Analysis of the West Castle seismic surveys

Part II. 2D seismic data processing and modelling of the vertical component data

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ABSTRACT

As part of the West Castle seismic surveys, a 2D vertical-component 10 km crooked line was acquired and processed. The main objective was imaging the geologically complex subsurface structures of this area. During the processing we noted the low signal to noise ratio of the data as well as the variable quality of the data along the line. The pre-stack time migrated image allowed the observation of strong reflectors in the south of the line and the interpretation of some of the major geological structures of the areas such as the Lewis and Gardner thrusts.

INTRODUCTION

A 10 km vertical component seismic line was acquired in southern Alberta with the purpose of imaging a geologically complex area underneath overthrust layers. The near-surface high velocity rocks, variable topography and lateral velocity changes each caused problems for seismic data acquisition and processing as they gave rise to seismic signal attenuation, noise contamination and distortions of arrival times.

Acquisition parameters and seismic data processing description

This vertical vibrator crooked line was acquired with a split-spread configuration (+/-2000 m), source interval of 10 m and group-receiver interval of 5 m. The split-spread receiver configuration had 272 channels at a 5 m station interval. The nearest offset was 5 m and farthest 3110 m, which is bigger than the expected one because of the crooked line geometry. The data were quite noisy and suffered from statics problems caused in part by the high velocity, absorbent rocks at the surface, the severe changes in elevation from 1100 m to 1400 m and the rough topography. Figures 1 and 1a show shot gathers for the south, middle and north portions of the line, as well as the raw data stack section. We can see how the quality of the shots in the middle and north of the line degrades, with a higher signal to noise ratio in the south, which is the area closer to the Lewis thrust. High amplitude, low velocity surface wave noise dominates the near offsets while back-scattered surface waves degrade reflections. The data were processed as well as possible to attenuate the noise, enhance coherency, resolve the statics problems and determine velocity models for stack and migration.

Extensive testing was done to derived a refraction static solution, the methods tested included a delay time method (MISER®), Tomography and the Extended Generalized Reciprocal Method (EGRM), this last method showed the best solution even though this surface-consistent technique is best suited for linear first breaks and regular acquisition geometries, which is not the case for crooked line geometries (Cox, 1999; Yilmaz, 2001 and Marsden, 1993). Despite the theoretical limitations of this method, the refraction statics obtained from this solution removed the static inconsistencies observed and helped to enhance some reflections (see Figure 3). We also applied residual statics later in the processing flow allowing a maximum shift of 32 ms. To address the problem of noise 3 passes of signal enhancement techniques were applied at different stages of the processing (Figure 2). The first pass targeted surface wave noise, coherent and random, as well as some linear noise such as airblast. The noise attenuation techniques were applied in the shot domain and included an air wave removal technique, f-x filters, generation of noise models that are removed using match filters, and spatial median filters applied in the frequency domain for limited and small frequency bands attenuation. This first pass of signal enhancement was followed by a surface consistent deconvolution testing, which produced the best results using an operator length of 160 ms and a unique linear window (Figure 4).

