TRUE SURFACE PROCESSING OF SPRING COULEE

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ABSTRACT

The true surface processing approach takes into account the difference in the source and receiver raypaths introduced by variable elevation and weathering. In this project seismic data from the Spring Coulee line, in this case P-P, are processed using the true surface methodology. The post-stack time migrated P-P section obtained shows important differences with respect to other published results.

INTRODUCTION

The NMO or Dix equation (Dix, 1955) is derived for a model of N flat layers with small angle ray bending. In this equation the time, *t*, is given by

$$t^2 = t_0^2 + \left(\frac{x}{v}\right)^2 , \qquad (1)$$

where $t_0 = \sum_i^N \Delta t_i$ and $v^2 = \frac{\sum_i^N v_i^2}{t_0^2}$. Δt_i is the traveltime and v_i the interval velocity through the i^{th} layer. In the real earth looking at different shots and receivers there are variations in elevation and near surface velocities.

For zero offset typically statics are calculated which shift the traces up and down as follows: the refraction first breaks are used to build a weathering model of the near surface down as deep as the refraction energy penetrates. This is generally the top of the well consolidated rock - an event called the marker. The static time shift is then the travel time from the flat datum to the marker at the replacement velocity minus the real travel time from the surface to the marker. This places the marker event in time at its true position in depth scaled by the replacement velocity. Velocity changes in the material below the marker will cause some pull up/down but the large shifts due to the surface/near surface have been removed. A replacement velocity is chosen that is close to the mean sub marker velocity between the high and low points of the Marker. If there is a flat event beneath the lowest point on the marker this velocity will cause it to remain flat in time. Now this solves the problems for zero offset traces but in practice there are many non zero offset traces that should be corrected for the horizontal travel (NMO) so that can be stacked together.

Clearly if static shifts are applied to the traces for the shot and geophone positions and then it is assumed that the wavefield travels from datum to the reflection point where no static shift has been applied a serious error is introduced. The error decreases with time but is unnecessary. If the NMO equation is going to be used it should at least be used with the traveltimes and velocities of the material through which the sound waves have actually passed. So since the shot and geophone positions are different then each side of the raypath must be corrected separately. Moreover since travel above the surface has been corrected with a vertical time shift this time must be removed from the equation. This results in the following surface referenced NMO equation:

$$t = t_s + t_g + \sqrt{\left(\frac{t_o}{2} - t_s\right)^2 + \left(\frac{x_s}{v}\right)^2} + \sqrt{\left(\frac{t_o}{2} - t_g\right)^2 + \left(\frac{x_g}{v}\right)^2}, \tag{2}$$

where t is the two way time on the trace with statics applied, t_0 is the two way time from datum on the output trace for stacking, t_s and t_g are (datum-elevation)/$v_{replacement}$ for the shot and geophone respectively, x_s and x_g is the cmp to shot/geophone (s/g) horizontal distance, v is the stacking velocity used at this (*time,cmp*) location. Note that the same stacking velocity for all traces imaging at a given (time,cmp) location is used.

It is not obvious that this is the best equation to use with variable weathering and elevation but is easy to see that it makes sense as follows: if the elevation is different but the weathering layer stays the same then more sub marker material has been added. Since this is consolidated material (fast) it will not change the Dix equation velocity considerably and only the vertical travel time ($t_0/2-t_{g,s}$) need to be changed to get the right answer. The equation works for this case.

If the elevation is constant but the weathering velocity decreases then the travel time to the target increases and the Dix stacking velocity that should be used decreases. The equation uses a smaller time based on replacing all the weathered material with replacement velocity and the larger stacking velocity. These two effects tend to cancel each other and still the correct moveout is obtained provided that the location considered is beneath the marker. As moving away from the marker time to the true surface in time (which is above the replacement surface $t_{g,s}$) the equation fails catastrophically so for this region $t_{g,s}$ is moved progressively up to the true surface in time.

