

Multiple suppression with land data: A case study

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ABSTRACT

Some of the most important methods for multiple suppression are based on the *moveout* difference between the hyperbolas corresponding to primary and multiple reflections in a CMP gather. This moveout difference is exploited by means of the Parabolic Radon Transform. In this case study I review the methodology and show the result of its application to a 2-D land seismic line. Of particular importance are the results that show that without the suppression of multiples a distorted image is obtained of the Paleozoic and its stratigraphic terminations against basement, which constitute the exploratory objective in the area. This is partly due to the improved stacking velocities afforded by the suppression of the multiples.

INTRODUCTION

Accurate interpretation of subsurface seismic images is of the utmost importance for oil exploration and production. To achieve this goal it is necessary not only that the images be of good quality, but also that they correspond exclusively to the energy from the primary reflections, that is, those reflected from only one subsurface interface before their recording at the surface of the earth. Any other form of energy is undesirable. Such energy may correspond, for instance, to refractions, surface noise, guided waves and multiple reflections. They are collectively called coherent noise. Multiple reflections, energy that has been reflected at more than one interface, are particularly troublesome for seismic interpretation since they can be easily mistaken as primary reflections. Figure 1 shows a schematic representation of some of the more common forms of multiples. In general, long period multiples are more common in marine data, whereas short period multiples are more common in land data.

Multiple reflections are particularly difficult to discriminate from primary reflections in land data because they generally lack the familiar periodicity associated with marine data multiples. This has led to the misconception that multiple reflections are only a problem with marine data. Seismic interpretation in areas such as the one illustrated here can be severely jeopardized by the presence of short period multiples which are extremely difficult to identify. Figure 2 shows such a seismic line. It will be shown later that it is plagued with multiple reflections; but just from the seismic section, there is no way to tell immediately which reflections are multiples.

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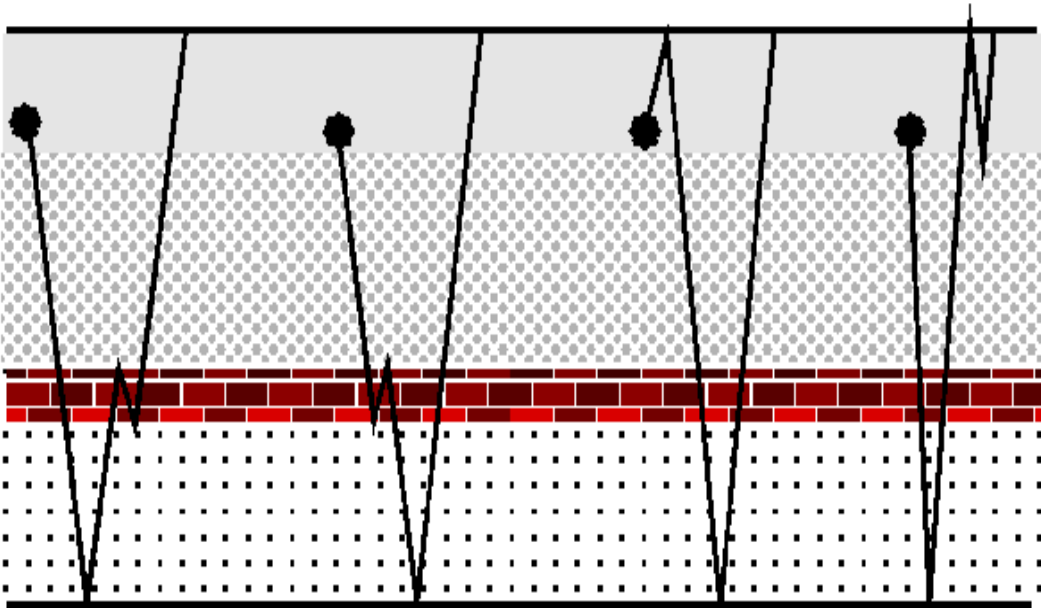
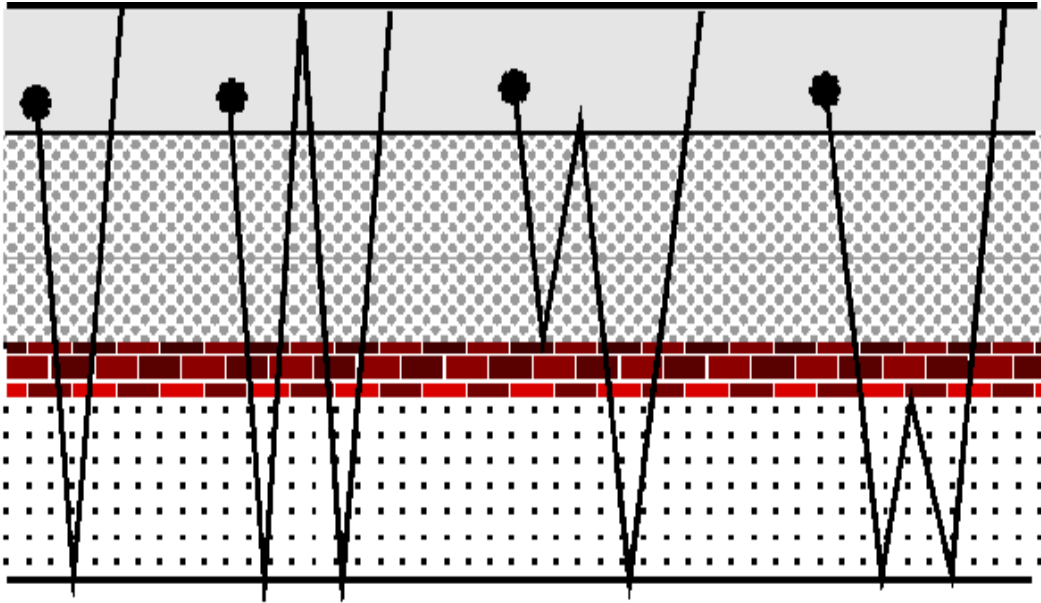