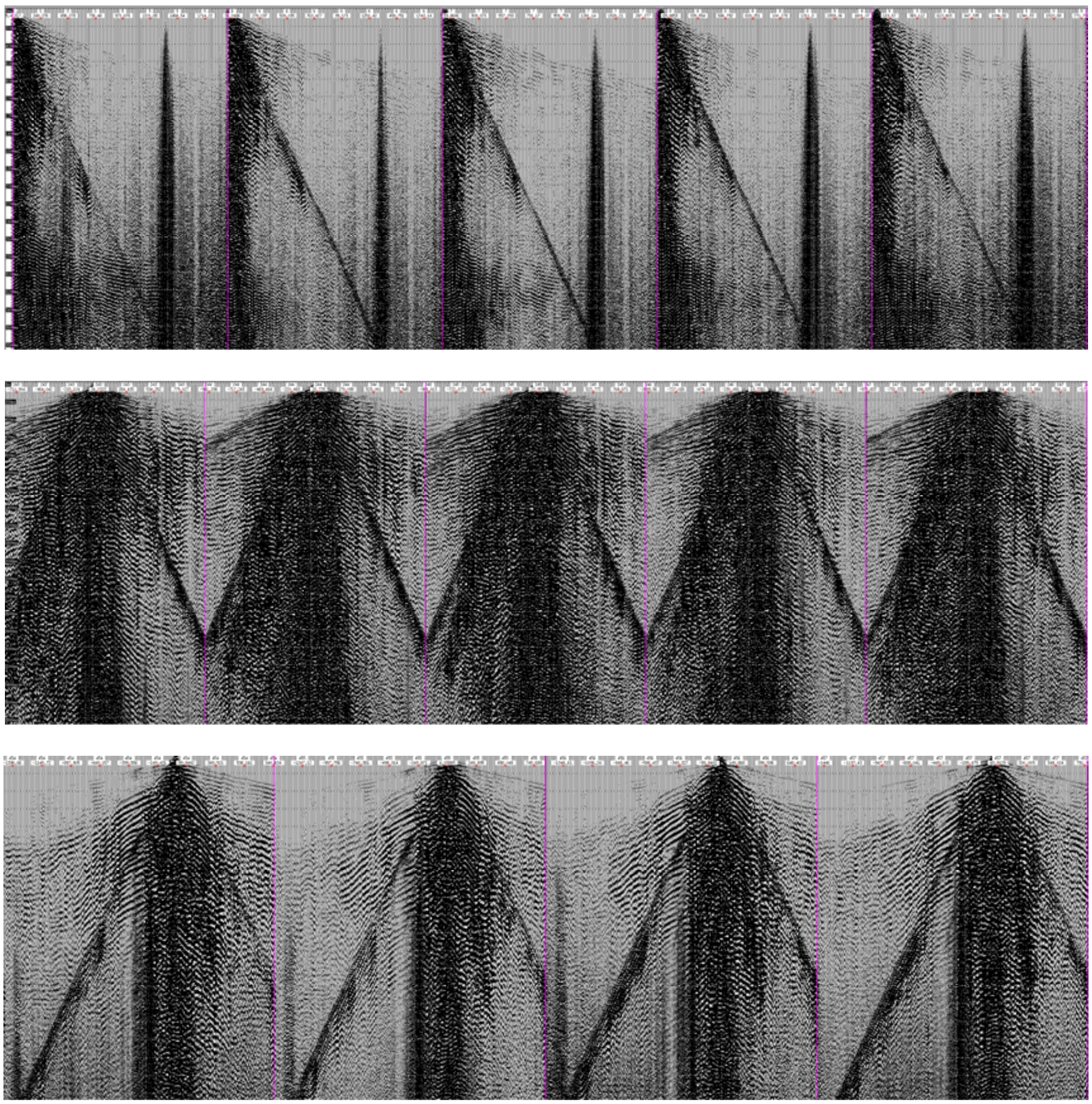

FIG. 1. Raw shots after geometry: South of the line shots (top), middle of the line shots (middle panel), north of the line shots (bottom).

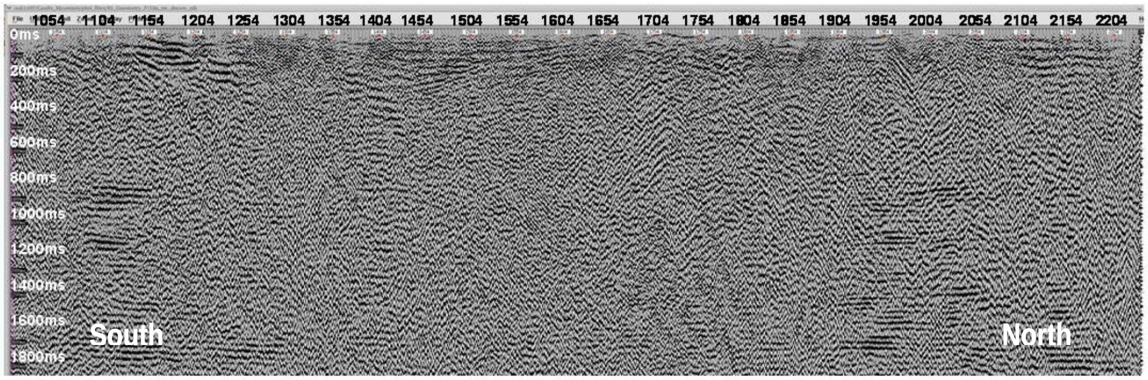

FIG. 1a. Brute stack section.

