Data decimation study for multi-component seismic acquisition purposes

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Abstract

It's been learned from practice that a good acquisition for P-wave imaging not necessarily is good for PS-wave imaging, all illumination problems for converted waves depends on geological and processing parameters that it's not usually taken in account during acquisition design. A high fold 2D-4C seismic line, acquired in Gulf of Mexico with ocean bottom cable system, was used to study illumination and resolution of PS images for different acquisition schemes commonly used for P-wave data. The shot and the receiver line interval were decimated in different ways to investigate the effect of different acquisition parameters on PS-wave images and try to identify some converted wave acquisition rules when designing a seismic line for PS-waves. This investigation was made comparing PS-wave images generated from the same line and processed with the exact same sequence and the only difference is shot and or receiver intervals.

Introduction

What is the best acquisition design for converted waves? Is it sufficient to use P-wave acquisition design rational to produce seismic images of converted waves? How does the acquisition geometry affect the final result of the seismic section? These questions were addressed, following the acquisition of an experimental 2D/4C seismic line in Brazil, and became the motivation of a joint research project between PUC-Rio and PETROBRAS, as part of the strategic program PRAVAP19.

The purpose of this paper is to describe a study carried out to establish the influence of the acquisition geometry in the final converted wave seismic section. A high fold, 2D-4C seismic line acquired in Gulf of Mexico, with ocean bottom cable system, was used to produce 4 pseudo-acquisition campaigns by dividing the original data in 4 subsets. For each dataset, P-wave and converted waves seismic sections were generated, following the same processing flow, and used as references for investigating the influence of the acquisition geometry on the final seismic section quality. The original dataset was also used for comparison purposes.

This exercise, using real data instead of using numerical modeling, certainly lead us to understand more about the converted wave as a tool for illuminating the subsurface. As a result we expect to optimize the design of the 3D-4C seismic acquisitions in terms of shot and receivers intervals.

Methodology

The seismic line used for this test is a 2D/4C, high fold seismic line. The main characteristics of this acquisition are: water depth between 18m and 30m; source cable length of 19km with 25m source interval, and receiver cable length of 10km with 25m receiver interval, as can be seen in Figure 1.

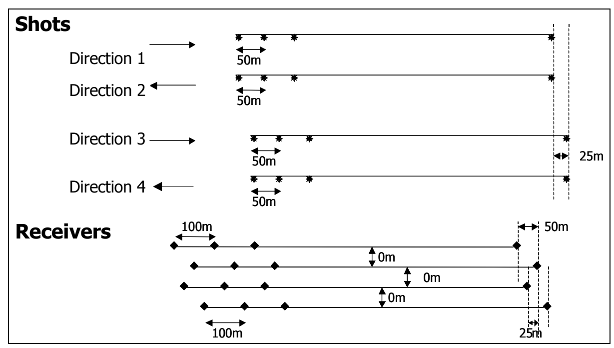

Figure 1: Acquisition scheme of original line used for decimation

This survey line, mentioned from now on as original, was used to generate 4 pseudo-acquisition through decimation of its shot and receiver points. The CMP spacing and offset interval for this line are 12.5m and 50m, respectively. Four decimation schemes were selected, namely:

Scheme 1: Shot interval of 100m and the receiver interval of 25m. The shot interval is four times the corresponding interval of the original dataset, see Figure 2, the CPM spacing is kept the same but the offset interval is four times as large (*i.e.* 12.5 and 200m, respectively) as the original one.

Scheme 2: Shot and receiver interval of 50m (Figure 3). The CMP spacing and the offset interval are two times larger (*i.e.* 25m and 100m, respectively) than the corresponding values for the original survey.

Scheme 3: Shot interval of 50m and receiver interval of 100m (Figure 4). The CMP spacing is four times as larger and the offset interval is twice as large (*i.e.* 50m and 100m respectively) as the original ones.

Scheme 4: Shot interval of 100m and receiver interval also of 100m (Figure 5). The CMP spacing and offset interval are four times as large (i.e. 50m and 200m respectively) as the original survey.