In short, if statics are applied as described, provided the latter modification is used, equation (2) gives an accurate travel time correction in regions of variable elevation and weathering.

The True Surface processing approach has been an attractive tool to deal with the seismic data processing of converted waves (e.g. Kirtland Grech et al., 2004). In this paper the true surface processing of the P-P data of Spring Coulee is carried out as a preamble to its application to the processing of the converted wave component.

The Spring Coulee seismic lines

In January of 2008, a 3C-2D seismic program was by conducted by CREWES, ARAM and CGGVeritas near Spring Coulee, Alberta. An overview of the Spring Coulee 3C-2D survey is given by Bertram et al. (2008), and preliminary processing results are given by Lu and Hall (2008). Only the Line 2008-SC-01, ARAM, 2xMertz, SM7 is considered in this report.

Processing sequence for the vertical component

A true surface sequence processing was applied to the vertical component as follows

- Geometry and data QC

- Surface consistent deconvolution
- Filtering in the radial transform domain to attenuate linear noise
- Time Variant Spectral Whitening
- Refraction and elevation statics (Fixed datum)
- 2 iteration of velocity picking and Residual Statics
- Post-Stack Time Migration

Data QC

During the data QC the cross plot of the Max_Freq and the offset revealed the presence of a high frequency noise packet affecting around 4% of the traces (Figures 1 to 3). The Max_Freq is obtained as the frequency for the maximum amplitude in the Amplitude Spectrum for each trace.

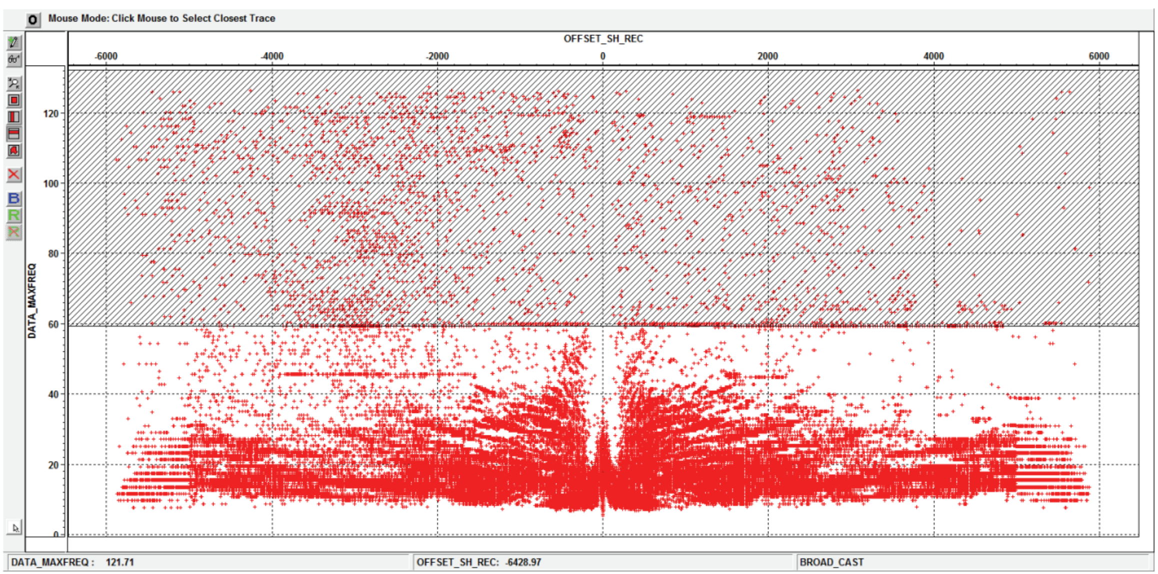

Figure 1. Maximum frequency vs. Offset. There are 4% of the traces with maximum frequency greater or equal to 60 Hz. This is an indication of high frequency noise.