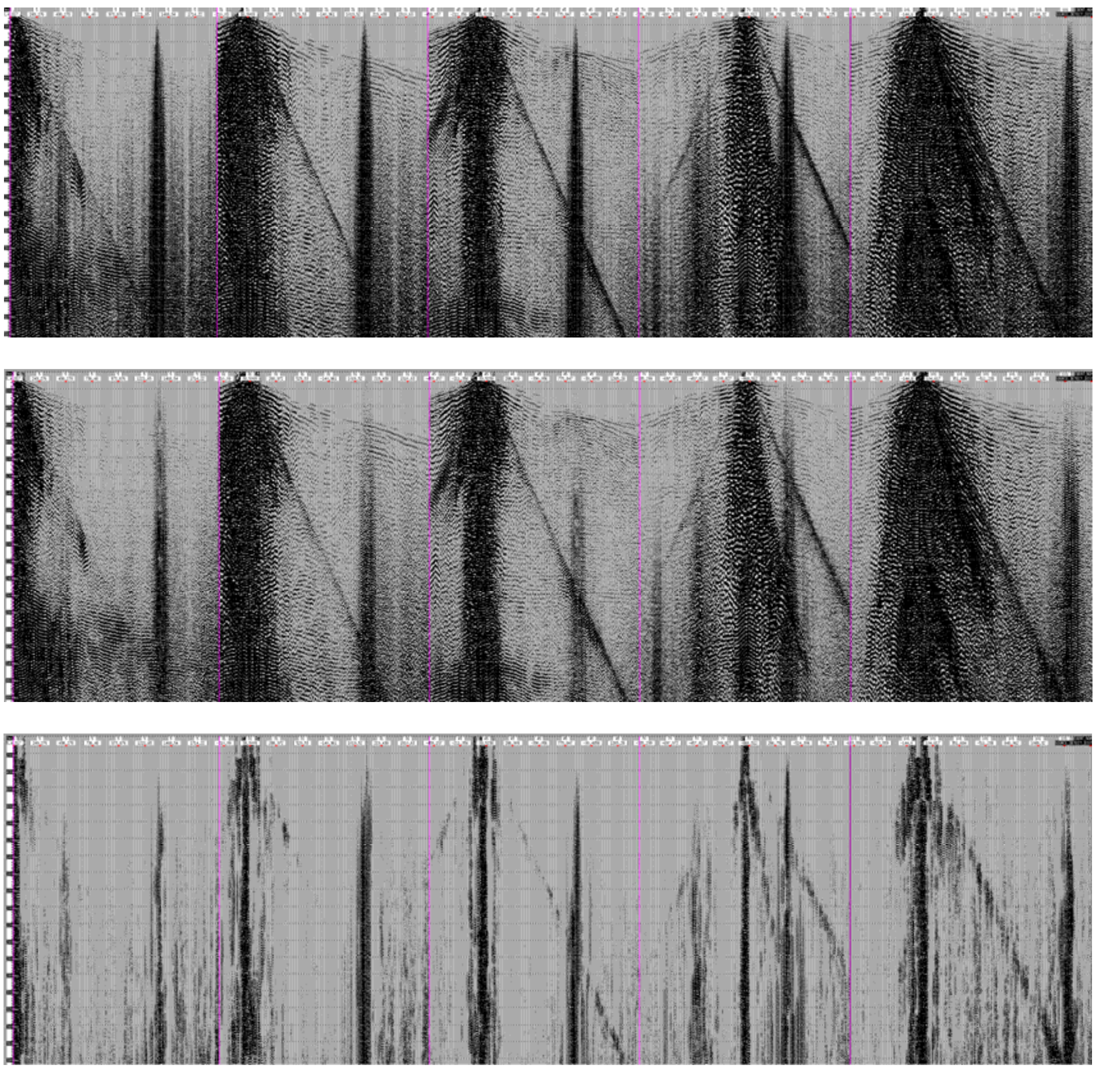

FIG. 2. First pass of signal enhancement using f-x filter: Raw shots (top), filtered shots (middle), difference between raw and filtered shots (bottom).

Velocity analysis on these data was not an easy task even after filtering, there did not seem to be many coherent events and some of them were masked by the remnants of the surface wave and airblast. In total, 6 velocity analyses were done for these data: after the first pass of noise attenuation; after refraction statics; after residual statics and deconvolution; after the first pass of pre-stack time migration; and after final migration to pick final stacking velocities.

After deconvolution a second pass of signal enhancement was applied in the shot and CMP domain, where the domain used depend on how random some of the noise appears and on the noise rejection algorithm (spatial median filter in the frequency domain). Up to this point only an exponential gain amplitude compensation method has been applied to the data, and even with this kind of gain the data look unbalanced as a consequence of the poor performance of the exponential gain, due to the low signal to noise ratio. All the stack sections generated since the brute stack until the deconvolution stack section have had a pre-stacking automatic gain control of 500 ms window as an alternative to the unbalance amplitude and the high level of noise. To try to balance the amplitudes a Surface-Consistent Amplitude Compensation (SCAC®) was calculated and applied to the data. With this method we were compensating for shot, detector and offset amplitude variations that are caused by acquisition effects and are not a consequence of the subsurface geology. In the presence of some high amplitude spikes SCAC adds some extra noise to the data, so a noise rejection technique to eliminate these new spikes in the data is necessary. The third pass of signal enhancement was applied after SCAC in the CMP domain Once again it was used a spatial median filter in the frequency domain to attenuate the high amplitude spikes.

