Imaging dipping layers in horizontal well borehole seismic surveys

Carlos E. Nieto and Robert R. Stewart

ABSTRACT

This work analyzes how the location and number of sources affects the imaging quality of dipping layers using borehole seismic techniques in horizontal wells. A MATLAB program was written and used to model and image a geological scenario. A diffraction modelling algorithm was used to obtain the shot gathers.

Assuming a walk-away surface source and two different models, it was found that in order to properly image steeply dipping layers, either long receiver arrays in the horizontal well or greater source offsets would be required. It is also important to have a symmetrical source spread with respect to the receiver array. Additionally it was found that fine source spacing does not improve the quality of the seismic image substantially.

INTRODUCTION

The use of VSP tools in horizontal wells presents an opportunity to provide useful downhole images. The question arises of where to place sources on the surface to properly image dipping layers beneath the horizontal well. The calculations consisted first in modelling the geology (that consisted on scatter points) and then perform a prestack migration on the seismic gathers obtained.

The constant velocity impulse response for prestack migration of subsurface seismic data is an ellipse with source and receiver at the foci (Claerbout, 1985). Previous work (Liner et. al., 1994; Slawinski et. al., 1996; Bancroft, 1999) has shown that for given source and receiver locations and a correct seismic velocity, there is an ellipse of possible locations for scatters (an aplanatic surface) for each trace sample. Trace amplitudes for the entire trace form a series of concentric ellipses. Liner et. al. (1994) shows that if the aplanatic surfaces are generated for a large number of traces at various source and receiver positions and summed together, the position of the scatters can be successfully imaged.

From a numerical point of view, Miller et. al. (1987) refer to migration as the problem of reconstructing the earth's acoustic scattering potential from its integrals over isochron surfaces. They point out that this method is very flexible because it can handle both complex velocity models and (nearly) arbitrary configurations of sources and receivers. Their approach is based on integrating the data over dual (isochron) surfaces recovers and image of the scattering potential.

These concepts are used in this work to define an algorithm that does prestack migration from the shot gathers obtained by modelling the geological input.

MODELLING AND IMAGING GEOLOGY

Different geological models were considered to analyze the quality of imaging, (Figures 1a and 1b). The shot gathers were obtained by diffraction modelling (Figure 1c). Neither direct arrivals nor phase or amplitude effects were included in the seismic modelling. The first, centre and last shot gathers, (Figures 2a, 2b and 2c) show how the destructive and constructive interference can either enhance or diminish reflections obtained from the dipping layers (model 2). A 40 Hz zero-phase Ricker wavelet was considered to create these gathers.

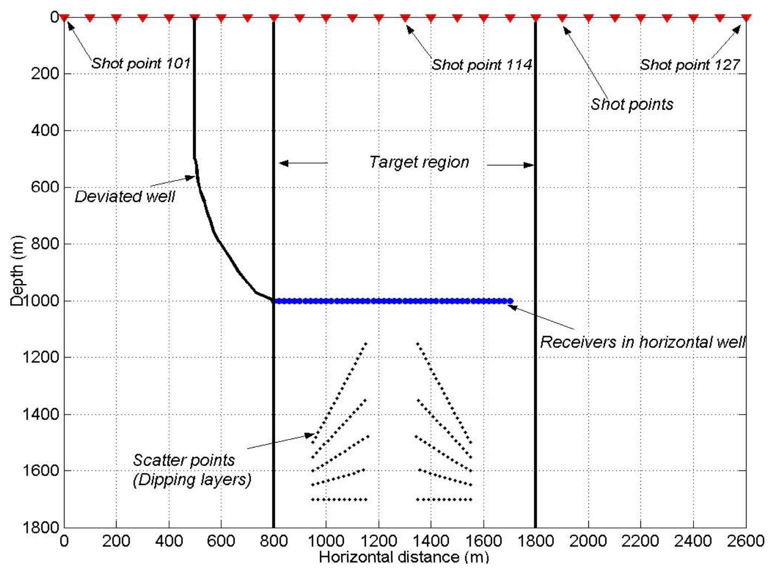

FIG. 1a. Walk-away VSP model 1. A string of 46 receivers is used on the horizontal well.

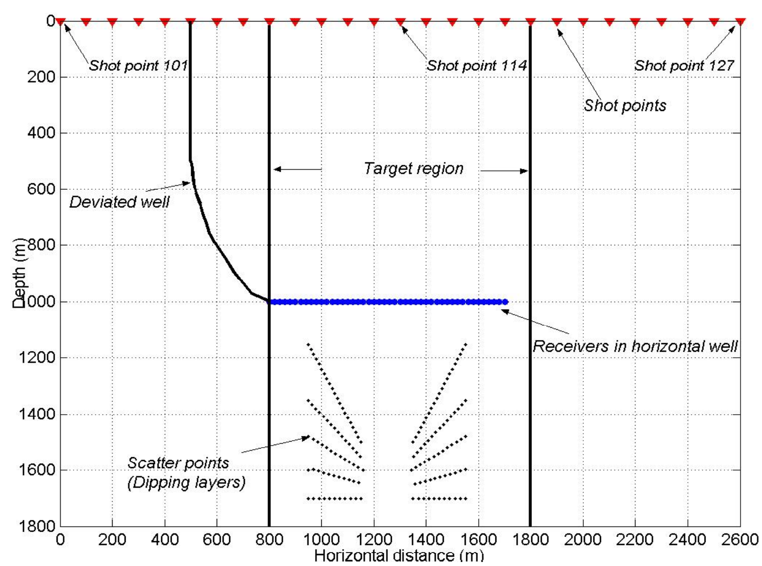

FIG. 1b. Walk-away VSP model 2. A string of 46 receivers is used on the horizontal well.