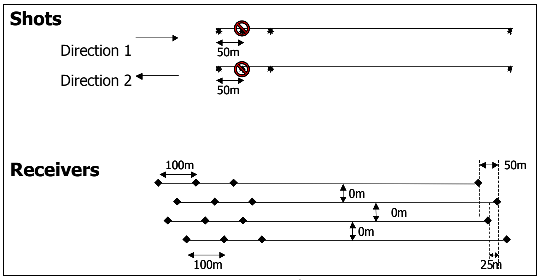

Figure 2: Acquisition scheme of scheme 1.

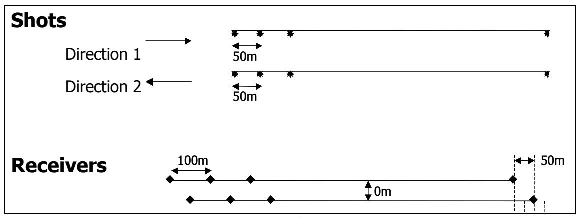

Figure 3: Acquisition scheme of scheme 2.

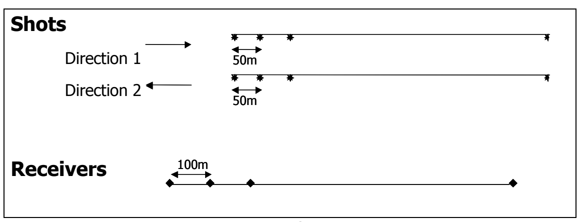

Figure 4: Acquisition scheme of scheme 3.

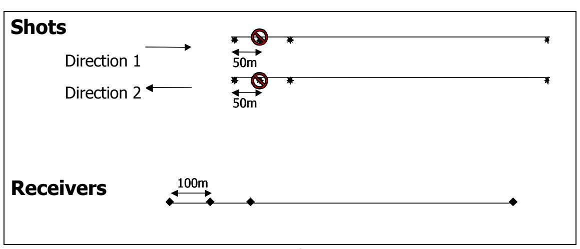

Figure 5: Acquisition scheme of scheme 4.

All data were processed following the same following seismic processing sequence, described in Silva *et al* 2003, and indicated next:

Processing flow for P-Wave data:

- *True Amplitude Recovery* (spherical divergence function);
- *Deconvolution* (minimum phase predictive function);
- *Normal Move-out Correction* – conventional velocity analysis;
- *Residual Static Correction*
- *CPD Stack* – for build the final section for P-wave

Processing flow for C-Wave data:

- *T-V Spectral Whitening* ;
- *True Amplitude Recovery* (spherical divergence function)
- *Deconvolution* (minimum phase predictive function)
- *Normal Move-out Correction* – hyperbolic approximation, the same procedure used for P-wave section;
- *Residual Static Correction* – calculated from the P-wave data;
- To build the image section for all lines, two different approaches were used:
    - *CCP stack;*
    - *Kirchhoff Pre-stack Time Migration for Converted Waves* followed by *CDP Stack.*

The CCP stack algorithm uses the approximated solution for conversion point suggested by Thomsen (1999) and the Kirchhoff PSTM algorithm uses the methodology described by Schneider (2000). The two approaches were taken into account because these algorithms produced quite different images: in CCP stack, the image has the converted wave time, its interpretation is difficult when the Vp/Vs ratio is not well defined.

The algorithms used for converted wave are part of ProGold, a proprietary code by Fairfield Inc running under ProMAX 3D®. The converted wave seismic section was migrated to equivalent P-wave times in order to allow comparisons between events displayed in both sections.

The CCP locations were defined at a 25m interval and identified by X-Y coordinates. The gathers were built according to equation (1) derived by Thomsen (1999).

$$x_c(x,t_{c0}) \approx x\left[c_0 + c_2 \frac{\left(\dfrac{x}{t_{c0}V_{c2}}\right)^2}{\left(1+c_3\left(\dfrac{x}{t_{c0}V_{c2}}\right)^2\right)}\right] \qquad (1)$$

where $c_0 = \lim_{x\to 0} \frac{x_c}{x} = \frac{\gamma_{eff}}{1+\gamma_{eff}}$

$$c_2 = \frac{\gamma_{eff}}{2\gamma_0}\frac{(\gamma_{eff}\gamma_0 - 1)(1+\gamma_0)}{(1+\gamma_{eff})^3}$$

$c_3 = c_2/(1-c_0)$ and $\gamma_{eff} = \gamma_2^{\,2}/\gamma_0$

The Vp/Vs function for the area was available from well log data and ranges from 2.5 (on deep part of section) to 7 (shallow muddy section). Next, the results of the processing of each pseudo-acquisition scheme are presented.