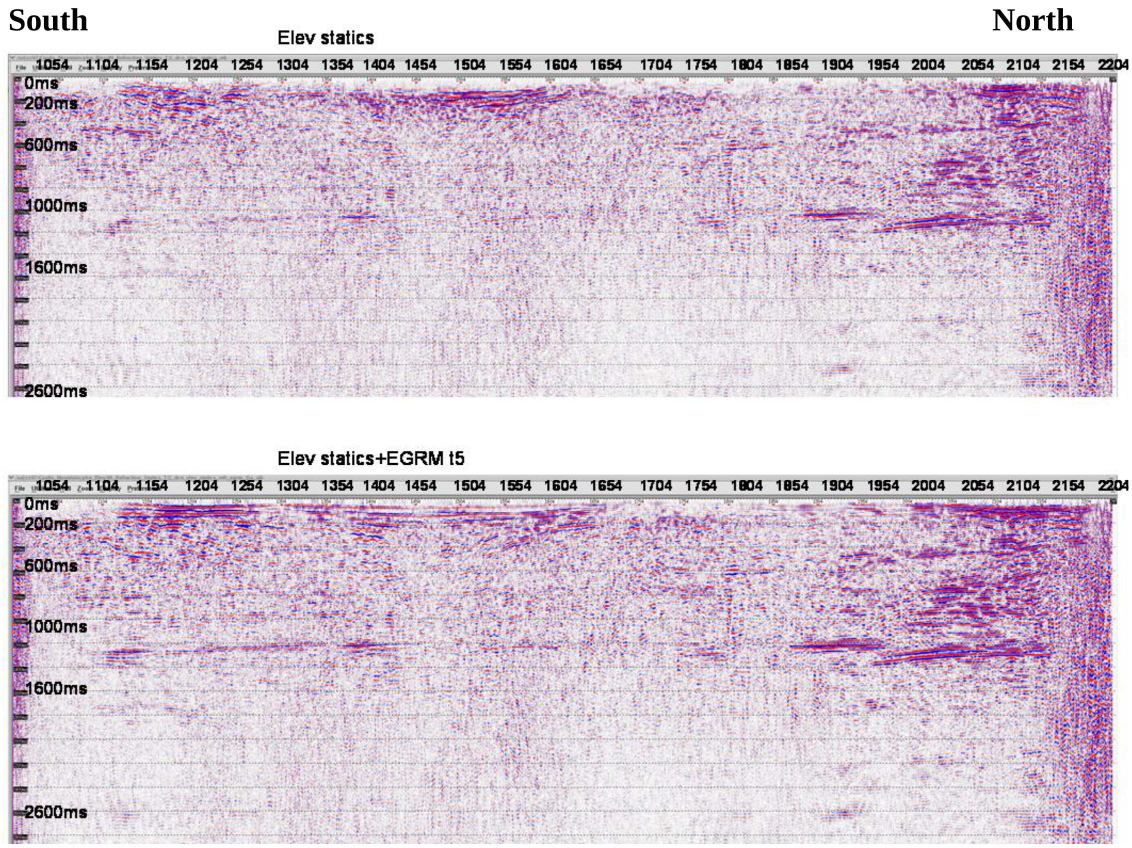

FIG. 3. Stacked setion before and after refraction statics: Stack section with elevation statics (top), stacked section with elevation statics+final refraction statics (EGRM).

Despite the three passes of noise rejection there is still some remaining random noise in the data. In cases such as this, a 3D approach is very effective at attenuating this kind noise. One of these approaches for 2D data is the 3D random noise attenuation that uses a 3D grid where the main direction is offset and the secondary direction is CMP numbers.