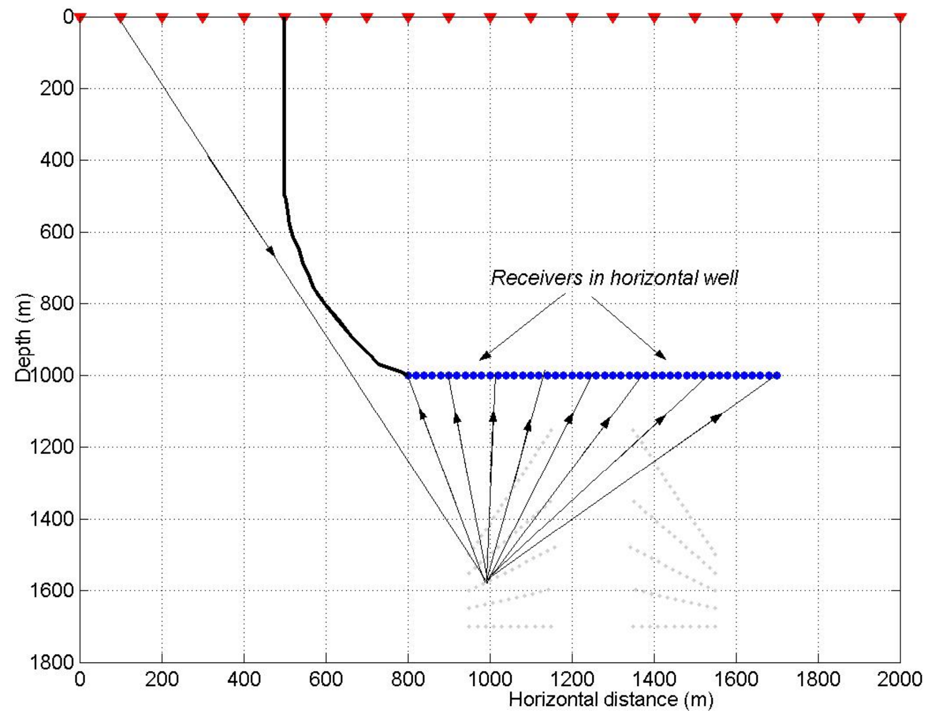

FIG. 1c. Diagram showing scattered energy coming from one of the SP102 rays.

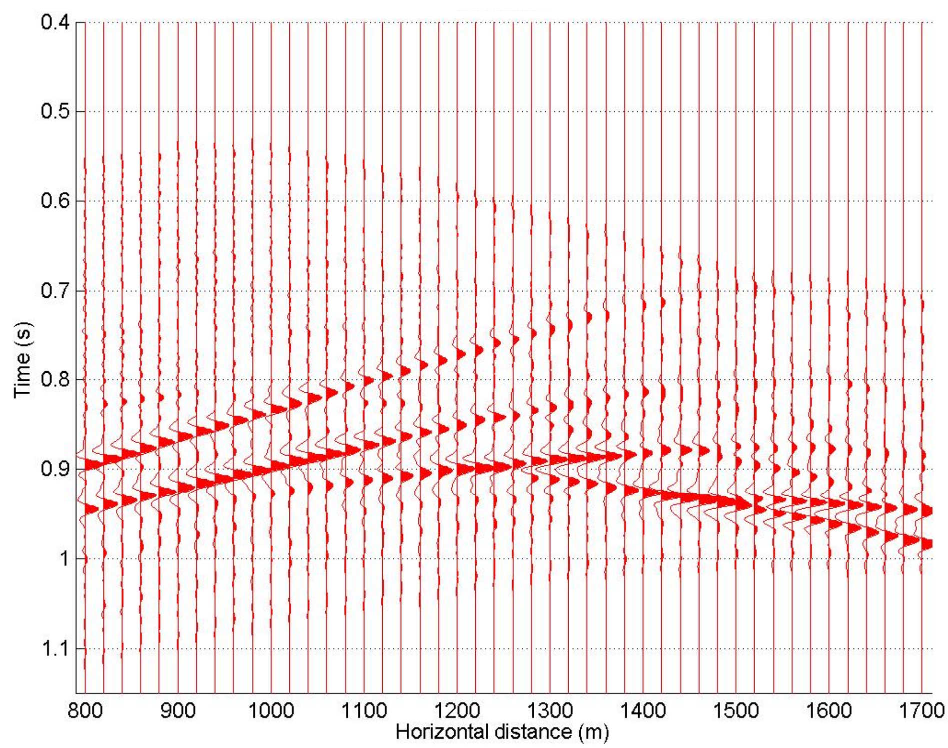

FIG. 2a. Shot gather SP101 over Model 2 for all horizontal receivers.

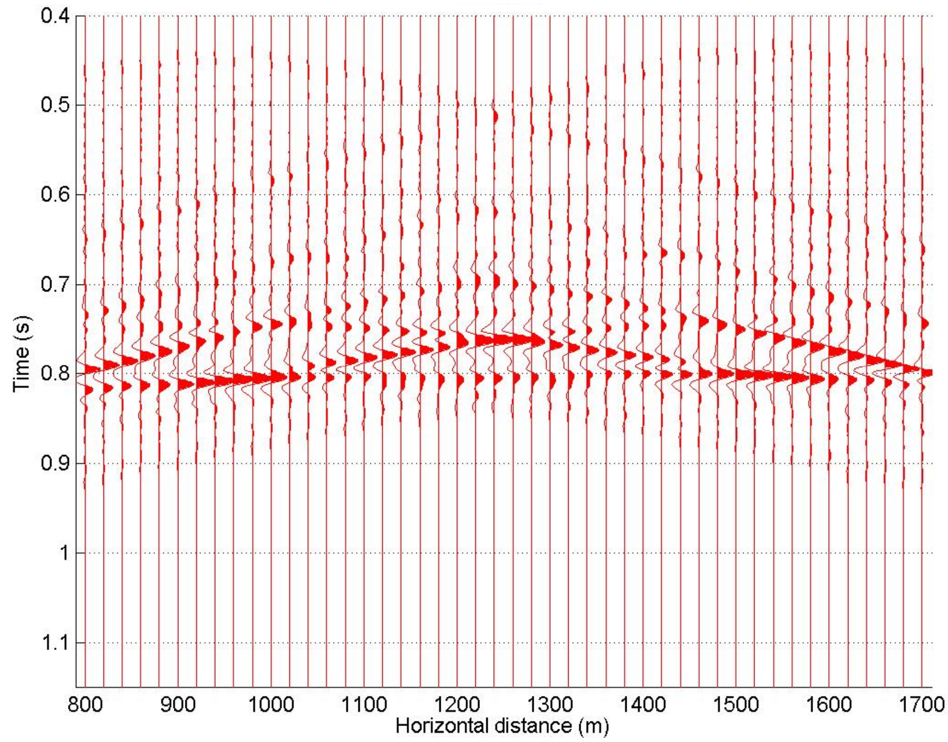

FIG. 2b. Shot gather SP114 over Model 2 for all horizontal receivers.

