X003

Estimation of Imageable Dip Range of Target Structures in Interferometric Salt Flank Imaging with Limited Illumination

A. Loureiro* (LNEG), J. van der Neut (Delft University of Technology), D. Alves (FCUL), J. Carvalho (LNEG), A. Afilhado (UL-IDL / ISEL), D. Draganov (Delft University of Technology), L. Matias (UL-IDL) & T. Martins (GALP E&P SA)

SUMMARY

When applying seismic interferometry to image sub-vertical salt flanks or structures with large dips from vertical or deviated wells, we are often confronted with poor target illumination. Strong directional-illumination footprints caused by non-ideal placement of sources at the surface degrade the interferometric image quality and may prevent the retrieval of particular dips in the image. The effect of the well's orientation on the interferometric image is investigated. Moreover, a method is presented to estimate the imageable dips in an interferometric image, which can be used to design a more favorable shooting geometry and to gain additional knowledge about the target structures.

Introduction

Seismic interferometry can be used to turn physical receivers in boreholes into downhole virtual sources (Schuster, 2009). When applying this method in practice, there are several limitations, such as a non-uniform distribution of sources and intrinsic losses, which are not accounted for by theory (Wapenaar and Fokkema, 2006). Scattering in the overburden and non-ideal source geometries (in both azimuth and offset) can limit the illumination aperture, illumination direction and affect the radiation pattern of the generated virtual sources (van der Neut et al., 2011). These limitations reduce resolution and increase the blurring of interferometric images, but can also prevent some structures from being correctly imaged or even fail to be imaged at all. The radiation patterns of virtual sources generated by poor illumination may have a directional-illumination imprint that does not respond well to specific dips of the target structures. In the following, we apply seismic interferometry to synthetic data based on a real field marine salt-flank imaging scenario with non-ideal illumination. We will show that studying the directional-illumination imprint can help us to estimate the range of imageable dips of the target structures for a specific surface shooting geometry. Knowing the imageable dips from a specific well and shooting-geometry combination can aid to steer other imaging techniques, further drilling operations or aid in designing new shooting geometries.

2D modelling

The model we use is inspired by a location on a continental passive margin with deep sedimentary layers and large salt diapirs. These salt domes bound oil and gas reservoirs of economic interest, but also greatly reduce the quality of traditional seismic imaging for their correct assessment, mainly because of propagation velocity inversions and steep salt structures that prevent reflected energy to reach the surface. The velocity model (a simplified version is shown in Figure 1f) was adapted from seismic data and used for generating synthetic data using the acoustic lossless medium scheme of a 2D finite-difference modeling program (Virieux, 1986). The fake well locations and shooting geometry were compatible with VSP data acquisition techniques. In this scenario, 160 active sources located on the sea surface were modeled and the transmission-response panels for the pressure field were recorded for 101 receivers evenly spaced along the well located near the salt dome and roughly parallel to its flank. Two additional wells, with different inclinations and number of receivers were also modeled; see Figure 1f for a simplified impression.

Interferometric imaging

Seismic interferometry by cross-correlation was used to generate virtual sources at the downhole receiver locations (Shuster, 2009). Preliminary analysis of the modeled data, ray-tracing (Zelt and Smith, 1992) and the cross-correlation results themselves allowed us to get a rough notion of which receivers and active sources would give better and meaningful contributions to a final image of the target area. The illumination problems due to insufficient illumination from the source geometry were apparent in the virtual shot records, where a strong directional imprint dominated the greater part of the shot gathers. This was especially apparent when we compared them with directly modeled shot records from active sources at the location of the virtual sources. The active sources radiate energy in all directions, as opposed to the virtual sources, that depend on the illumination conditions of the receivers to which they have been redatumed. After the retrieval process, the virtual-source gathers were migrated and stacked. For migration, we used a one-way wave equation migration algorithm (Thorbecke, 1997) and a velocity model that was created from only the measured propagation velocities along the well, much like a well log in real scenario. We emphasize that apart from this, no additional velocity information was used.

Effects of varying inclination of instrumented well on imageable dips

To estimate the influence of the receiver positions on the imaging limits with the same shooting geometries, three scenarios of well placement were tested: wells A, B and C; see Figure 1f. The interferometric images of these wells are shown in Figures 1a, 1b and 1c. Note that the images are rotated with respect to the well orientations. In Figure 2 an illustration of this rotation is given. Note from this figure that the imaged part of the salt is similar for all three wells and that no noticeable difference can be found between the images, except for those caused by the extra length of the receiver arrays of wells B and C. Even with significant well inclination variations, the imaged target dips are quite similar. This suggests that the strong directional-illumination imprint caused by the poor shooting geometry is a more decisive factor for limiting the range of imageable target dips than the orientation of the receiver array.