Figure 1: Broad multiple classification. Left: long period multiples. Right: short period multiples. `gabriel1-mul_esq1` [NR]

The suppression of multiples in seismic data processing can be achieved by several means of which filtering in the parabolic Radon Transform domain is the most common (Hampson, 1986). This process will be described in some detail and the results of its application to the seismic line in Figure 2 are presented. It is shown that the suppression of the multiples not only produce a more faithful image of the subsurface, but has the added benefit of allowing for the computation of more accurate NMO-stacking velocities.

THEORY OVERVIEW

Primary reflections in a common midpoint gather exhibit a hyperbolic moveout as a function of offset (gray lines on the left of Figure 3). The governing equation of the hyperbolic moveout is:

$$t_x = \sqrt{t_0^2 + \frac{x^2}{V_s^2}}, \quad (1)$$

where t_x corresponds to the arrival time of the reflection at offset x , t_0 corresponds to the arrival time at zero offset and V_s is the NMO-stacking velocity. This velocity is the one that best fits the moveout of the hyperbola and is determined by trial and error from among a series of probable velocities. If correctly chosen, this velocity allows the moveout corrected primary reflections to become horizontal (solid black horizontal lines in left of Figure 3).

Clearly the selection of the stacking velocities must be done to correct for the moveout of the primary reflections and not for the multiples. At a given zero-offset arrival time the velocity of a primary reflection is greater than that of a multiple, which according to Equation (1) implies a smaller moveout. This difference in moveout makes it possible to flatten the primary reflections while leaving the multiples under-corrected with a moveout approximately parabolic (Hampson, 1986). The Parabolic Radon Transform exploits this difference by summing trace amplitudes along parabolas of different zero-offset time and curvature. Hence, the transform can be considered a mathematical operator that maps parabolas in the t - x domain to small regions of the parabolic moveout (p) and zero-offset time (τ) domain.

This is schematically shown in Figure 3 which shows that the horizontal events in t - x domain map to a vertical strip in the τ - p domain at $p = 0$. The multiple reflections, on the other hand, are mapped in the τ - p domain to a region away from the $p = 0$ vertical line. This separation allows for the suppression of the multiple energy by zeroing out the τ - p region to the right of the dashed line in Figure 3. The inverse τ - p transform would then return the primaries to the t - x domain.

In practice the process is applied a little differently: it is the energy of the primaries that is suppressed (energy to the left of the dashed line in Figure 3) and inversely transformed to the t - x domain. The primaries are computed by subtracting the multiples from the original data in this domain. This method was first introduced with the name “inverse velocity stacking” (Hampson, 1986). The mathematical equivalent of the qualitative description given before for