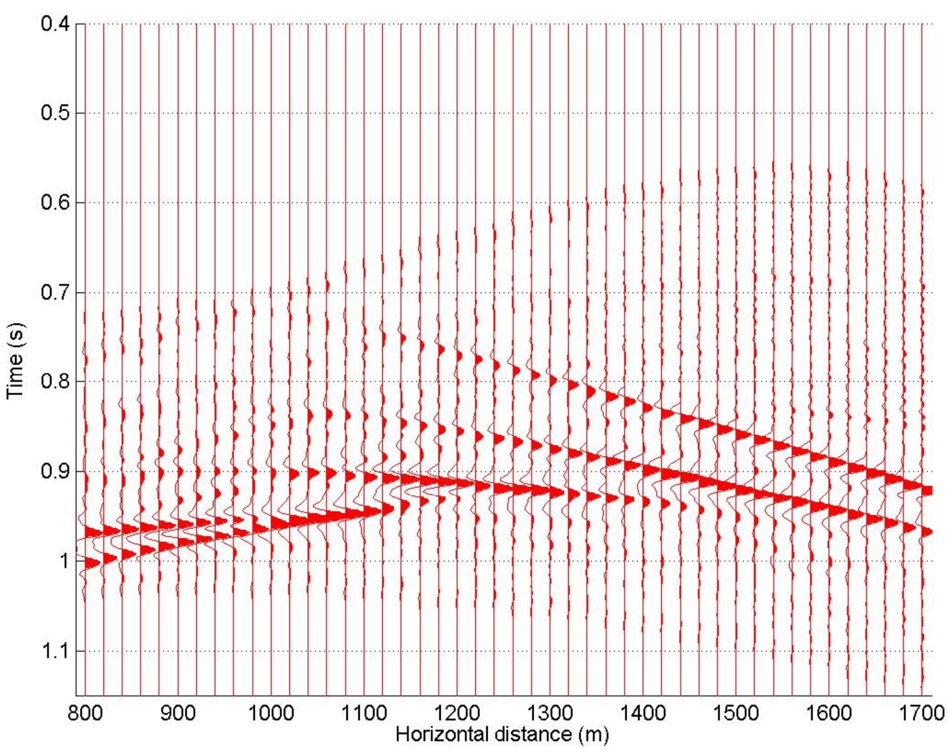

FIG. 2c. Shot gather SP127 over Model 2 for all horizontal receivers.

To analyze the effect of the number and location of sources on the imaging quality, different scenarios were considered, for both models:

1. Migrated data obtained from shots located every 100 m, Figure 3a and 4a.
2. Migrated data obtained from shots located every 800 m. Figure 3b and 4b.
3. Migrated data obtained from shots located every 400 m, from SP101 to SP114. Figure 5a and 6a.
4. Migrated data obtained from shots located every 400 m, from SP114 to SP127. Figure 5b and 6b.
5. Migrated data obtained from shots located every 400 m, from SP108 to SP120. Figure 7a and 8a.
6. Migrated data obtained from shots located every 400 m, from SP101 to SP105, and SP 123 to SP 127. Figure 7b and 8b.

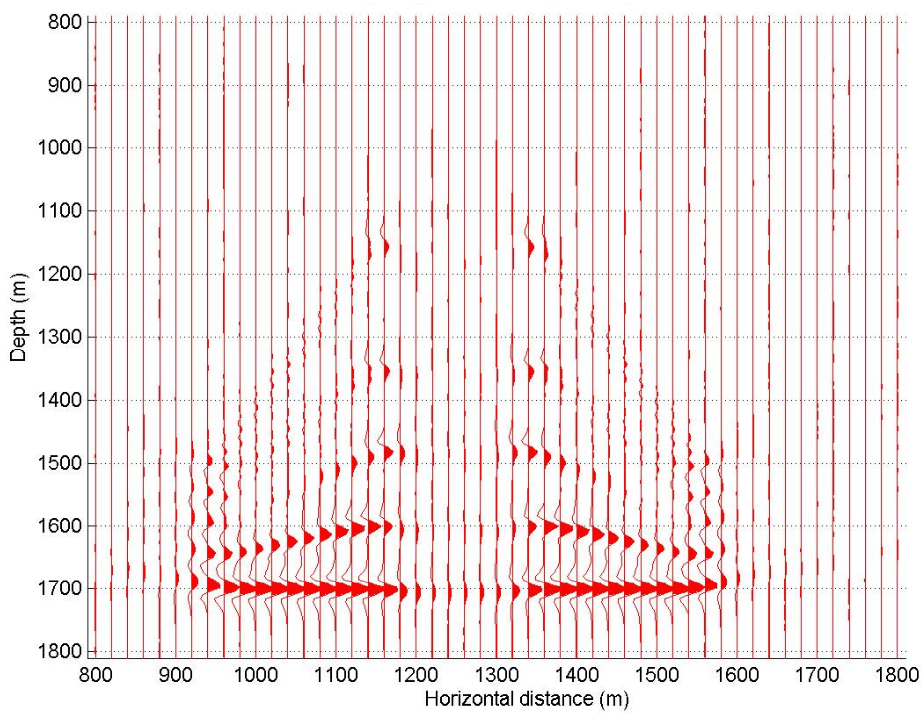

FIG. 3a. Migrated section (model 1) using shots every 100 m, from SP101 to SP127.