Results

Figure 6 shows a typical CCP Gather for the original dataset and Figures 7 through 10 displays similar CCP gather corresponding to the 4 pseudo-acquisition dataset.

As described earlier, scheme 1 simulates a case where the offset interval is four times larger than the corresponding one for the original acquisition, and the CMP interval is kept the same as in the original dataset. The CCP gather for this scheme, as indicated in Figure 7, shows a number of "open spaces", both in time and offset, which can be interpreted as loss of illumination when compared with original scheme (Figure 6), even when the same CCP interval (25m) is used.

For scheme 2, shot and receiver intervals are twice as large as in the original survey. The CMP interval and the offset interval are two times larger than the corresponding values of the original dataset. The CCP gather displayed in Figure 8 was calculated in the exact same position as original scheme CMP (25m). It is clear that the loss in illumination is smaller than the one observed for scheme 1.

Schemes 3 and 4 have the same CMP interval (four times larger than original) and different offset intervals, (100m and 200m respectively). The CCP gathers for these schemes presented approximately the same loss of illumination as indicated in Figure 9 for scheme 3 and Figure 10 for scheme 4. It is also noticeable that the loss of illumination is very large compared to the CCP gather for the original dataset.

Similar observations regarding loss in illumination for each dataset can be made when using stacked sections. Due to space limitation, only one comparison is shown: between Figure 11, that shows the CCP stack for the original acquisition and Figure 12, that displays the CCP stack for scheme 4. Comparing these two figures, it can be observed the different resolution of each section, which is caused mainly by the illumination losses in scheme 4, and this resolution problem is variable with depth. If the target is shallow (PS-wave time < 2.2s), schemes 3 and 4 do not seem to be good acquisition geometries to be used, because there was some missing data above this time. If the target is shallower than 1,6 seconds (PS-wave time), schemes 1 and 2 are not efficient as well. This effect is also very much dependent upon the Vp/Vs ratio, Silva et al. (2003).

We further analyzed this question using migrated sections as elements to compare horizontal resolution among the different acquisition designs. Figures 13, 14 and 15 present the PSTM sections corresponding to the original dataset, dataset for scheme 2 and data for scheme 4, respectively. The image interval used to perform migration is the same used for CCP stack (25m). Notice that scheme 2 section is very similar, in resolution and illumination, to the original scheme data (Figure 13) and scheme 4 produced the poorest section, which presents resolution problems. The early part of the section of Figure 15 presents alias problem caused by bad sampling of the diffractions and energy losses on the shallow events compared to the original section (Figure 13). The bottom part of the section presents an even worse illumination compared to the original dataset.

The P-wave data was also investigated. The CMP interval used for stacking was also of 25m. It can be seen, comparing Figure 16, for original scheme, with Figure 17, for scheme 4, that P-wave section was not as influenced by the geometry acquisition as converted wave sections. The different acquisition parameters only changed the fold.

Conclusions

The same OBC line was decimated in four different schemes :

- On contrary of P-wave CMP acquisition increasing the receiver interval does cause illumination losses in the CCP gather;
- The illumination losses is more sensitive in increasing the shot point interval than increasing the receiver interval;
- If the target is shallow, the acquisition must have small shot and receiver intervals;
- If the geology is complex, the resolution for migrated section can be affected by receiver (line) interval;
- The best acquisition design noticed in this exercise is at least keeping the same shot interval but relaxing at most the receiver (line) interval twice larger. This procedure suites pretty much well with OBC offshore where it the costs to shoot in smaller interval is not much affected, while reducing the receiver line interval can increase the significantly the costs,
- P-wave section is not affected by geometry at the same way as C-wave section. Thus, we conclude that the PS surveys must be design considering Vp/Vs for the area alias for the low velocities and illumination issues,
- Observing the process results of the worst scheme for pure and converted waves, it can be concluded that it's not possible to define shot and receiver intervals based on P-wave schemes to image PS-waves properly.