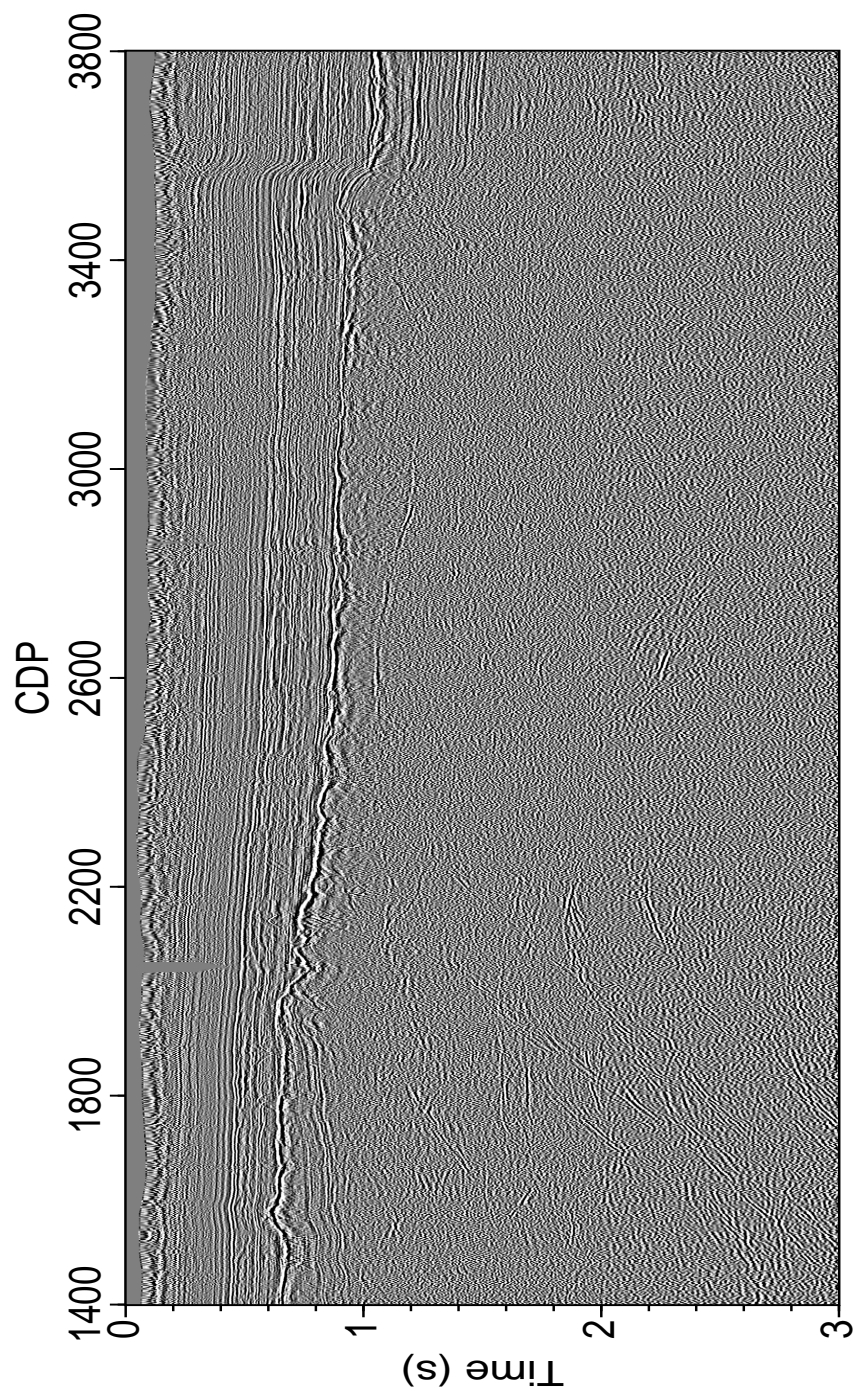


Figure 2: Stacked seismic section. Which reflections are multiples? gabriel1-res2_stack.rot
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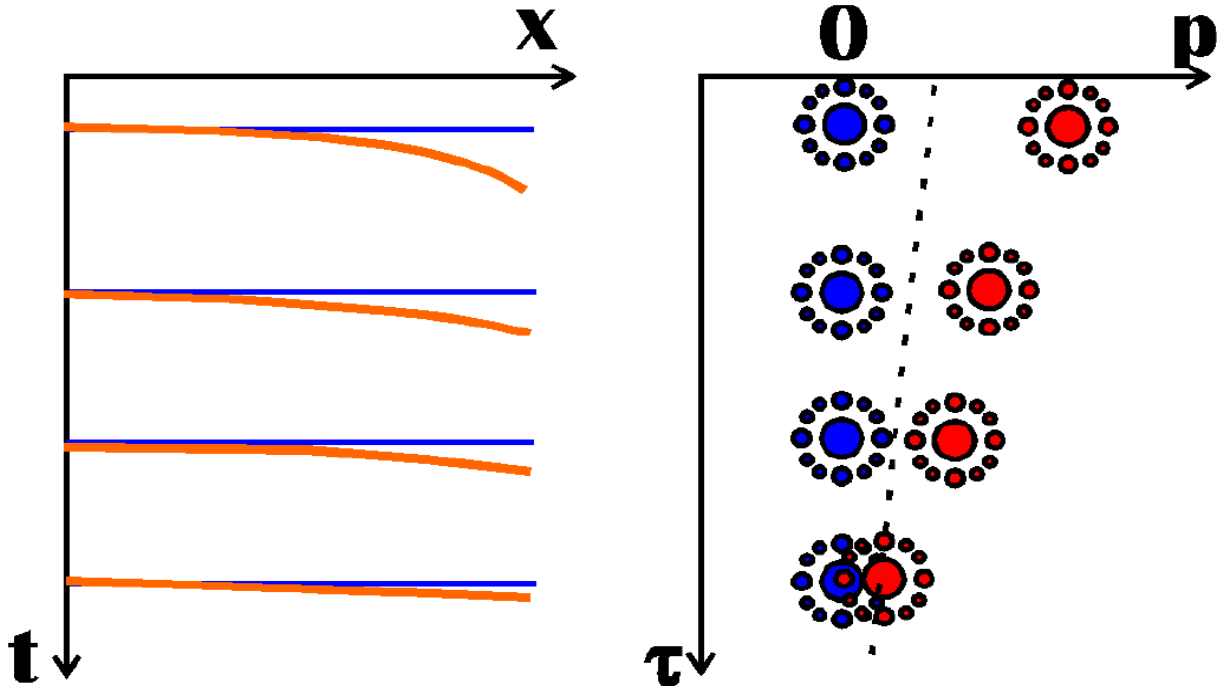