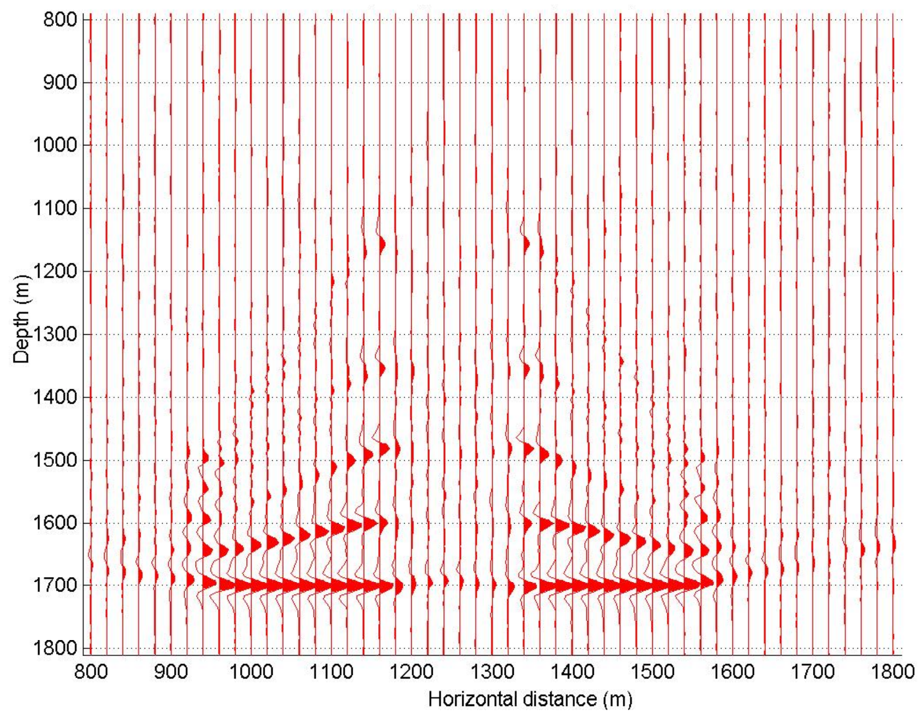

FIG. 3b. Migrated section (model 1) using shots every 800 m, from SP101 to SP127. Not too much downside for fewer shots.

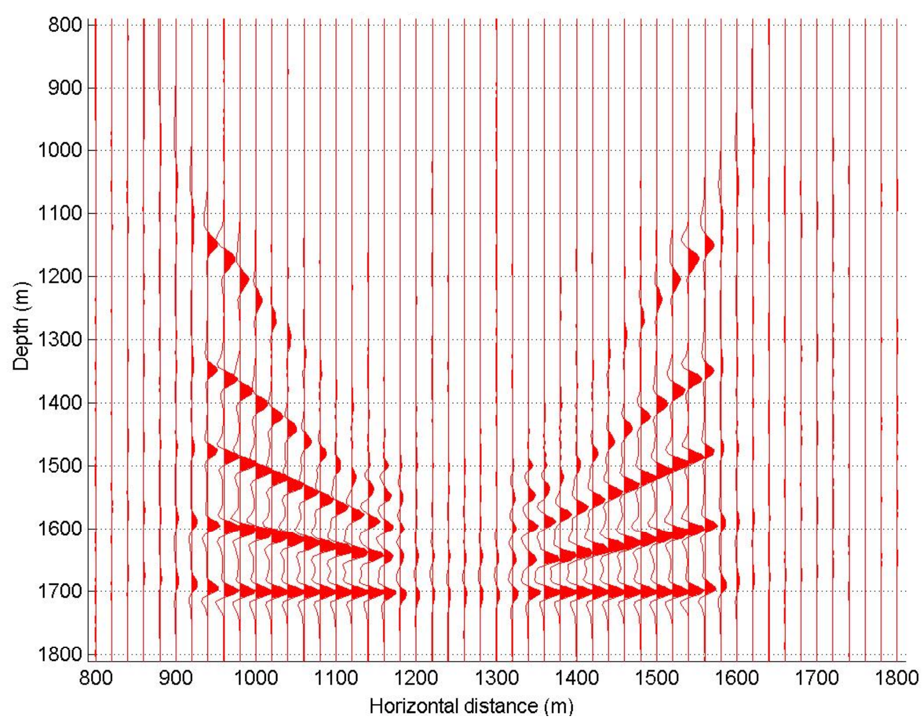

FIG. 4a. Migrated section (model 2) using shots every 100 m, from SP101 to SP127.

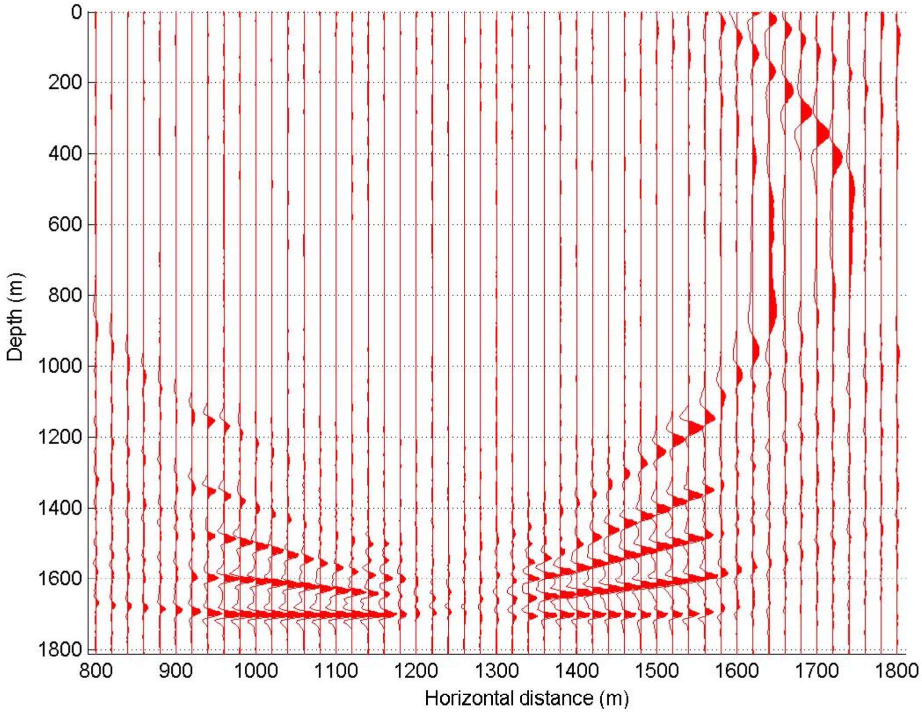

FIG. 4b. Migrated section (model 2) using shots every 800 m, from SP101 to SP127. Notice the low fold residual energy on the right side of the image.