Acknowledgments

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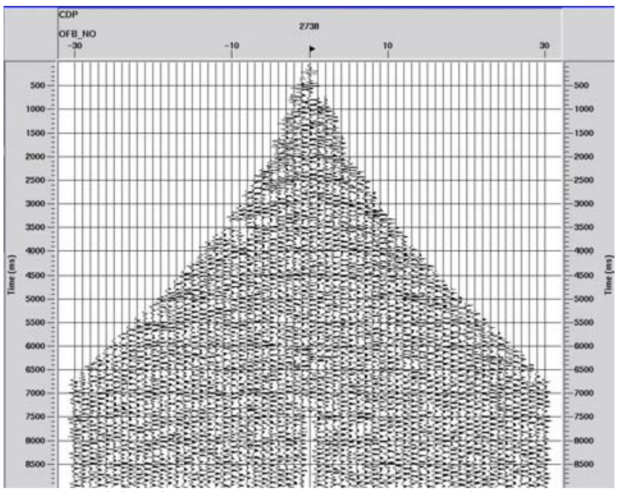

Figure 6: CCP Gather with shot point interval (SPI) = 25m and the receiver line interval (RLI) = 25m.

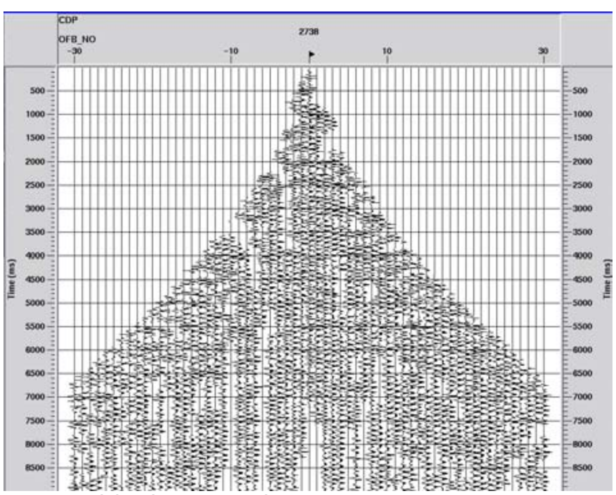

Figure 7: CCP Gather with SPI=100m and RLI=25m.

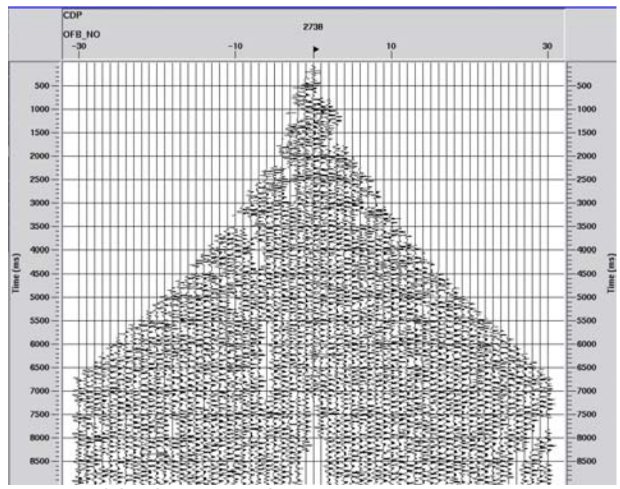

Figure 8: CCP Gather with SPI=50m and RLI=50m.

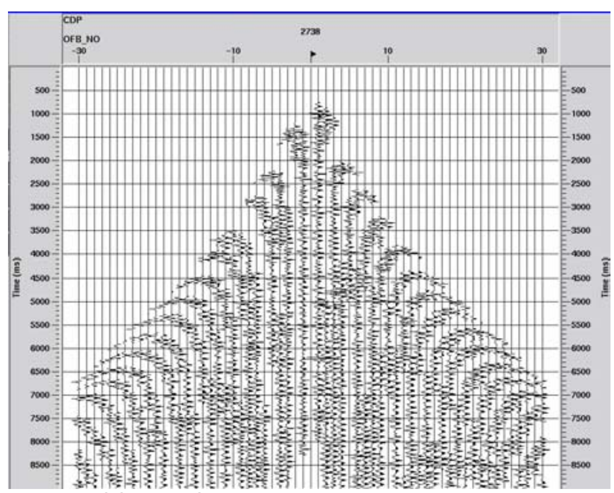

Figure 9: CCP with SPI=50m and RLI=100m.

