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Free Surface Downgoing VSP Multiple Imaging

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Abstract. The common usage of a vertical seismic profile is to capture the reflection wavefield (upgoing wavefield) so that it can be used for further well tie or other interpretations. Borehole Seismic (VSP) receivers capture the reflection from below the well trajectory, traditionally no seismic image information above trajectory. The non-traditional way of processing the VSP multiple can be used to expand the imaging above the well trajectory. This paper presents the case study of using VSP downgoing multiples for further non-traditional imaging applications. In general, VSP processing, upgoing and downgoing arrivals are separated during processing. The up-going wavefield is used for subsurface illumination, whereas the downgoing wavefield and multiples are normally excluded from the processing. In a situation where the downgoing wavefield passes the reflectors several times (multiple), the downgoing wavefield carries reflection information. Its benefit is that it can be used for seismic tie up to seabed, and possibility for shallow hazards identifications. One of the concepts of downgoing imaging is widely known as mirror-imaging technique. This paper presents a case study from deep water offshore Vietnam. The case study is presented to demonstrate the robustness of the technique, and the limitations encountered during its processing.

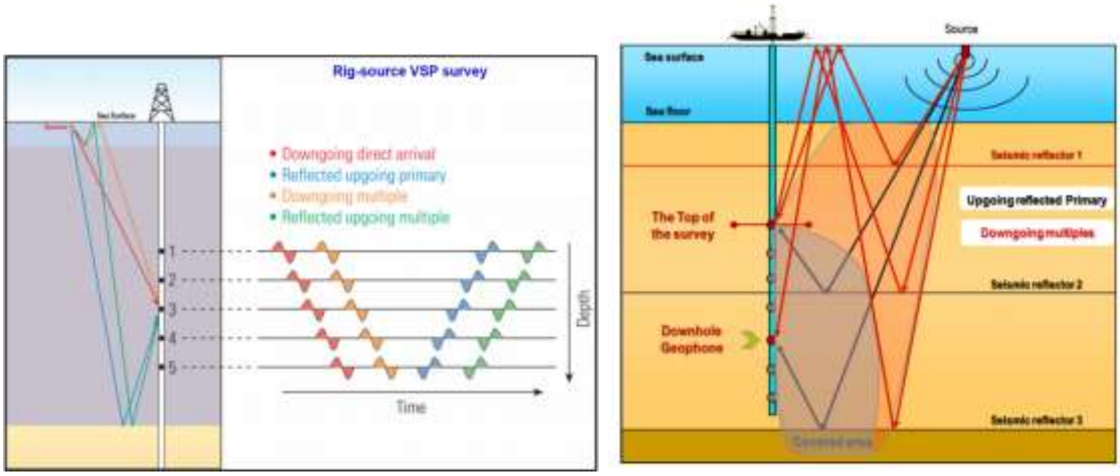
1. Introduction

Borehole seismic or vertical seismic profiling (VSP) plays an important role in oil and gas exploration. Throughout the years, the technology has developed beyond providing time-depth relations into providing high-resolution images in the reservoirs. The traditional subsurface imaging from VSP data consists of extracting the up-going Wavefield (reflection Wavefield) from below the well trajectory.

With the receiver in a borehole and its source on the surface, borehole seismic data will record both downgoing and up going waves, along with their multiples. In normal processing, multiples have been considered unwanted arrivals, and several processing methods are normally proposed to eliminate multiples. For certain environments (such as deep-water) a free surface multiple can be generated and differentiated for imaging, since the free surface multiple will have larger time separation with direct arrival.

This free surface multiple travels a longer path in the subsurface and has the possibility to illuminate certain areas better than the primary source. Downgoing VSP multiples provide a broader coverage area and enhanced illumination over the use of primary arrivals only [1]. Reflectors above receivers can be imaged with downgoing multiples [2].

The wave recorded in the borehole seismic configuration can be schemed in figure 1a below, where downgoing and upgoing can be differentiated based on their apparent velocity. The multiple is indicated by their time separation with the primary. Figure 1b shows the schematic of the possible free surface multiple and their ability to illuminate the reflection above the trajectory.



(a) (b)

Figure 1. (a) Schematic of basic wave recorded in borehole seismic – upgoing and downgoing wavefield, (b) illustration of free surface multiple for borehole seismic configuration. [3]

2. Methodology

2.1. VSP Mirror Imaging

As depicted in the schematic above, multiple is basically repetition of the primary arrival. In certain environments (such as deep water) and relatively noncomplex subsurface layering (i.e. flat layers), the multiple can be repositioned as if it's recorded by virtual receivers created by the free surface mirrors [2]. It has been proposed that lateral subsurface coverage in VSP surveys be extended [4]. In this study, the authors pose a real-life example of a barber shop having mirrors on opposite walls, allowing one to see the reflection repeatedly between two mirrors.