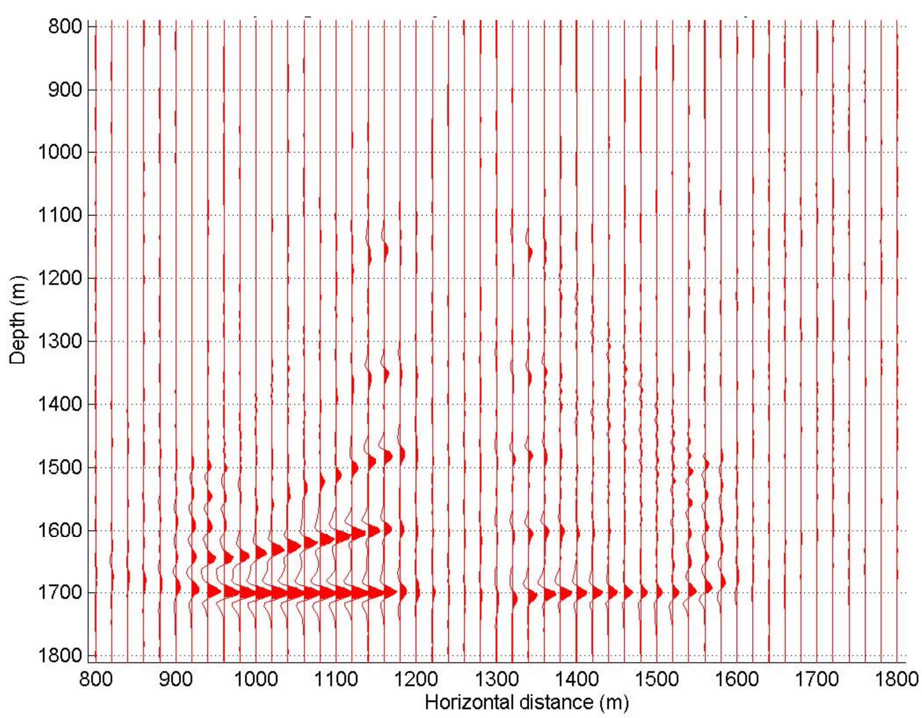

FIG. 5a. Migrated section (model 1) using shots every 400 m, from SP101 to SP114.

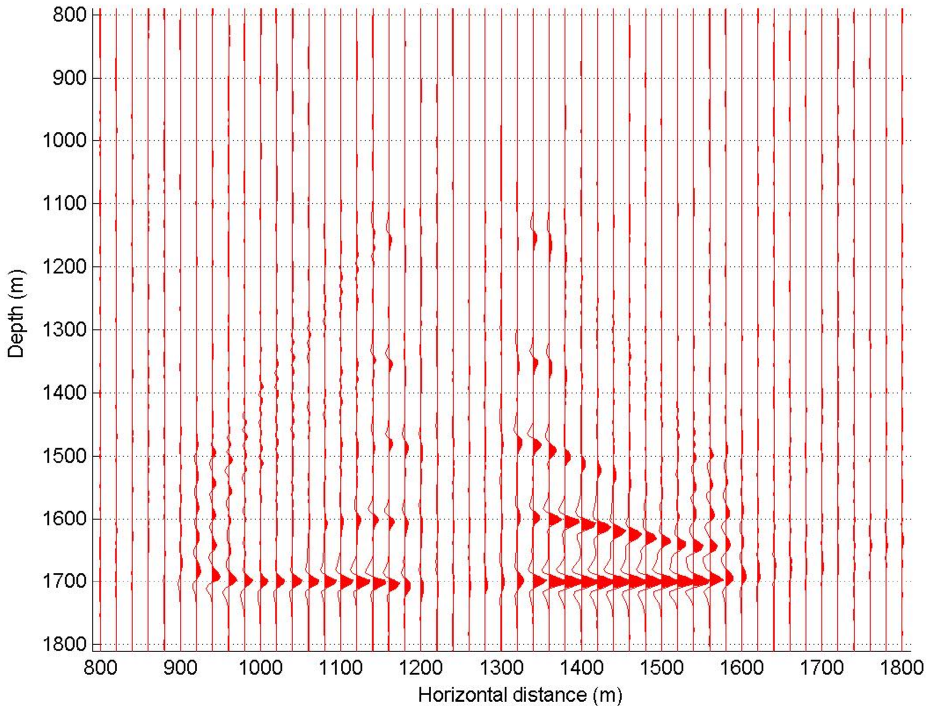

FIG. 5b. Migrated section (model 1) using shots every 400 m, from SP114 to SP127. Reasonable no signal arrival recorded due to geometry of the rays.

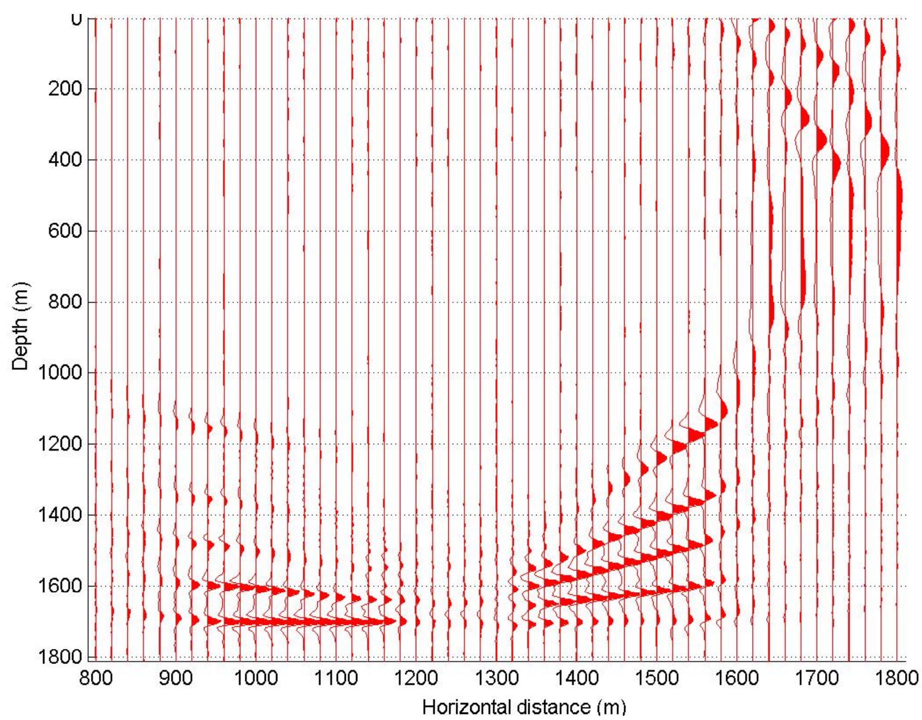

FIG. 6a. Migrated section (model 2) using shots every 400 m, from SP101 to SP114.