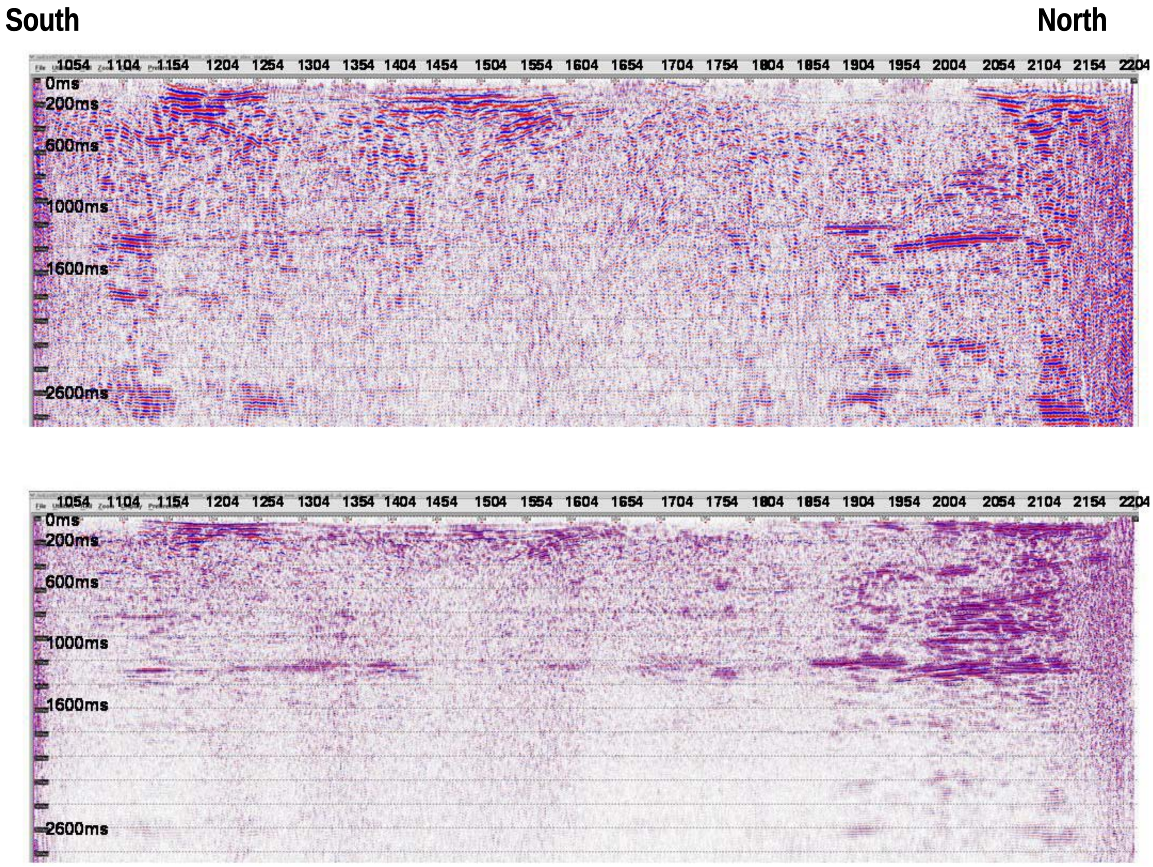

FIG. 4. Stack setion before and after deconvolution : Stack section with 1st pass of noise rejection (top), stack section with 1st pass of noise rejection + surface consistent deconvolution.

The last step to be completed is the migration. The first migration test done for these data was a post-stack migration using two alternative algorithms; finite difference and Kirchhoff. Both migrated sections suffer from migration artifacts because of the low signal to noise ratio but show surprising differences in reflector locations and character, even though the migrations were based upon the same velocity model. Because of the difficulty of interpreting these different post-stack time migrated sections with any confidence, an iterative pre-stack time migration analysis was done using once again a 3D approach for a 2D data set, that is perfect for a crooked line that is more similar to a 3D data set than to a 2D. Two passes of the pre-stack migration were done followed every one of them by a velocity analysis. We found that, in places, the velocities that flattened the CMP gathers were unreasonably high, and in other places we were unable to make any picks at all. In the absence of picks, we interpolated from the areas of better quality data. The final migrated section and a preliminary interpretation are shown in Figures 5 and 6. However, because of the lack of information about the velocities in the area, we cannot have a great deal of confidence that the interval velocities represent the true velocity structure of the subsurface because of the limited amount of good data and consequent lack of good focusing picks. There were no well data available to provide constraints on the velocity model.

