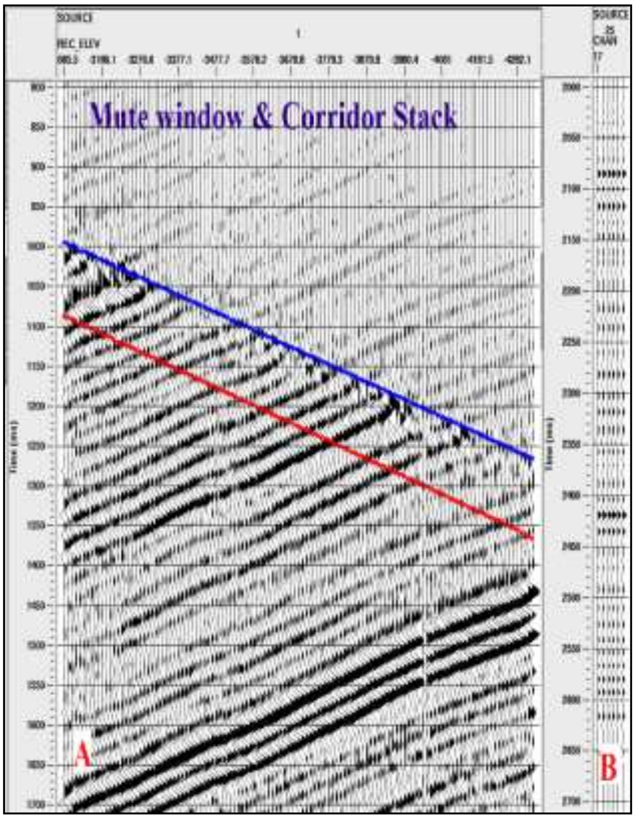

Fig.13: The mute window and corridor stack of VSP data.

IV. CORRIDOR STACK MATCH TO REFLECTION SEISMIC DATA

If the surface seismic wavelet is, indeed, a simple phase rotation away from zero-phase, the cross-correlation function under the optimal phase rotation becomes symmetrically autocorrelated (Pereira and Jones, 2010). Therefore, from a qualitative point of view, the degree of asymmetry in the cross-correlation under the "best" rotation is an indication of the amount of frequency dependence of the wavelet phase.

In Sindbad oil field seismic lines were recorded and processed to a bandwidth of 10-45 Hz while the zero-offset VSP data recorded and final process to keep the best bandwidth of (6-85)Hz, as mention before the phase match largely frequency dependent and geologically on distance of correlated data. VSP data was not that far from 2Br2 seismic line (200m) so the phase difference shows (25) degree and the simple bandpass filter to minimaize the frequency of VSP to surface seismic gives the good match as shows in Figure (14).

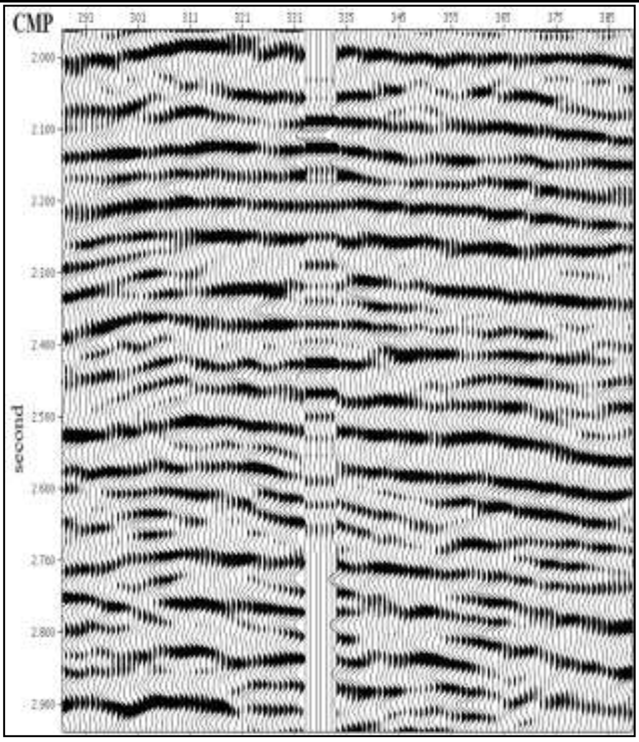

Fig.14: Shows the best match of VSP data with 2Br2 seismic 2D line.

V. CONCLUSION AND RECOMMENDATION

Based on the results of vertical seismic profile survey processing, for (Snd-2 well) and the matching with surface seismic data (2Br), the study comes with the following conclusions:

The processing of VSP surveys are very sensitive to filtering where any filters can remove an important event or reflector. In case of the Zero offset VSP of Snd-2 well, there is very good signal to noise ratio so that a simple processing sequence comes with good result without filtering (only the principle step to get the corridor stack). The multiple reflectors of the area could be remove successfully with deconvolution in VSP survey while in seismic section its hardly attenuate by using a special condition and multi domain transform filters (Hilbert, t-p and f-k), also VSP corridor stack can be used to define the multiple of the field.

According to the study result and for the future work it is recommended to do the following procedures: The field work of VSP surveys should be carefully for S-wave recording in the horizontal component borehole receiver and the S-wave where not recorded because of azimuth of source or the fold of recording levels. The spacing between these receivers in future work less than 6 m will gives better results. It is recommended to record more than one type of VSP (zero-offset) in field which gives more benefit in seismic imaging and solving seismic problems such as subsurface salt dome and highly fracture targets. The recording of VSP must be over whole depth of well in order to calculate the best attenuation factor (Q) of the area.The recording over all well depth also provide a direct way for delineate the multiple reflectors. The processing of VSP should be before the processing of seismic surveys in order to get the information of velocity profile which in turn simplify the velocity analysis and indicate the reverse zones of velocity.

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