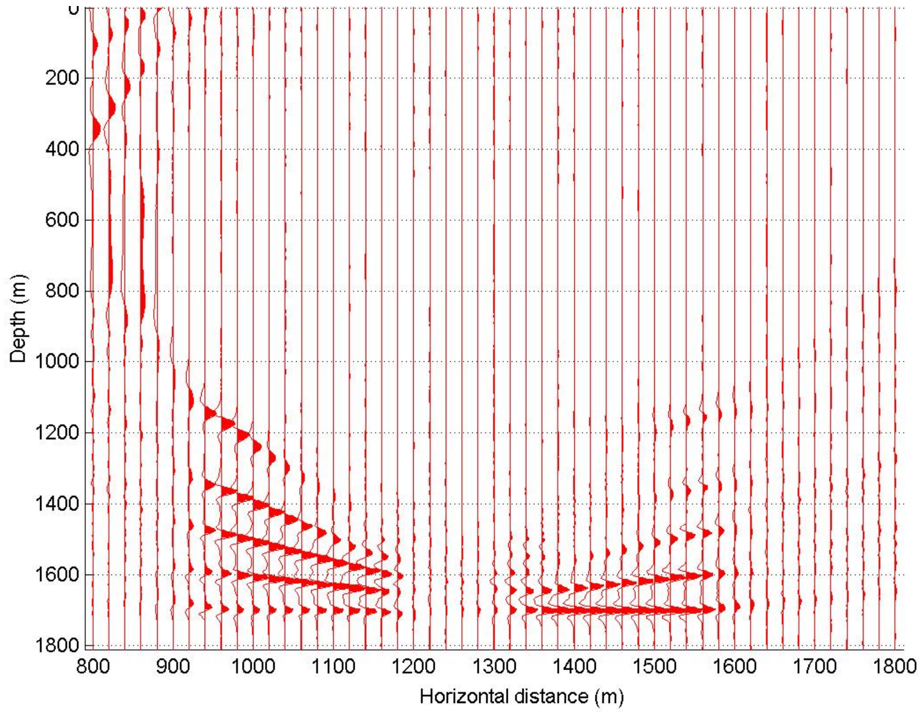

FIG. 6b. Migrated section (model 2) using shots every 400 m, from SP114 to SP127.

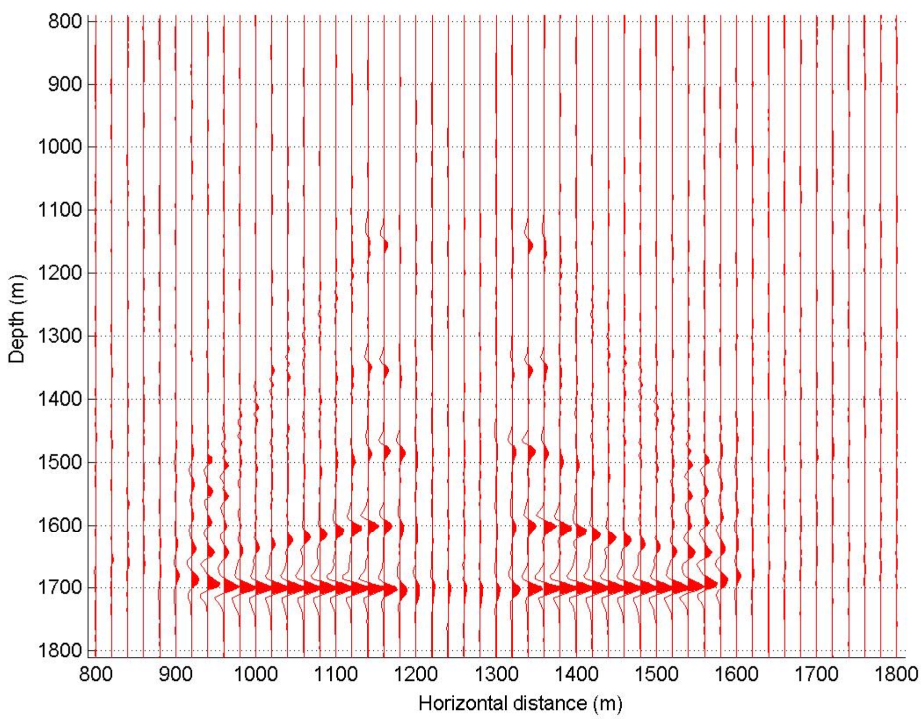

FIG. 7a. Migrated section (model 1) using shots every 400 m, from SP108 to SP120.

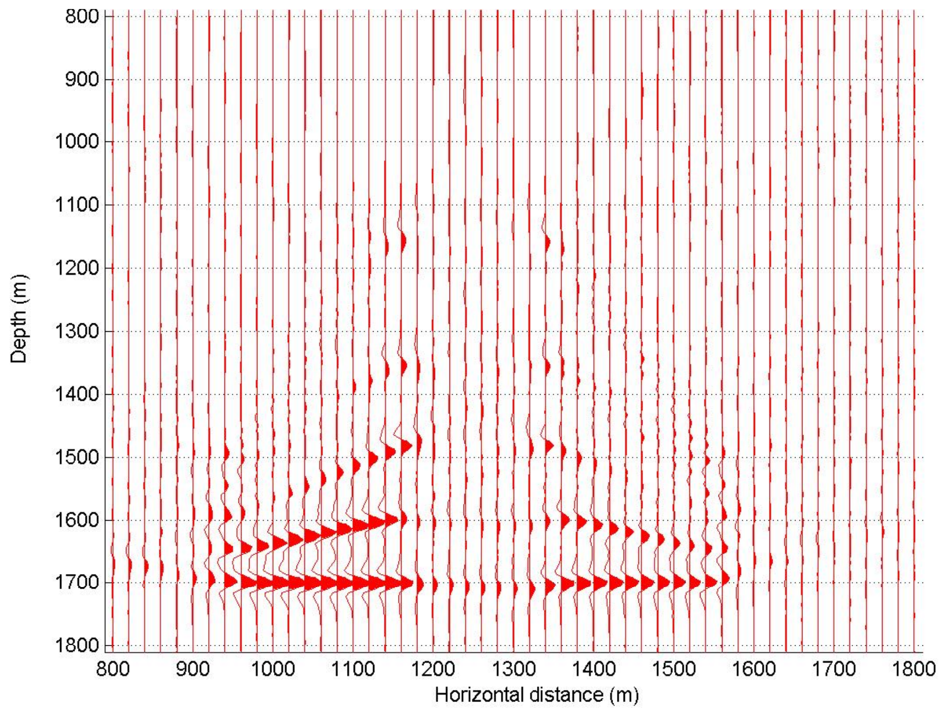

FIG. 7b. Migrated section (model 1) using shots every 400 m, from SP101 to SP105 and SP123 to SP127.