Figure 3: Schematic representation of multiple suppression by filtering in the parabolic Radon transform domain. Left: t - x domain, right: τ - p domain. gabriel1-mul_esq2 [NR]

the Parabolic Radon Transform is a set of two equations:

$$y(p, \tau) = \int_{x_{min}}^{x_{max}} z(x, t = \tau + px^2) dx \quad (2)$$

$$z(x, t) = \rho(t) * \int_{p_{min}}^{p_{max}} y(p, \tau = t - px^2) dp \quad (3)$$

The first equation corresponds to the forward transform (from t - x to τ - p) and the second one to the inverse transform (from τ - p to t - x). z and y represent the trace amplitudes in t - x and τ - p domain respectively. x_{min} and x_{max} correspond to the minimum and maximum CMP offset, p_{min} and p_{max} to the minimum and maximum parabola curvature used in the transform, and, as usual, the symbol $*$ denotes convolution. It is interesting to note that except for the difference in sign and the presence of the ρ term, the equations for both transforms are basically the same. The term ρ represents a filter that corrects the high frequency loss incurred in the forward transform (Claerbout, 1995). In the case of continuous functions these transforms are exact inverses of one another. In seismic data processing we deal with sampled information, however, which means that we need to use the discrete equivalents of equations (2) and (3):

$$y(p_i, \tau) = \sum_{k=0}^{N_x-1} z(x_k, t = \tau + p_i x_k^2) \Delta x \quad (4)$$

$$z(x_k, t) = \rho(t) * \sum_{t=0}^{N_p-1} y(p_i, \tau = t - p_i x_k^2) \Delta p \quad (5)$$

where N_x and N_p are the number of traces and parabolas respectively.

The need to work with discrete equations may give rise to aliasing problems (Yilmaz, 1987) as well as to some stability problems related to the selection of the number of parabolas used in the transform. In commercial software packages the transform is normally implemented in the f - x domain because of issues related to the amplitude of the inverse transform which is computed via a numerical optimization process. The discussion of these details, which are very important for the successful application of the method, are out of the scope of this paper. See for example (Anderson, 1993) and (Alvarez, 1995).

GEOLOGICAL TARGET

The geological and geophysical target in the study area are the pinchouts of the Paleozoic sequence against a metamorphic basement. The area is characterized by a series of paleohighs and an important Paleozoic section. These basement highs controlled the sedimentation of Tertiary sandstones. For the most part, the Cretaceous has been eroded away. The main risk for exploration is the detection of the sandstone pinchouts and the quality of the reservoir rock. In general the Paleozoic sequence has not been thoroughly studied although it is believed to be of great potential for large oil accumulations.

METHODOLOGY

The selected line was processed in the following way:

- Conventional reprocessing of the original field data without any special regards for multiple suppression except for the usual selection of high stacking velocities. The resulting seismic section is illustrated in Figure 2 and can be considered the control section against which the results of the multiple suppression will be evaluated. It is virtually impossible to identify the multiple reflections in this section.
- Multiple suppression with Hampson's method using three different implementations of the Parabolic Radon transform: (1) SU package of Colorado School of Mines, (2) Hampson-Russell AVO package, and (3) Promax processing system. Input data were the NMO-corrected CMP gathers from the conventional processing sequence.
- Velocity analysis and stacking of primaries and multiples independently. DMO, velocity analysis and finite difference migration of primaries.