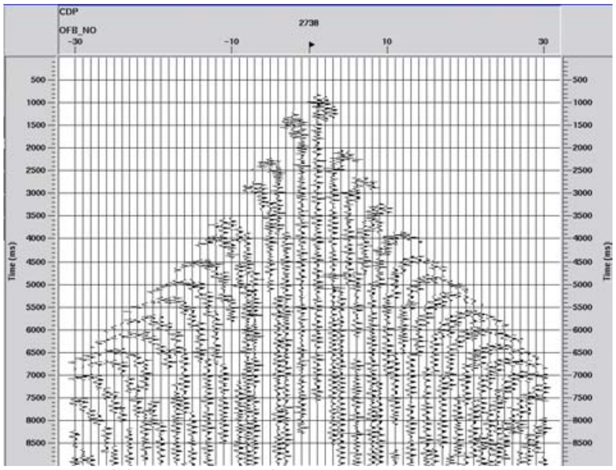

Figure 10: CCP gather with SPI=100m and RLI=100m.

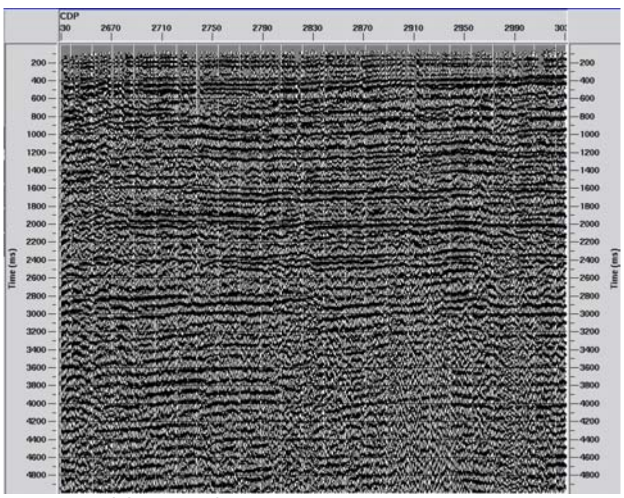

Figure 11: CCP stack for original scheme

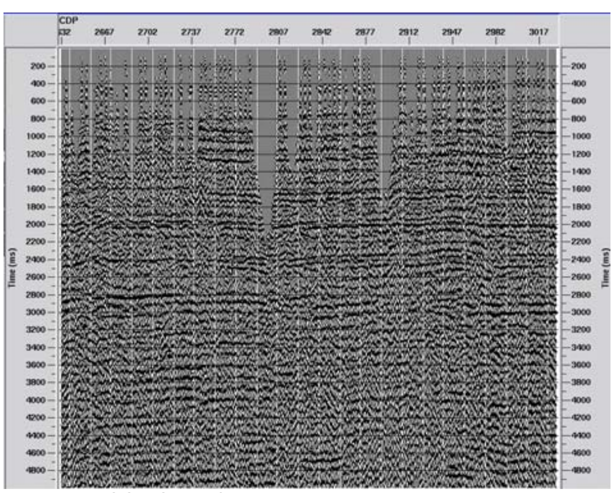

Figure 12: CCP Stack for scheme 4

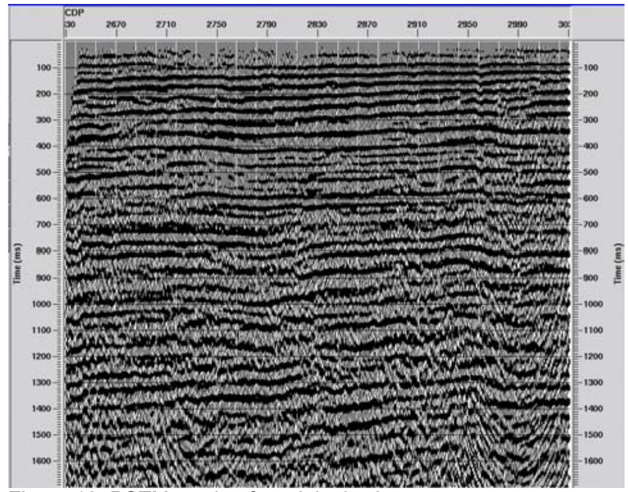

Figure 13: PSTM section for original scheme