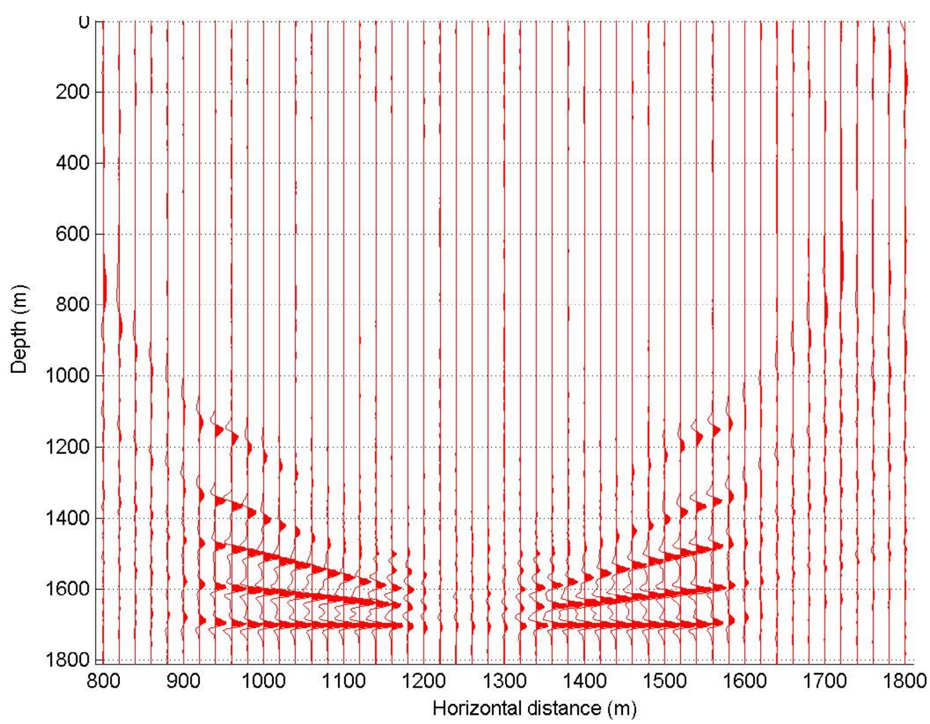

FIG. 8a. Migrated section (model 2) using shots every 400 m, from SP108 to SP120.

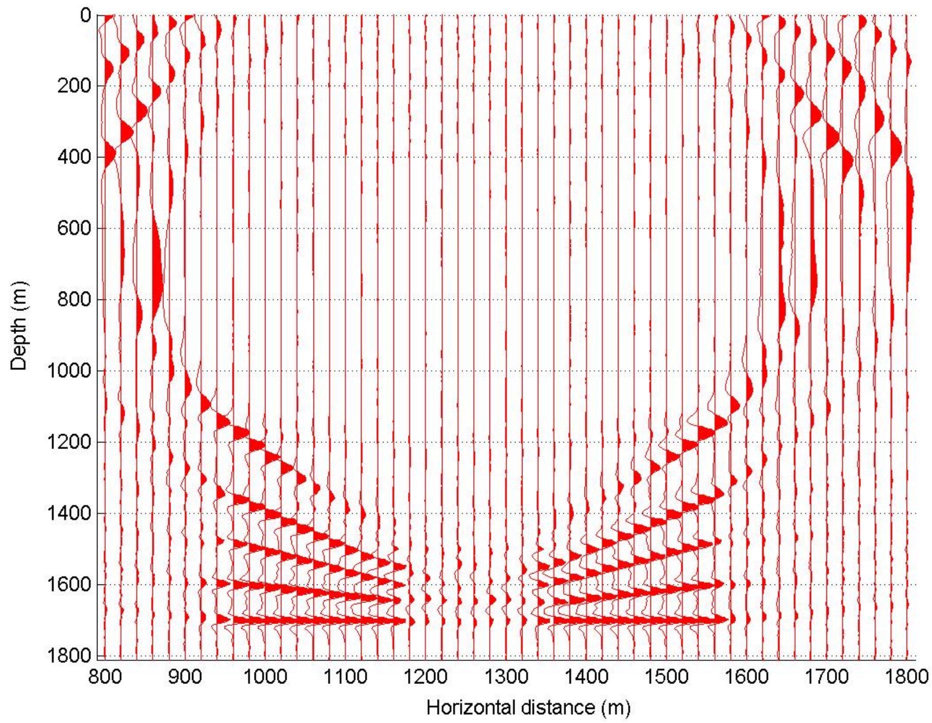

FIG. 8b. Migrated section (model 2) using shots every 400 m, from SP101 to SP105 and SP123 to SP127.

The algorithm used is based on imaging concepts mentioned by several authors (Claerbout, 1985; Miller et. al., 1987; Liner et. al., 1994; Slawinski et. al., 1996; Bleistein et. al., 2001): the energy recorded from the i^{th} shot location and the j^{th} receiver location could have come from any point of the subsurface (2D) located on the geometrical figure known as an ellipse with foci located at the shot and receiver spatial coordinates.

ANALYSIS OF SOURCE CONFIGURATIONS

The first geological model, Figure 1a, was migrated using the five different source configurations. A different result is obtained when the second geological model, Figure 1b, is migrated.

At first glance it can be seen the disability of imaging layers dipping as in model 1. This is caused because the scattered energy from the steepest layers can’t be recorded by the array configuration. To properly image these dipping layers, we will need to extend the range of receivers. The result obtained from using a longer range of receivers shows the improvement in the quality of the image, Figure 9b. The shot spacing used in this configuration was 100 m, and the receivers were extended as in Figure 9a.