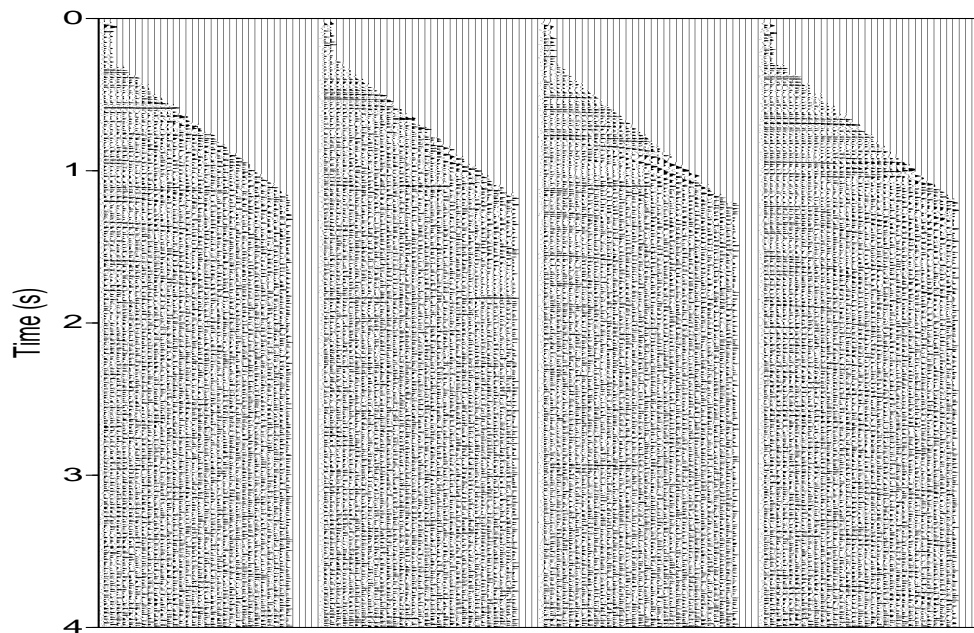


Figure 4: Supergathers before multiple suppression. `gabriel1-HR_prim_mul1.SG` [NR]

RESULTS AND ANALYSIS

In order to increase the signal-to-noise ratio of the data for comparison purposes “supergathers” were created, with each one taken as an average of 11 consecutive CMP’s. Figure 4 shows some of these supergathers before the multiple suppression. Notice the almost flat primary reflections and the curved multiples. Figure 5 shows the same supergathers for the extracted primaries. Figure 6 shows the remaining multiples (the plot amplitude has been amplified to show the details of the curvature). The extraction of the multiples was successful except on the shallow part where there are not enough traces to discriminate between primaries and multiples. Basically the same results were obtained with all three implementations of the Radon Transform.

Figure 7 shows the stacked section of the primary reflections after the suppression of the multiples. Comparison of this section with Figure 2 shows that many of the reflections in the original stacked section did indeed correspond to multiple reflections. As mentioned before, these multiple reflections would have been virtually impossible to identify in the original stacked section. To stress this point, Figure 8 shows an amplified version of the stacked section for the multiples. Obviously the shallow part is suspect as explained before, but the deep section shows the most prominent multiple reflections. If a stacked section such as this were handed to a seismic interpreter, there is the risk that he could make erroneous inferences about the subsurface. A more extreme case would be that in which the NMO correction was performed

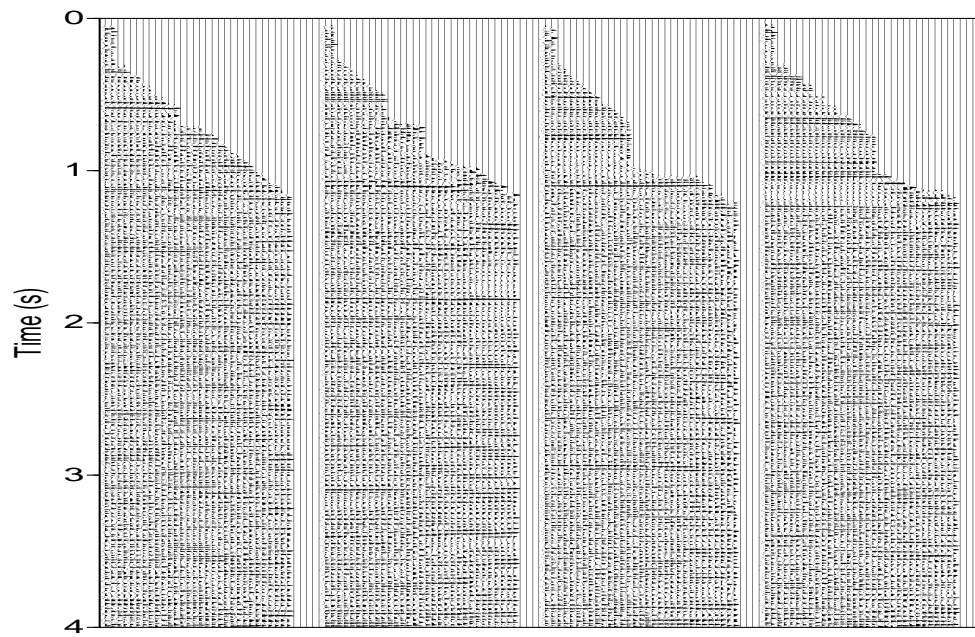


Figure 5: Supergathers after multiple suppression. Primaries only.
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with the velocity of the multiples, such as could happen if the multiples (at least some of them) were incorrectly taken to be primaries.

