Subsalt Interferometric Imaging using Walkaway VSP and Offset Free Cable geometry: A Modeling Study

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Summary

This study suggests that the sub-Salt image obtained from a walkaway vertical seismic profiling data could be substantially improved if an offset free cable is added to the acquisition geometry. The proposed acquisition design uses the same acquisition parameters and the same source boat. No additional source effort is needed The current study indicates that the seismic interferometry with pre-stack reverse time migration is a practical tool for simultaneous imaging of Walkaway VSP and Offset Free Cable data to help enhance the sub-Salt image..

We tested our data processing and imaging approach on a finite difference modeling data. The model has steeply dipping beds under the Salt (Figure 2). The subsurface properties of density and velocity are varied horizontally and vertically. The VSP receivers are below the Salt, and a Free Cable is located at 4000 ft away from the borehole. The interferometric imaging approach on the composite data yielded successful imaging of the steeply dipping beds under the Salt. The imaging of the layers from the composite data have more lateral illumination compared to imaging of the VSP only data.

A composite depth image, obtained from the walkaway VSP and offset free cable, is shown in Figure 1. The model overlaid image is provided in Figure 2. The Salt boundaries and the dipping layers below the Salt are clearly imaged as seen.

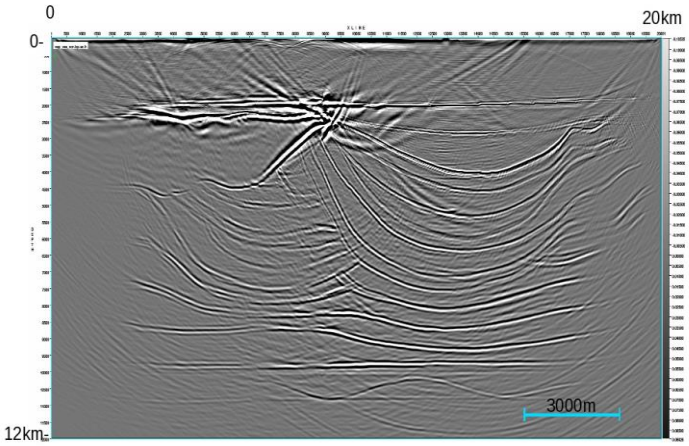

Figure 1. Composite image from the EWVSP (=WVSP+VC)

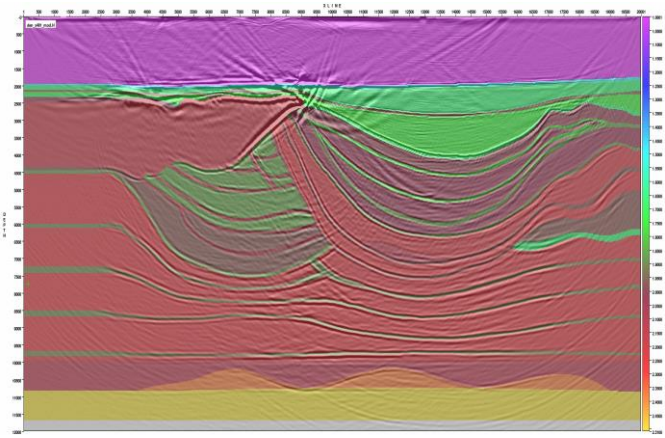

Figure 2. The composite image with the Density model overlaid.

Introduction

Imaging sub-Salt geology is always a challenging problem due to the high velocity effect of the Salt on the seismic rays. Masking and bending of the rays due to the Salt is well known. It is usually difficult to obtain information about the layers under the Salt using the recordings located above the Salt. The seismic recording geometry located above the survey. Salt (e.g. Streamers or the OBS systems) has either limited apertures or expensive to utilize, also since the seismic rays have to go through the Salt twice (one way down – one way up) the seismic data quality degrades.

DOI http://dx.doi.org/10.1190/segam2013-1455.1

Enhanced Walkaway VSP

In order to reduce the effect of the Salt on the seismic rays, the VSP technique is generally recommended and is used, where the receivers are located in or under the Salt so that the seismic rays are recorded before they travel to the surface, only one-way traveling in the Salt. Walkaway VSP (WVSP) or 3D VSP techniques have been applied in many instances, the technique has been proven effective (Hornby et.al, 2006). One known draw back of the WVSP technique however is that it has limited imaging aperture due to the raypath geometry. The effective imaging radius is limited to the surrounding area of the VSP borehole. As the locations of the receivers get closer to the layer of interest (target layer) at depth, the imaging radius shrinks horizontally. Eventually image of the layer coincides to the down-going first arrival wave when the receiver is at the target layer. This imaging radius can be determined by a modeling study.