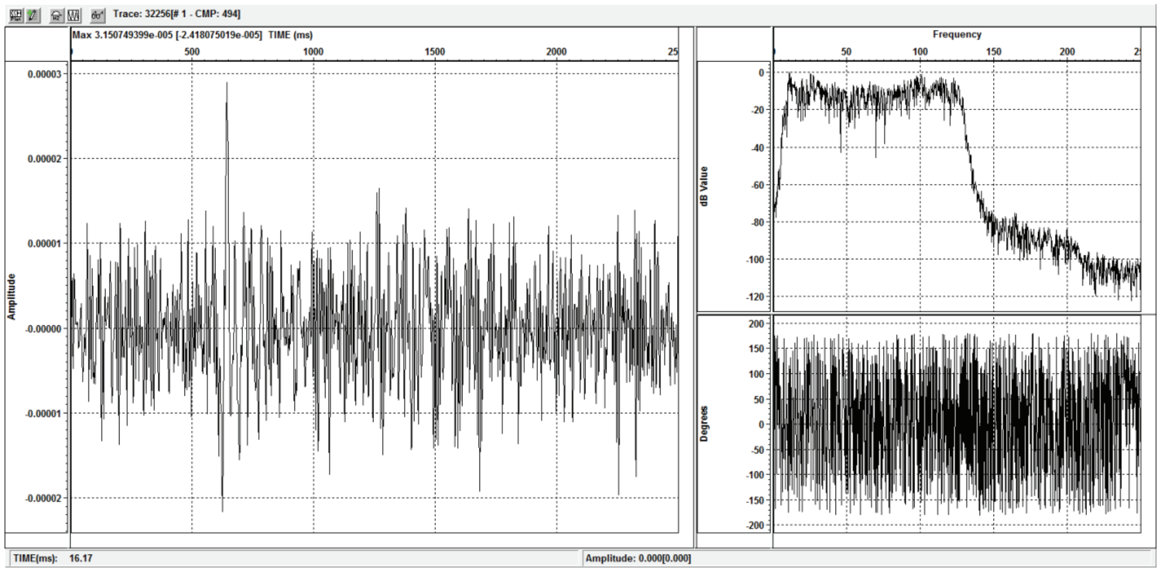

Figure 2. One of the traces and its amplitude and phase spectra selected randomly from the dashed area in Figure 1.