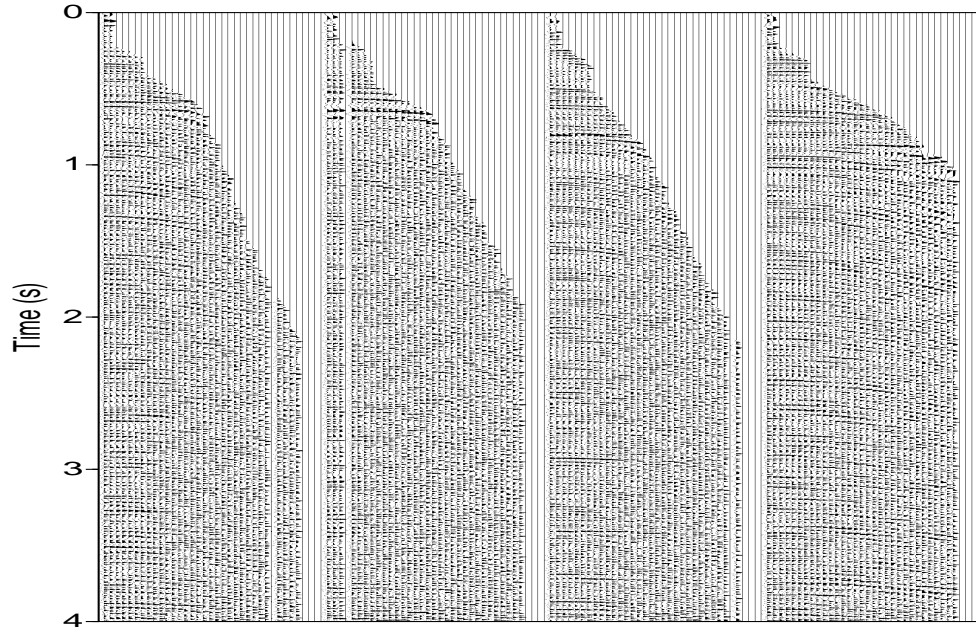


Figure 6: Supergathers after multiple suppression. Residual multiples.
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It is important to realize that the suppression of the multiples not only makes interpretation easier by highlighting the primaries, but also improves the resolution of the primaries by allowing a better selection of the primary stacking velocities. Figure 9 shows a typical velocity analysis before the suppression of the multiples, whereas Figure 10 shows the same velocity analysis after the suppression of the multiple energy. It is clear that the presence of the multiples masked the velocity trend of the primaries making it more difficult to select the correct stacking velocity function appropriate for the NMO correction of the primaries. By getting rid of the multiples it becomes clear what the primary stacking velocities should be. The better selection of the primary velocities improves the image of the stratigraphic features of interest such as pinchouts of Paleozoic against the basement.

CONCLUSIONS

Multiple reflections often occur in land data, in particular in areas with layer-cake geology and strong acoustic impedance contrast between adjacent layers in the subsurface. The fact that these multiples tend not to be periodic makes them difficult to identify in the stacked section and can lead to the erroneous conclusion that there are no multiples. The Parabolic Radon