We have shown here that the layers below the Salt can be imaged using the VSP's primary reflections. The horizontal images of the layers around the VSP borehole could be extended using the *surface multiples* with the help of *interferometry (Yu and Hornby, 2007)*. We demonstrated our approach on a Finite Difference Modeling (FDM) data. The FDM is done at three stages as 1) WVSP survey, 2) Offset Free Cable (OFC) survey, and 3) Surface Seismic survey. Resulting images are shown in the following sections. We combined the WVSP image with the OFC image to create a composite image of the EWVSP. The composite image yielded a superior result compared with either of the input images at a small acquisition effort. Based on this result, the EWVSP surveys could be recommended on every WVSP survey in the *marine environment*. ‘

Finite Difference Modeling (FDM)

In the Finite Difference Modeling (FDM) study, a Velocity model and a Density model were created. The velocity model, V(x,z), had smooth velocity values, the Salt boundary and the water boundary were honored. The density model, D(x,z), contained the subsurface geology. The density was different at each layer but was constant within the layer. The density model was shown in Figure 2. The Velocity model is shown Figure 3. It is recommended to calculate and carefully examine the impedance model before the FDM starts since it gives us clues on how the reflections would be on the FDM data; a weak impedance contrast would generate weak reflections, strong reflections come from high impedance contrasts.

The models have 6.25x6.25m grids on X and Z directions. Total size of 20x12km yielded 3201x1921 grids. The FDM data has fundamental frequency of 20Hz.

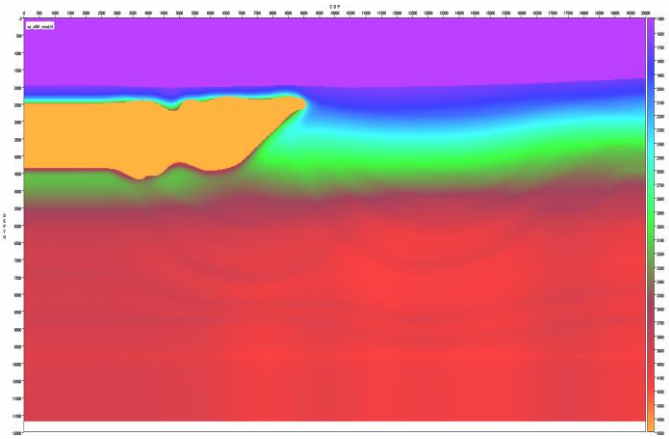

Figure 3. Velocity model used in Walkaway VSP (WVSP) and Offset Free Cable (OFC) Finite Difference Modeling study. Velocity is varied in both X and Z directions

Surface Seismic Modeling and the Problem

The surface seismic modeling was done on a 50m source interval, where the receivers and the shots are at the surface of the water. Several cable lengths were examined, the FDM data sets were migrated using the reverse time migration (RTM) algorithm. The image obtained from a cable length of 6 km is displayed in Figure 4. The area of interest below the Salt (shown with the question mark (?)) is not imaged well. The imaging problem below the Salt is obvious, and is well shown here. It is a known problem with the surface seismic recording. The bottom part of the Salt is imaged weak.

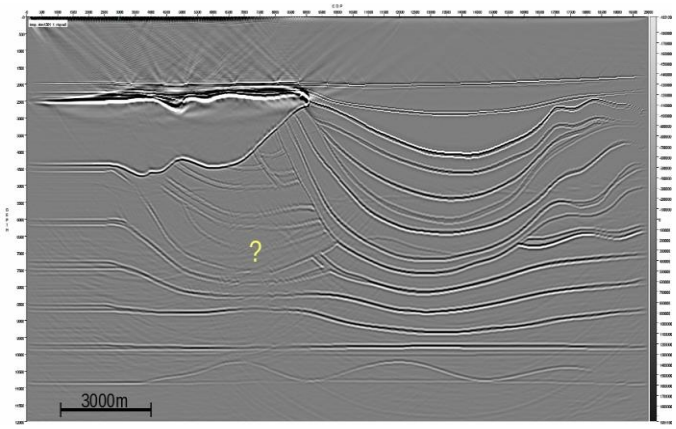

Figure 4. Image from the Reverse time migration (RTM) of finite difference modeling (FDM) data of surface seismic geometry. Area of interest below the Salt is not imaged

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Enhanced Walkaway VSP

The question here is how to illuminate and image the area of interest below the Salt shown with the mark (?).