Illumination diagnosis in the image domain

To evaluate the effects of the directional-illumination footprint at the receiver array, a response of a grid of evenly spaced point scatterers was modeled in the velocity model, but with active sources in the same location of the virtual sources. We subtracted a response without point scatterers and migrated the residual, using the same migration code as for interferometric imaging; see Figure 1d. The scatterers can be interpreted as trial image points. The blurred image points that show up in Figure 1d can be interpreted as migration butterflies or resolution functions (Schuster and Hu, 2000). Note that all dips are retrieved well because of the uniform illumination provided by the active sources from the well, although slight deformations occur because of the erroneous velocity model (most apparently visible in the water layer). From the redatumed virtual source data we estimated the generated virtual source functions (or point-spread functions), inheriting the strong directional-illumination footprint. To illustrate what would happen if the virtual sources instead of the actual sources where used to image the trial image points, we convolved the modeled response from the point scatterers with the virtual source functions and migrated the result. Because the directional-illumination imprint is strong, the image of the scatterers is now different and only a smaller range of dips is correctly imaged, see Figure 1e. Note that dips outside of the diffraction hyperbolas are not imaged. In figure 1e, one of these diffraction hyperbolas is highlighted to better show that all imaged dips of the target correspond to the dips present in the hyperbola.

Discussion

In this study, Figures 1d and 1e were modeled by placing point scatterers in the physical medium and subtracting the response without point scatterers. However, we could also place point scatterers in the background medium and perform our analysis without any additional velocity information. In this way, the quality of the interferometric image can be analyzed directly from the data without further velocity information. Instead of using point scatterers we could also place an interface in the background model to qualify how well a potential reflector at this location could be imaged. Additionally, the dip of this potential reflector could also be changed to estimate the sensitivity of a certain shooting geometry to different dips of the target surfaces.

Conclusions

Although seismic interferometry allows the extraction of additional information under difficult conditions, real case scenarios not always conform to the ideal illumination conditions required by theory. When planning a well for exploration or VSP imaging using interferometric techniques, some a priori knowledge of the target dips is advisable. This could help in selecting source locations to optimize illumination. It is shown that the dip of the well is less crucial than a good shooting geometry that reduces directional imprints in the radiation pattern of virtual sources. Finally, we have developed a tool to study the blurring of interferometric images and estimate the range of imageable dips of target surfaces for a given shooting geometry.