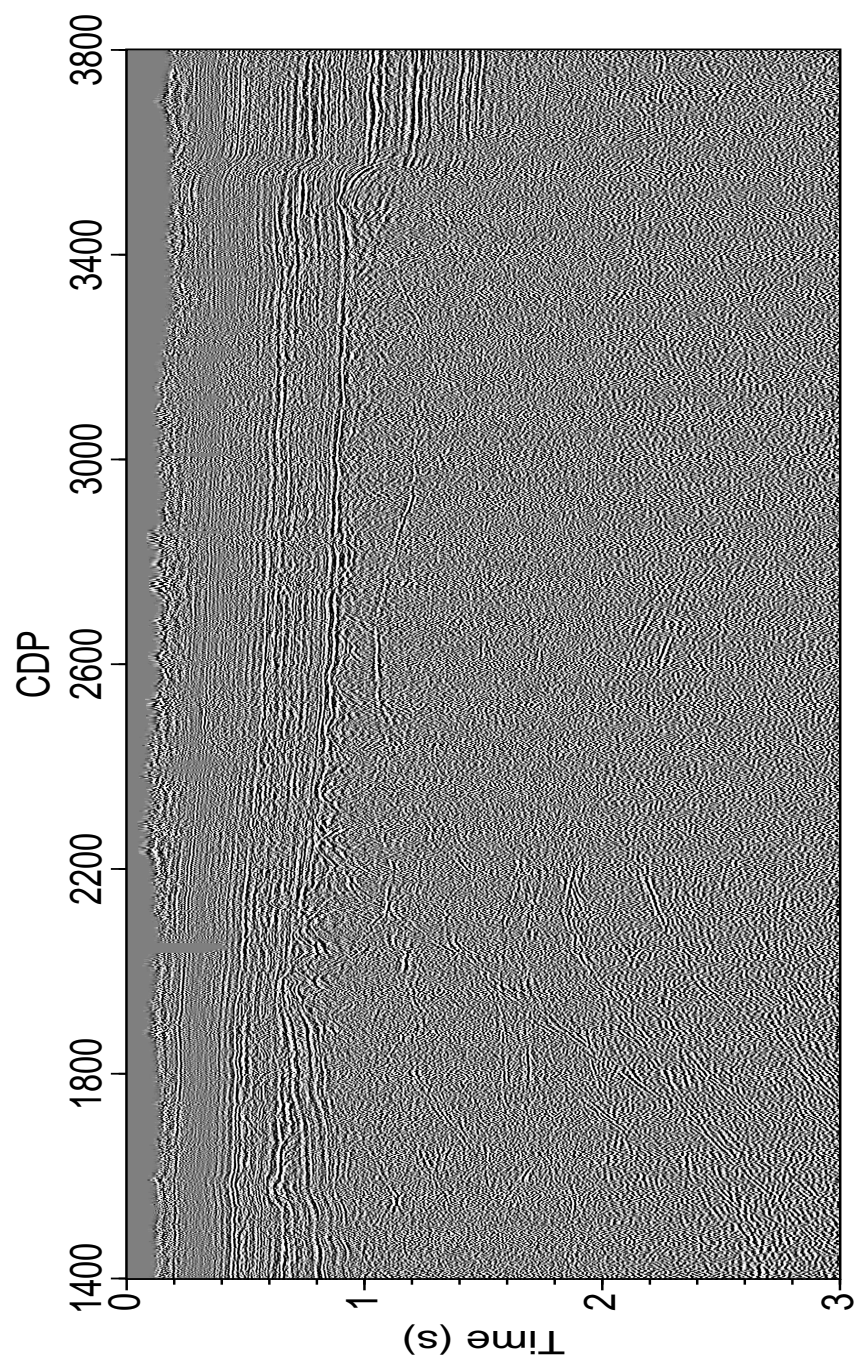


Figure 7: Stacked section of primaries only. `gabriel1-HR_prim_stack1.rot` [NR]

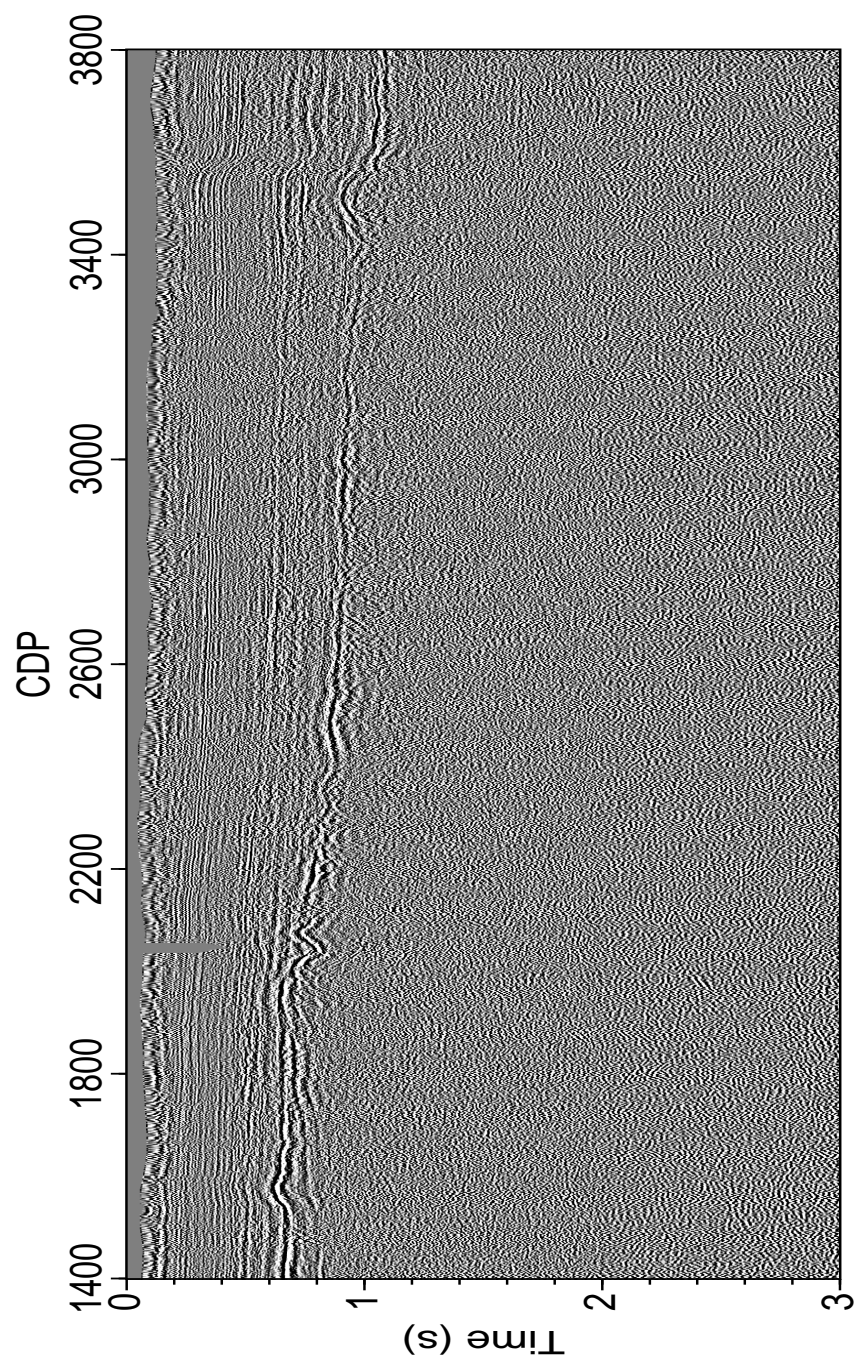


Figure 8: Stacked section of residual multiples. `gabriel1-HR_mul_stack1.rot` [NR]