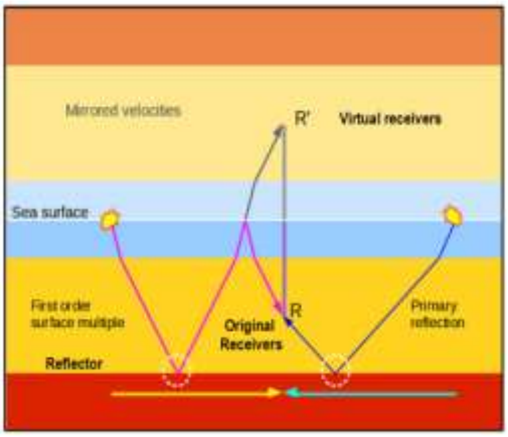


Figure 2. Illustration of VSP mirror imaging, by mirroring the velocity model and projecting the receiver for the free-surface multiple [2].

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2.2. VSP Processing Example (Traditional and Multiple Imaging)

The example data below shows the VSP record from deep water off the coast of Vietnam [5]. From this data, the sea surface multiple is comprised of a wave train of reflections. It started with the sea floor reflection and continued to the reflection below the seafloor. In deep water, the wave train is easily distinguishable, as the seafloor has low acoustic impedance in contrast with the overlying water.

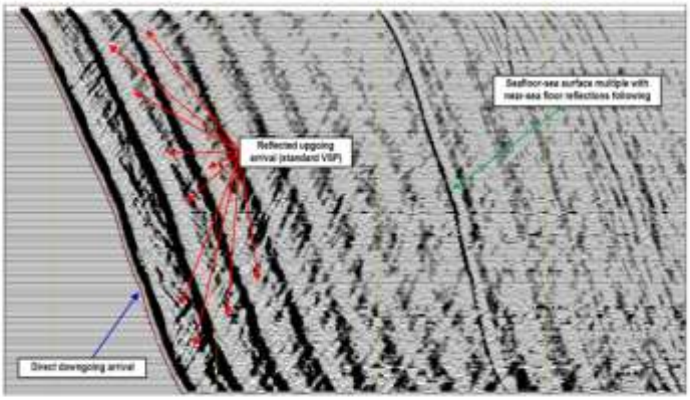

Figure 3. A vertical component of VSP data (offshore deepwater Vietnam), where the free surface multiple has a large time separation with the direct downgoing arrival.

The objective of this VSP acquisition is a seismic tie for a deviated well. Vertical incidence configuration was proposed to achieve the objective using the Schlumberger Versatile Seismic Imager (VSI*) as the downhole receiver. A vertical incidence survey will record vertical time and vertical reflection in deviated wells (maximum well deviation is 55 deg). Subsurface layering in the area is relatively not complex, and the dip is relatively gentle. These conditions are ideal for downgoing free surface multiple imaging.

For traditional imaging, standard VSP processing was proposed using a median velocity filter to separate the downgoing and upgoing wavefields. Deconvolution operators have been designed on downgoing wavefields and applied to the upgoing wavefield to collapse the multiple. Since this is vertical incidence imaging, the 2D reflection image below the well trajectory can be constructed to give a high resolution VSP image. This image represents the primary reflection from below the trajectory, captured by the VSP receiver within the borehole. This is the traditional way of looking at VSP data.

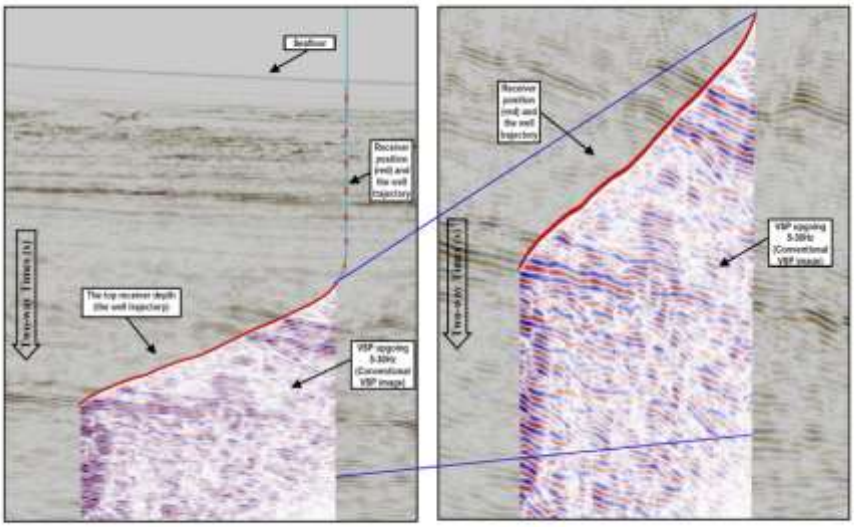

Figure 4. Upgoing VSP image (traditional VSP image) overlaid on surface seismic image; the traditional VSP image only gives correlation below the well trajectory.