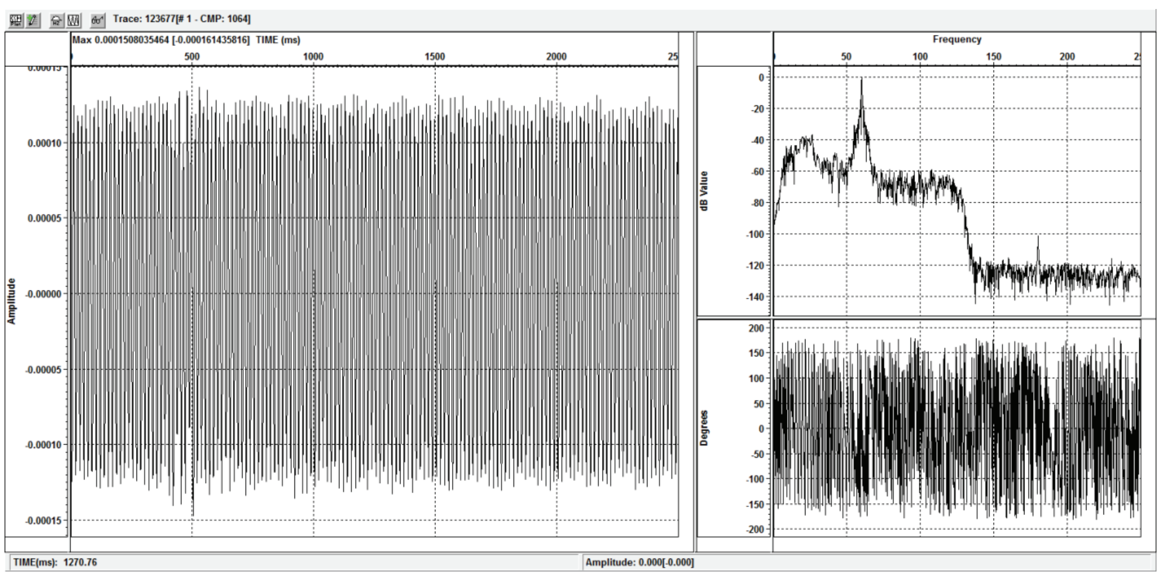

Figure 3. One of the traces with Max_Freq equal to 60 Hz. There are around 700 traces with this problem.

A closer examination of the traces in the receiver domain allows to detect that the following receiver stations were recording only noise: 101, 174, 175, 176, 326, 327, 359, 363, 364, 413, 416, 589, 694. As an example in Figure 4 station 174 is shown. 2483 traces that belong to these receiver gathers were killed.

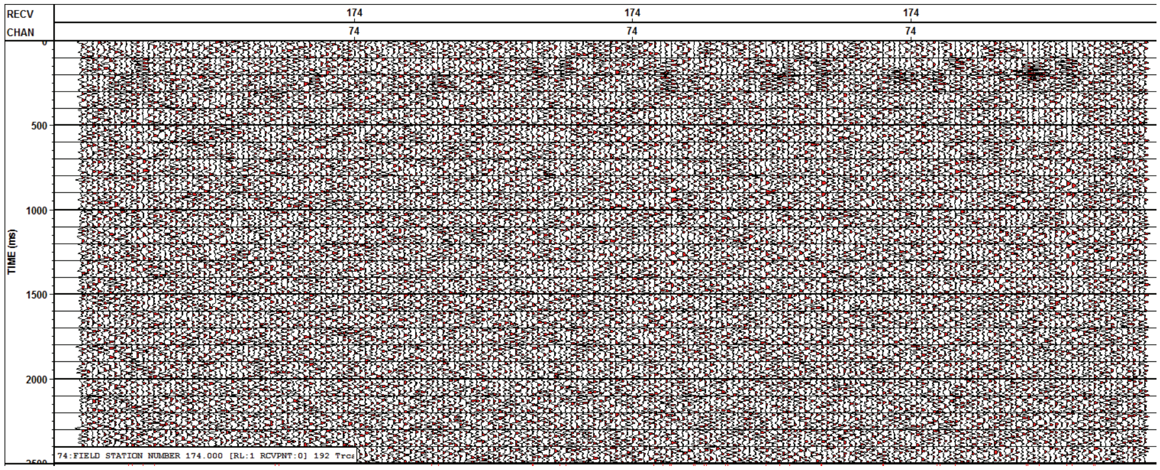

Figure 4. Receiver gather recorded at station 174.

Surface Consistent Deconvolution, linear noise attenuation and Time Variant Spectral Whitening

Only the data inside the window shown in Figure 5 and with offset greater than 1000 m were used to design the surface consistent deconvolution operators. Figure 5 also shows a shot before and after surface consistent deconvolution. The same shot is shown in Figure 6 and 7 after filtering in the radial transform domain and time variant spectral whitening respectively.