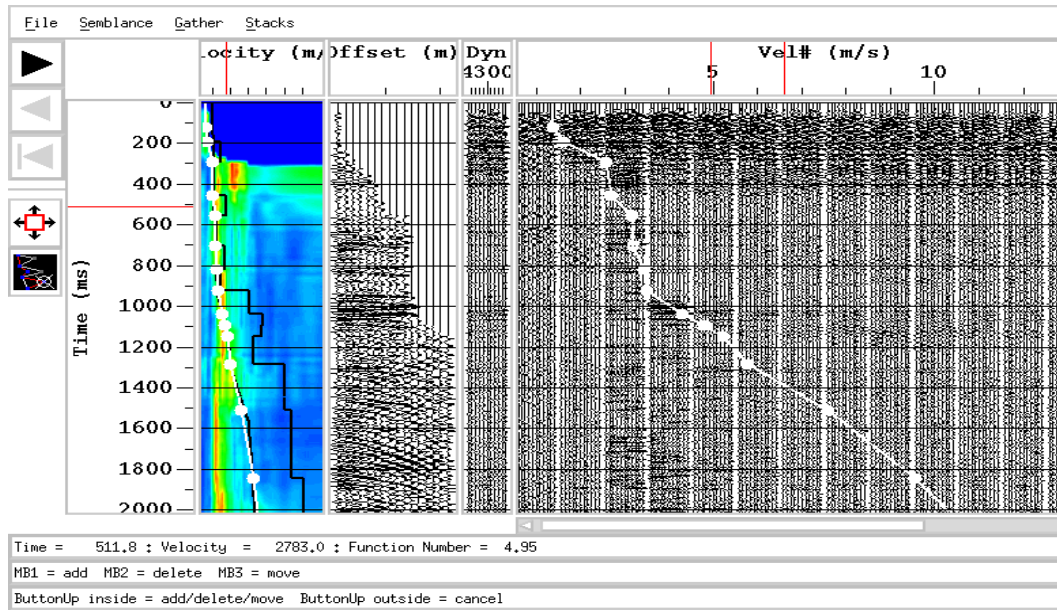


Figure 9: Velocity analysis before multiple elimination. Notice the multiples at low velocities.

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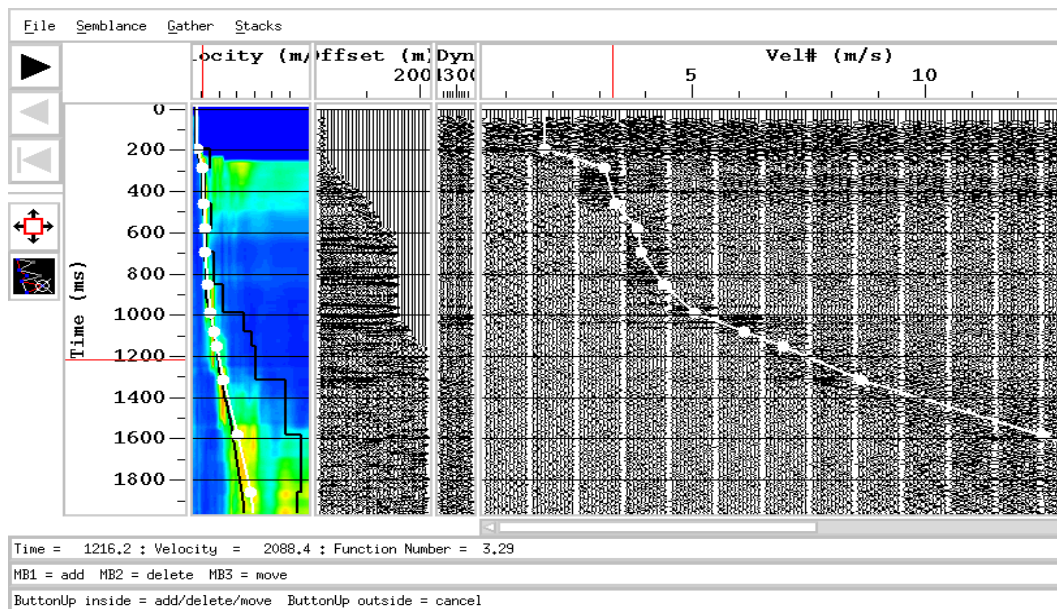


Figure 10: Velocity analysis after multiple elimination.

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Transform can be used to suppress the multiples if their difference in moveout with respect to the primaries is large enough (as usually happens). Suppressing the multiples is a requirement for any faithful interpretation of the seismic data.

The suppression of the multiples not only helps to identify the primaries, but also allows a better selection of the stacking velocities for the primaries, in that way improving the quality of the primary reflections themselves.

Multiples are a problem not limited to marine data. Multiples can be as severe a problem with land data, especially since they are more difficult to identify and hence are more likely to be mistaken as primaries.

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