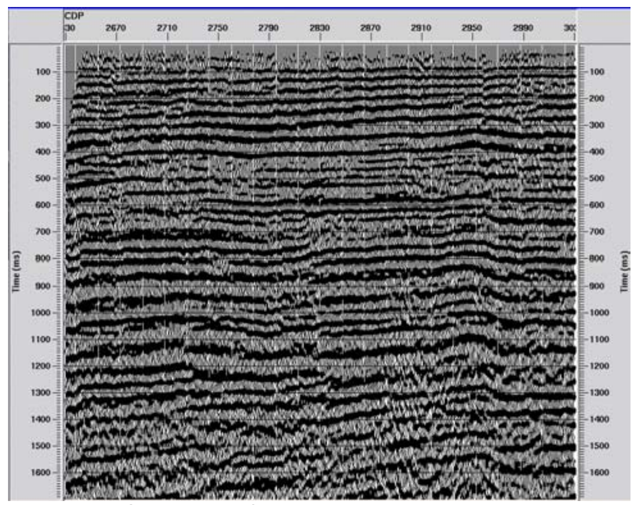

Figure 14: PSTM section for scheme 2

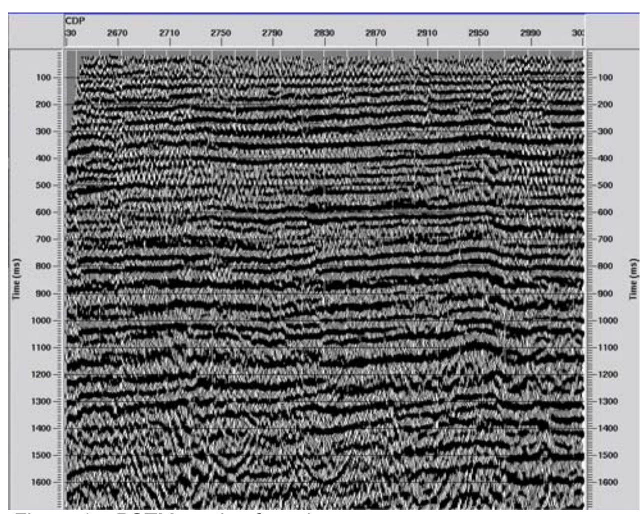

Figure 15: PSTM section for scheme 4

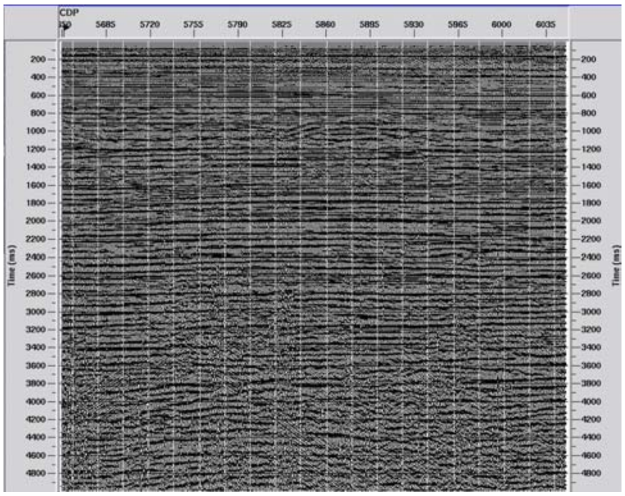

Figure 16: CMP Stack for P-wave – original scheme

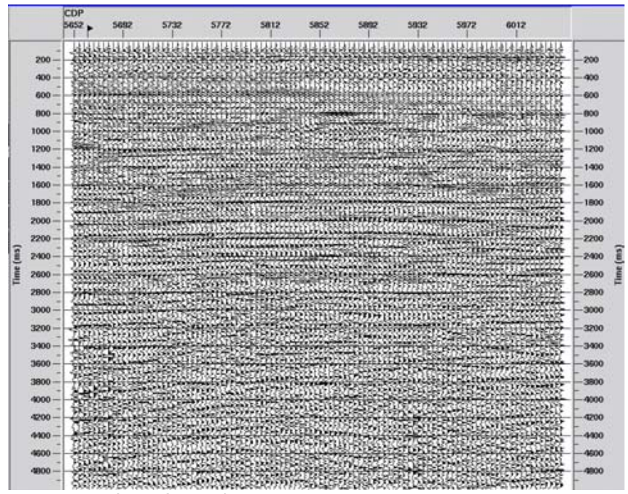

Figure 17: CDP Stack for Hydrophone – scheme 4