Walkaway VSP (WVSP), Offset Free Cable (OFC) and Interferometric Imaging of both data sets.

The walkaway VSP and Offset Free Cable (OFC) survey geometry is show in Figure 5. The sources were located at the surface of the model with shot spacing of 25m, there were 801 shots. The receivers were in the borehole in VSP case and the receivers were in the water for OFC case. The receiver interval was 50m. There were 164 receivers from the sea bottom to 10050m depth. There are 40 receivers in the OFC case.

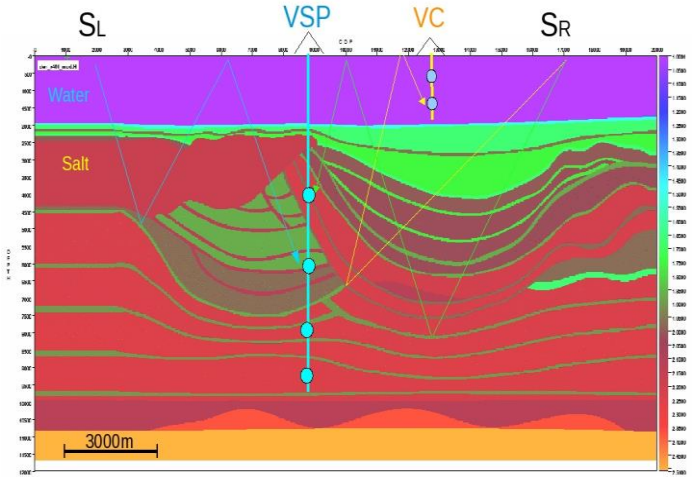

Figure 5. Schematic of Extended Walkaway VSP (EWVSP) survey geometry. The VSP and VC surveys are combined. The WVSP source boat is used for simultaneous data acquisition at both cables. The model is 20x12km in X and Z directions

Stacked image from the Reverse Time Migration of *Primary reflections* is shown in Figure 6. Horizontal extensions of the layers in the WVSP geometry is limited to areas around the borehole as seen in Figure 6 where the no-image zones are indicated with mark (?). With the help of the interferometry, the surface multiples were processed and migrated also, a combined image of the WVSP images is obtained, and it is shown in Figure 7. The combined image has great horizontal extend across the model, but the up-dipping layers are missing as marked in Figure 7. We filled the missing part of the image using the OFC data. We placed receivers in the water at 4000ft right offset from the VSP borehole, and recorded the same shots of WVSP. Using the interferometry we imaged the surface multiples of the OFC data, the image is shown in Figure 8.

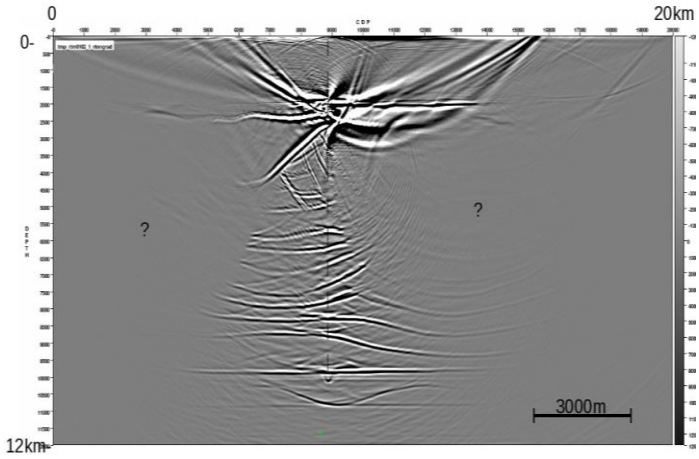

Figure 6. RTM image of Primary reflections

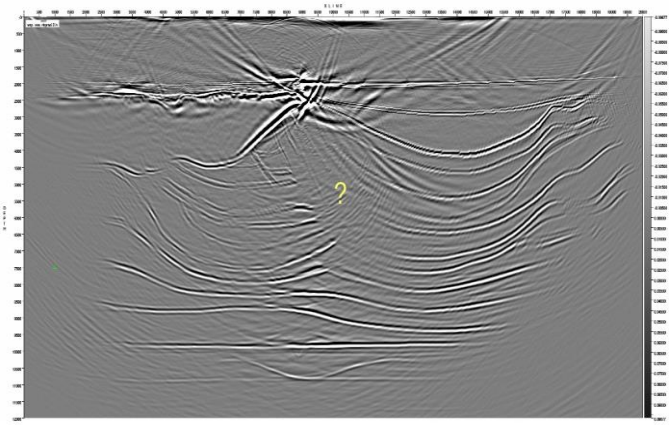

Figure 7. Stacked image of WVSP images (Primary and Surface multiples)