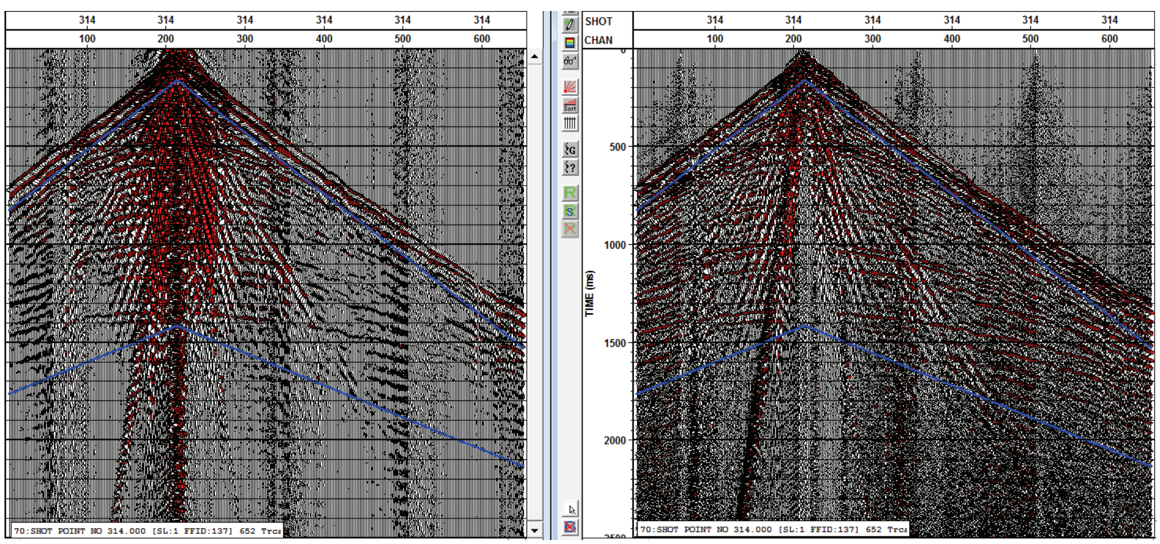

Figure 5. Shot 314, before (left) and after (right) surface consistent deconvolution. The blue lines correspond to the time window used to design the operators.

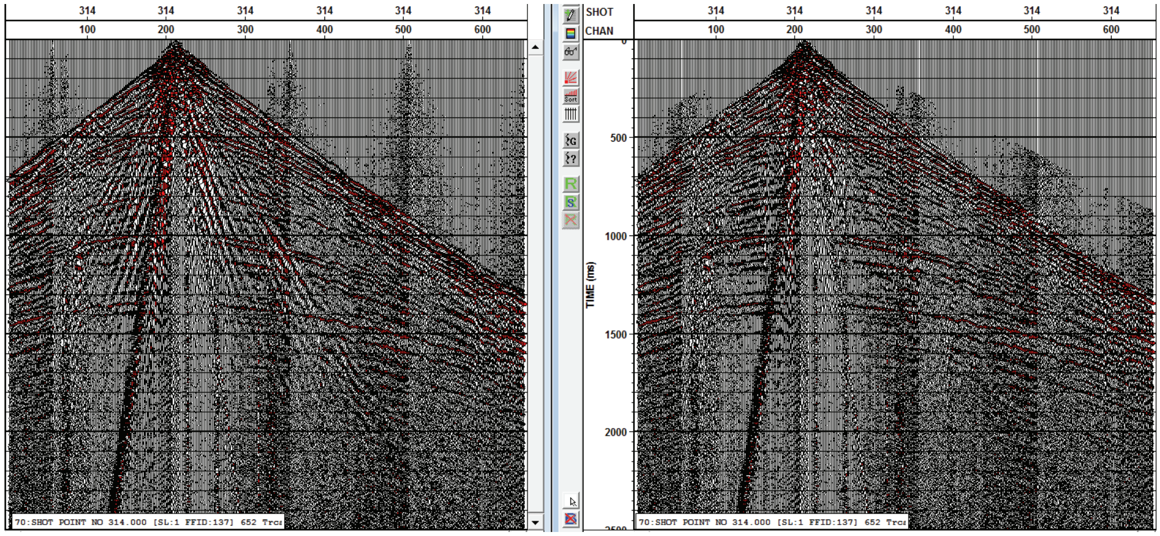

Figure 6. Shot 314 before (left) and after (right) linear noise attenuation in the radial filtering domain