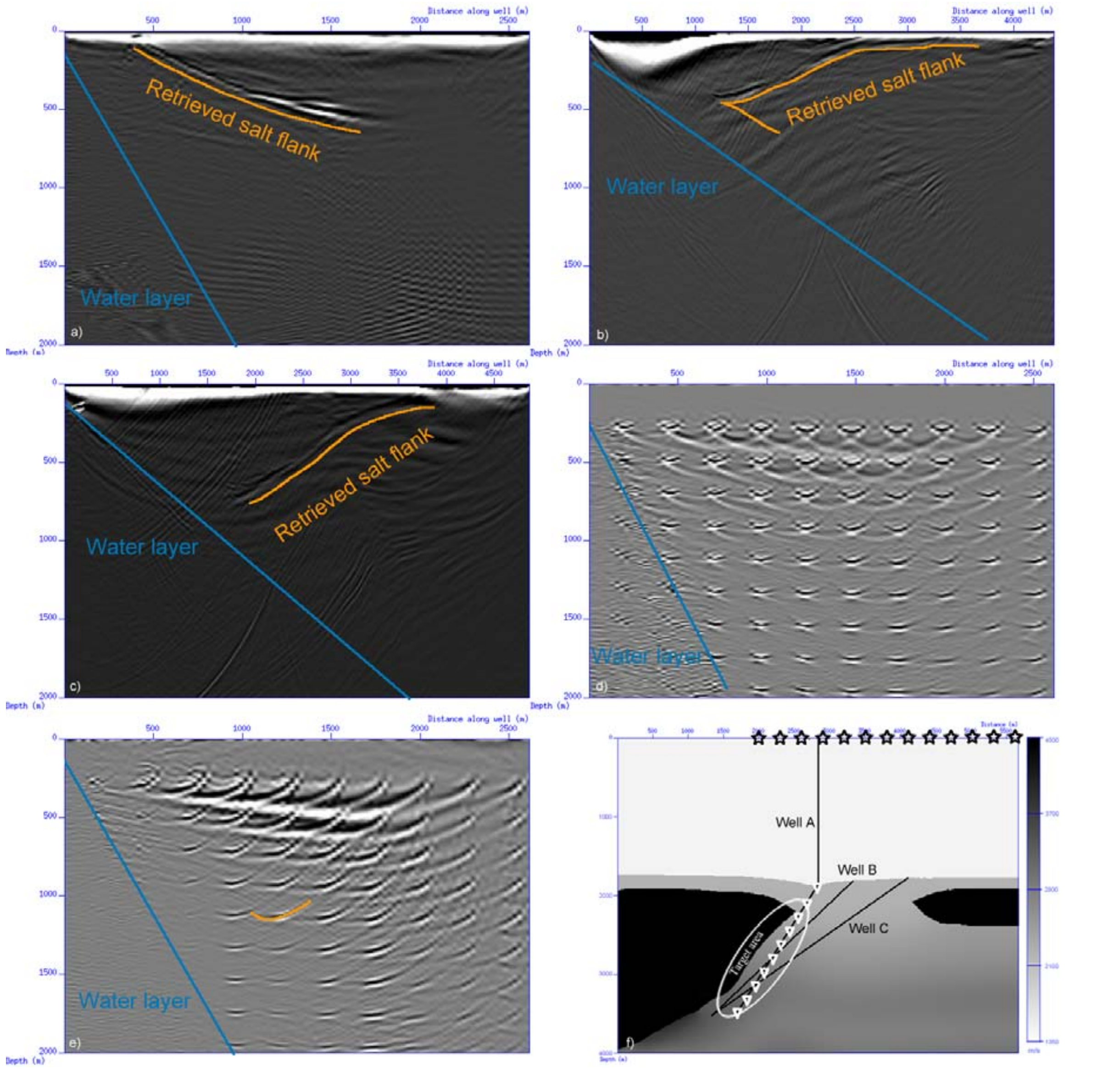

Figure 1: a-c) Salt flank images from fake well A, B and C, respectively. The images are rotated so that the instrumented wells are at the top, coincident with the horizontal axis (see Figure 2 for the orientation). d) Retrieved image of a grid of point scatterers over the background velocity model, using active sources along well A. e) Convolution of d) with the radiation pattern of virtual sources from the same well. f) Salt flank model, with target area (white ellipse), approximate fake well locations (black lines), receivers (white triangles) and sources (black stars). For clarity, receiver marks are omitted over the paths of fake wells B and C.

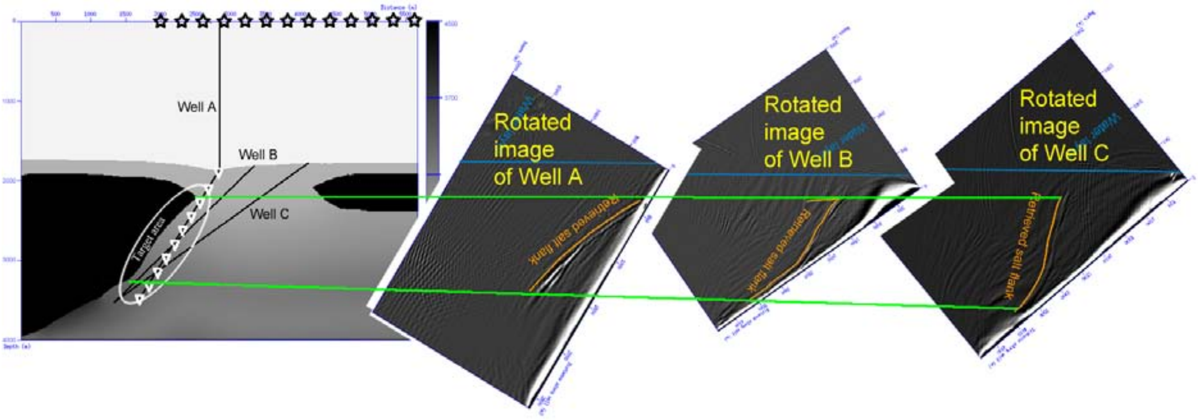

Figure 2: Cartoon to illustrate how the images from fake wells A-C (Figures 1a-c) should be interpreted, showing that they image the same portion of the salt as indicated by the green lines.

Acknowledgments

The authors acknowledge Galp E&P to support this project. This work is also supported by the Dutch Technology Foundation STW (grants DCB.7913 and VENI.08115), applied science division of NWO, the Technology Program of the Ministry of Economy.

References

Schuster, G. T., and Hu, J., 2000. Green's function for migration: continuous recording geometry. Geophysics, 65, 167-175.

Schuster, G. T., 2009. Seismic interferometry, Cambridge University Press, Cambridge.

Thorbecke, J. T., 1997, Common focus point technology: PhD dissertation thesis, Delft University of Technology, Delft.

Virieux, J., 1986, P-Sv wave propagation in heterogeneous media: velocity-stress finite-difference method. Geophysics, 51, 889-899.

Van der Neut, J., Draganov, D., and Almagro Vidal, C., 2011. Diagnosing virtual source radiation characteristics without a velocity model, in EAGE, Extended Abstracts, P377.

Wapenaar, K., & Fokkema, J., 2006. Green's function representations for seismic interferometry, Geophysics, 71, SI33-SI46.

Zelt, C.A., & Smith, R. B., 1992. Seismic Traveltime Inversion for 2-D Crustal Velocity Structure. Geophysical Journal International, 108, 16-34.