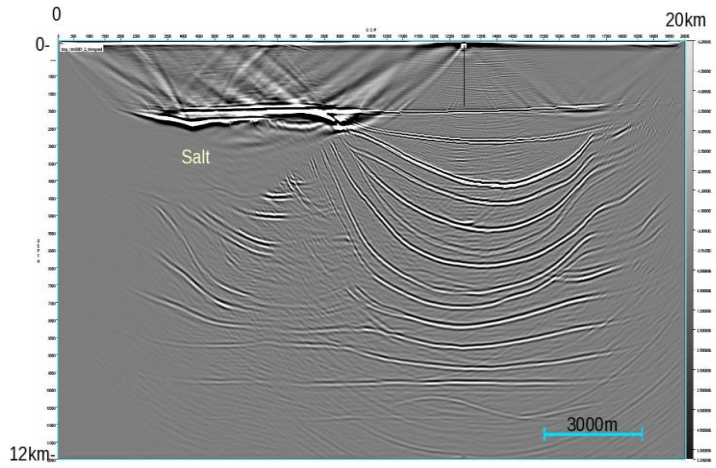

Figure 8. Image of surface multiples of Offset Free Cable (OFC) after interferometry and RTM. No-Salt is imaged

DOI http://dx.doi.org/10.1190/segam2013-1455.1

Notice no-Salt image is seen in the OFC case, but the up-dipping reflectors towards the Salt is imaged well. A composite image from the WVSP and OFC surveys is shown in Figure 9.

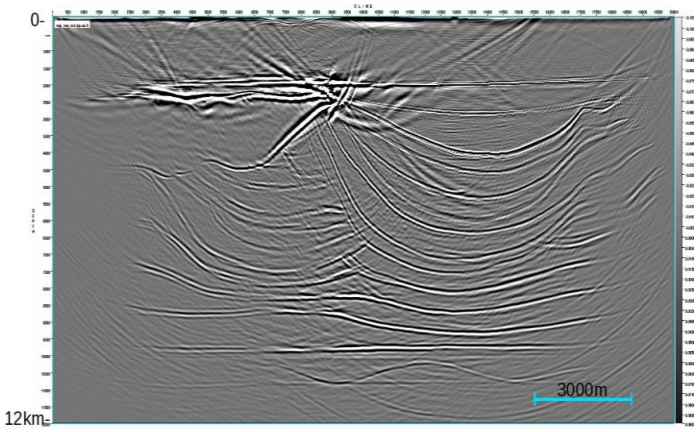

Figure 9. Composite final image from WVSP and OFC data sets. Compare this image to the image of Surface seismic of Figure 4.

In the migrations, all the VSP and VC data were migrated; no up-down separation was performed.

Conclusions

In this study we have introduced a method that, in marine VSP works, the image quality and the horizontal extension of the subsurface image from the VSP borehole can be substantially improved without much of an acquisition cost. In our modeling, we placed a free hanging receiver cable in the water at some offset to the VSP well. No additional recording vessel is needed, this could be achieved using a buoy), and simultaneously recorded the seismic data while shooting the WVSP survey. The data sets of the WVSP and the OFC individually processed using the interferometry technique to migrate the surface multiples. The stacked image from the surface multiples provided subsurface images that extended far beyond the VSP borehole. When the stacked image from the primary reflections of the WVSP was combined with the image from the surface multiples, an enhanced and superior quality image was obtained, shown in Figure 9. The final or composite image shows that the EWVSP method, introduced here, could be an important contribution to help solve the horizontal extends of the VSP images and illuminate the hard to reach reflectors such as below the Salt.

Acknowledgements

I would like to thank Ion Geophysical Company for the permission to publish his paper. Inputs and comments from Mike Mellen, Larry Wood, Alan Cohen, and Mike Edmunds greatly appreciated.

Key Words:

Interferometry, VSP, Free Cable, Prestack, Reverse Time, Modeling, Imaging.

DOI http://dx.doi.org/10.1190/segam2013-1455.1

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EDITED REFERENCES

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DOI http://dx.doi.org/10.1190/segam2013-1455.1