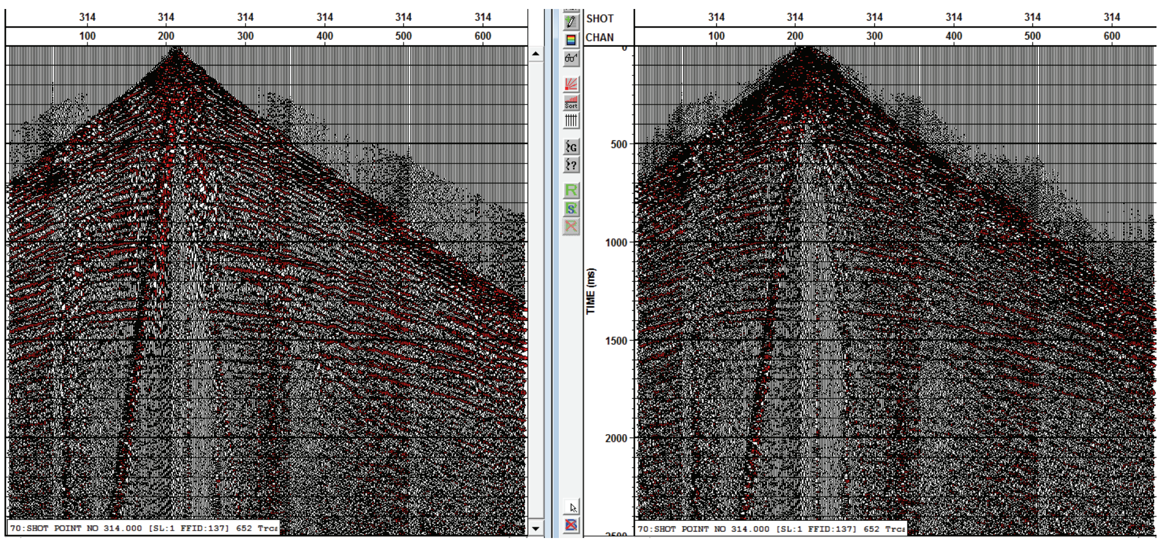

Figure 7. Shot 314 before (left) and after (right) Time Variant Spectral Whitening.

Refraction and elevation statics

The model of the near surface shown in Figure 8 was created from refraction statics calculation based on First Breaks. The fixed datum used is 1250 m, the replacement and the weathering velocities are 3500 m/s and 800 m/s respectively. The maximum offset of the first breaks used in the calculation is 3000 m. The strong lateral variation in the thickness of the modeled second layer and the differences in elevation at the surface suggest that true surface NMO would make a difference in the processing of this seismic line.