To extract the downgoing free surface multiple from VSP, the multiple reflection (identified by a later arrival in the data) was isolated. Waveshaping deconvolution using operators designed from direct downgoing wavefields were also applied to the free surface multiple to get a zero-phase image. To produce an image from these VSP multiples, a velocity model was constructed. These velocity models consist of the mirror image of the actual subsurface. Virtual receivers were placed in the mirrored region, and multiples were simulated using ray trace modeling. The ray trace modeling has been shown with mirror imaging, as the multiple can be used to image reflection above the well trajectory and the traditional VSP imaging can only give the image below well trajectory.

Using the mirrored velocity model, the multiple image can be migrated (VSP-CDP Transform) into a 2D seismic image. This will give a 2D VSP image above well trajectory with reasonably high frequency, which can then be used for seismic calibration up to the seabed.

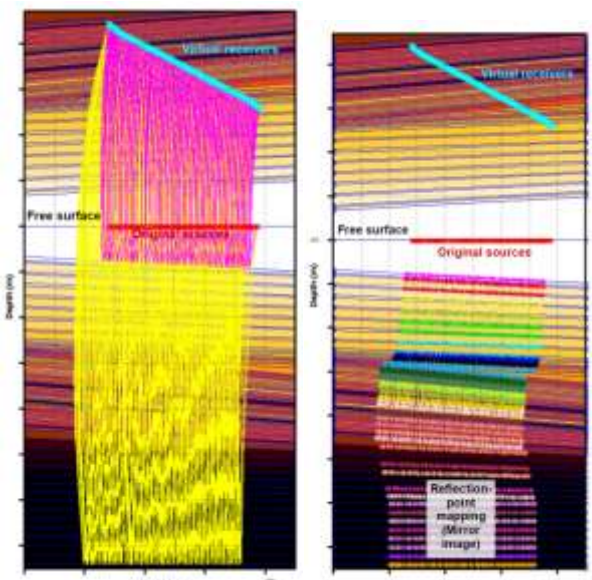

Figure 5. Velocity model for mirror imaging (left), and ray trace modeling has shown the reflection points from mirror image cover the reflection up to seabed.

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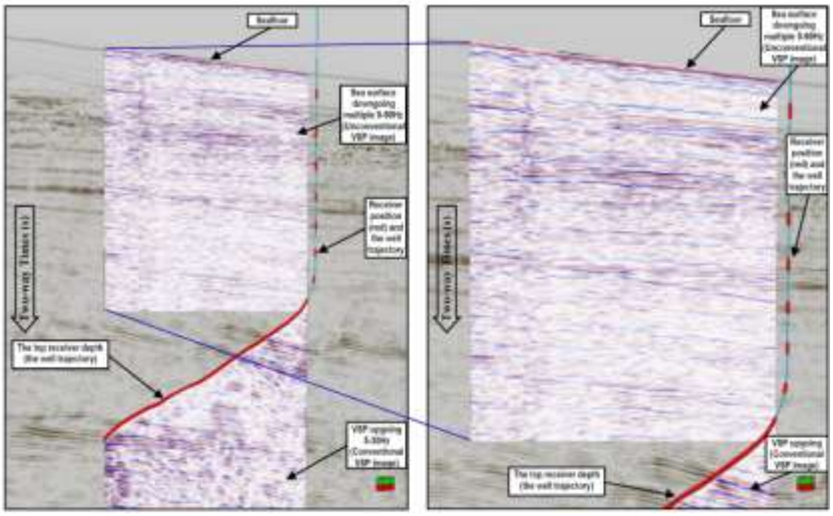

Figure 6. VSP upgoing image and VSP multiple image (left), zoomed in on the multiple image show reasonably good well tie with the surface seismic

3. Discussion

Mirror imaging is an alternative and simpler way to use free-surface multiple reflections from VSP data. By using virtual receivers created by free-surface mirrors, the illuminations can be extended to the surface. This methodology works best for receivers near the seafloor, because the seismic rays have traversed the shortest distance through the formations. If the receivers are placed deeper, the seismic multiple energy will suffer more attenuation due to the fact that the multiple will have traveled more than the primary (multiple rays traversing the formation three times).

The seafloor dip will also have an effect on the multiple image. If the seafloor is dipping, the multiple reflections will also move updip, and the data will require migration with proper velocity model to get the correct image. Since this is based on a mirroring technique, a relatively non-complex subsurface is preferred.

The mirror imaging technique works best in a deep-water environment, where the free surface multiple can be identified easily and have a larger separation from the direct arrival. Several case studies of using the method in shallow water have also been published [6], but the processing need to be carried out with caution when separating the free surface multiple.

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