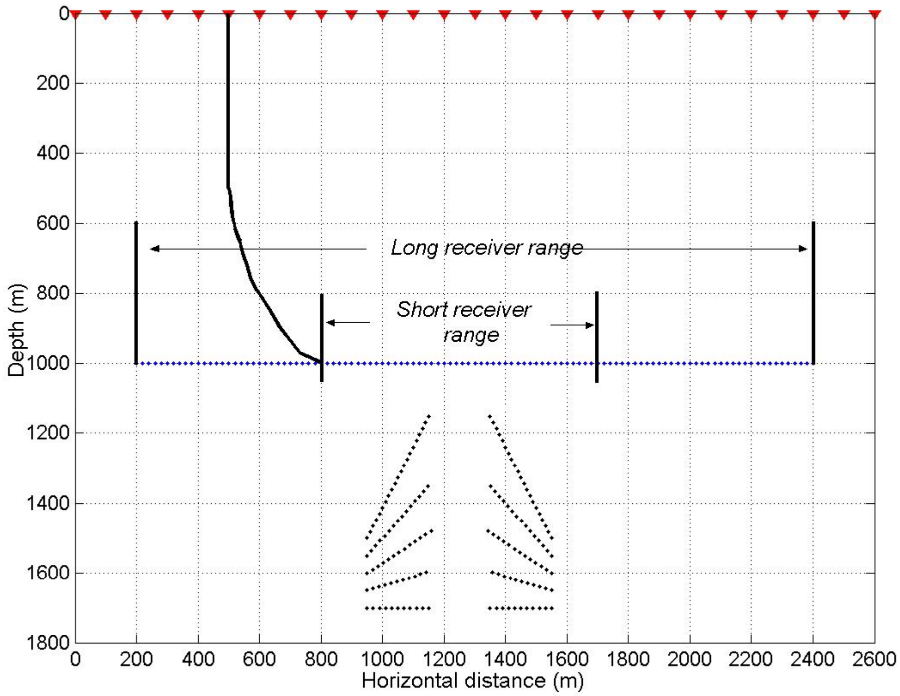

FIG. 9a. Model using a longer receiver range (65 additional sensors were used). Notice that the spread of receivers is longer to the right side respect to the scattering points centre (5 more receivers).

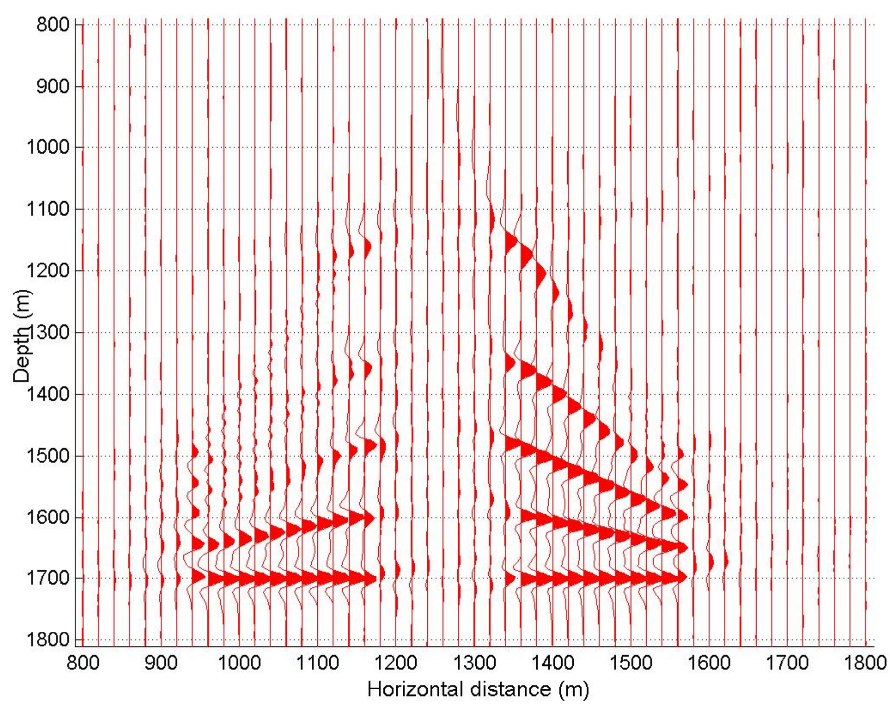

FIG. 9b. Migrated section obtained when more receivers are included in the model. Observe how the reflectors to the right side of the model (where there are more receivers) are better imaged.

A different picture is obtained when imaging model 2, Figure 1b. The position of these layers with respect the receiver array makes it possible to record all the scattered energy.

A slight difference in the quality is noticed when using a coarser source interval, Figure 4b. Observe how the energy couldn't be totally collapsed on the steepest reflectors, as well as the appearance of data smearing.

Assuming that shots were to be spaced 400 m and placed only on one side of the well, it can be observed how the image obtained is unbalanced, Figure 6a. It can be seen how the smearing of the data is severe at the opposite shots location and how the reflectors on the same side of the shots are not properly imaged. Figure 6b is the opposite of Figure 6a.

As final configurations, shots centred above the receivers and shots at the ends of the model were analyzed. In the first scenario, Figure 8a, the quality of the image is not much different than when shots had 100 m spacing, Figure 4a. The main problem with this configuration is that the reflections from the steepest layers won't be able to be recovered properly because they require longer offsets to be recorded.

The second scenario shows how using only shots at each end of the model cause smearing of the data, although the steepest layers are being properly imaged, Figure 8b.

CONCLUSIONS

With the ability of locating VSP tools in horizontal wells, the question of where to place the sources and design the surveys is germane. Different geological models and source configurations are analyzed and we find that

i) Depending on its location with respect to the receiver array, scatter points will or will not be imaged.

ii) Steep dipping layers require longer receiver arrays in the horizontal well or greater source offsets.

iii) It is required to have a symmetrical source spread with respect to the receiver array.

iv) Fine source spacing does not improve the quality of the seismic image substantially.

FUTURE WORK

i) Apply this method to vertically variable velocity media, and complex models.

ii) Test the velocity sensitivity of the method.

iii) Include amplitude and phase aspects in the code.

iv) Observe differences when using different number and location of sources and receivers.

v) Analyze the effect of using different receiver interval spacing.

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