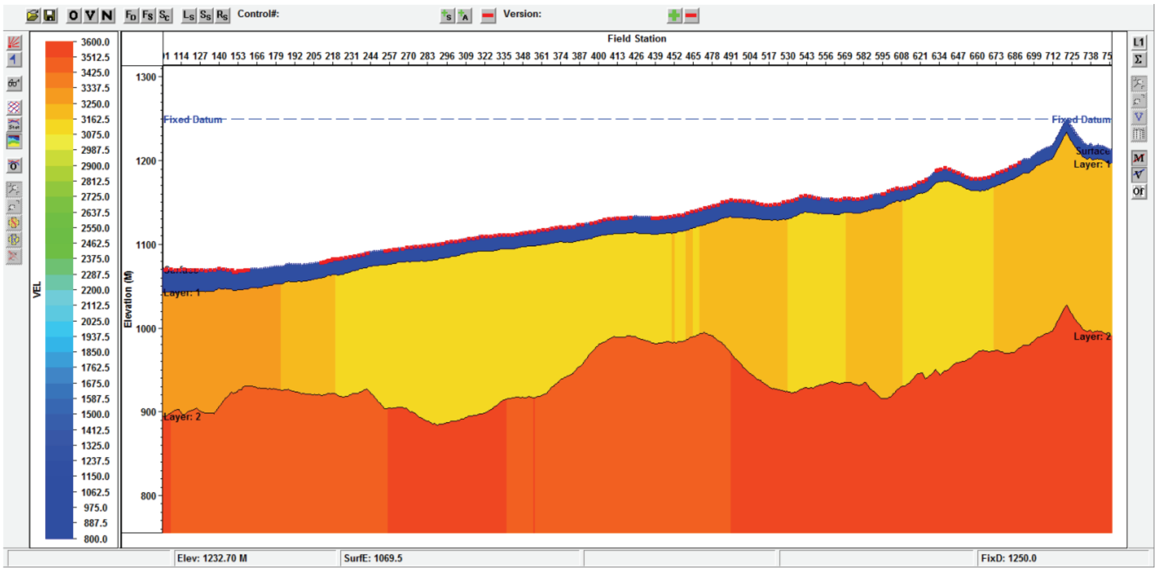

Figure 8. Near Surface model generated from first breaks. The color scheme corresponds to the near surface velocities.

Post Stack Time Migration

A 45-60 filtered finite differences migration algorithm was applied to the data after 2 iterations of residual statics and velocity picking were carried out. The result is shown in Figure 9.

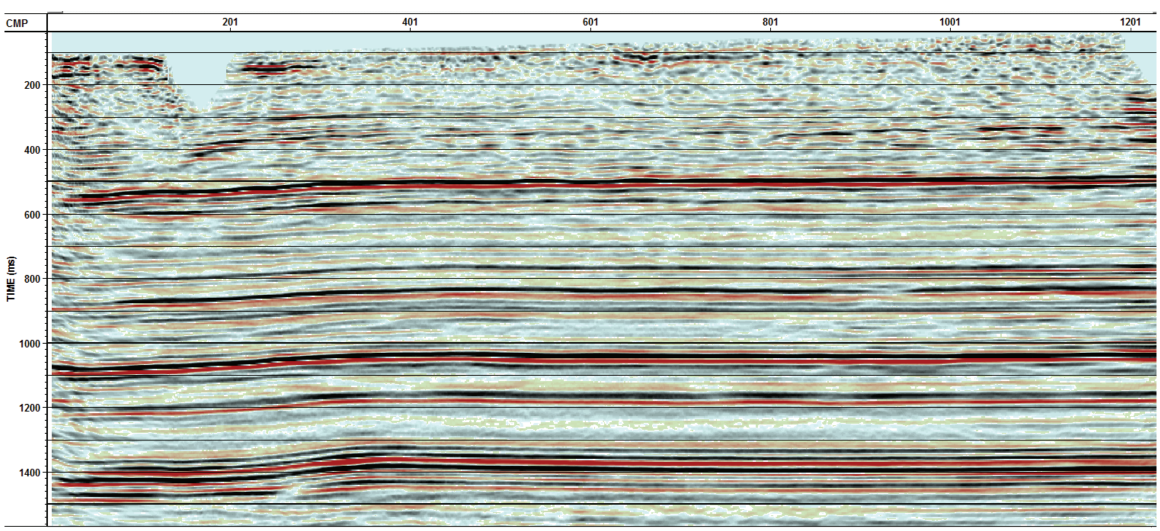

Figure 9. Finite Differences post stack migration of P-P section. North is left.

DISCUSSION

The variations in elevation and weathering observed in the two layers near surface model build from refraction is a sufficient reason to try the true surface layer approach in the processing of the P-P seismic data. In fact the post stack migrated section (Figure 9) shows important differences with respect to the results obtained by Lu and Hall (2008) shown in Figure 11 of their report. The application of True Surface processing yields flatter reflectors and less faults. The next step in this work must be the conciliation of the two results by establishing thoroughly the reasons of the dissimilar results. However the main direction of this project is the application of the True Surface approach to the P-S data of this line where a huge impact is expected.

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