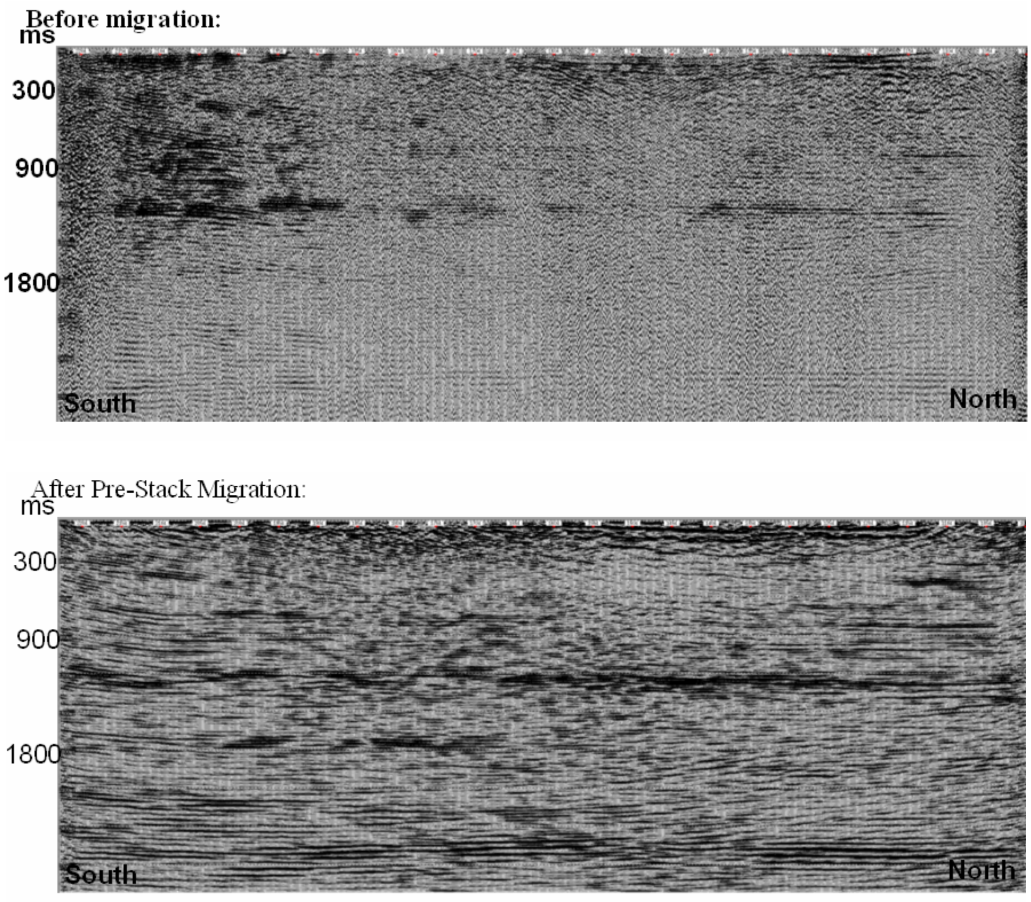

FIG. 5. Stack section before (top) and after (bottom) pre-stack migration.

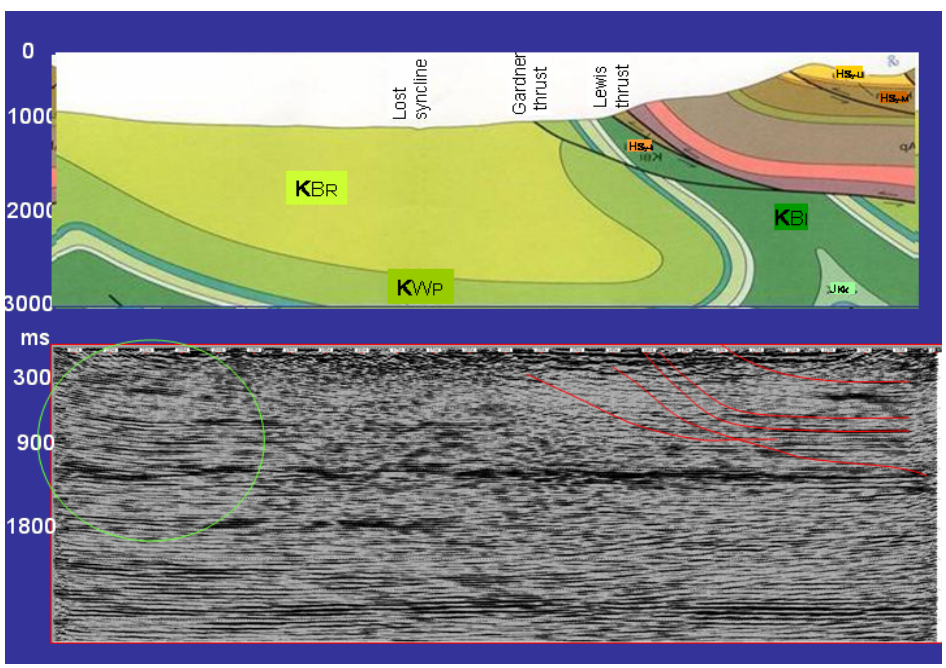

FIG. 6. Comparison of migrated image (bottom) with a geologic cross-section of the West Castle area (top) (modified from Norris, 1993).

CONCLUSIONS

The 2D seismic data set processed for the West Castle area constituted a challenge in terms of amplitude compensation, noise rejection and migration. The low signal to noise ratio caused by the strong air wave and surface waves made difficult the observation of the seismic reflectors for this area. The quality of the data was variable along the line, especially in the areas close to the West Castle River. Strong reflectors were observed in the south of the line and they allowed the interpretation of some of the small faults and thrusts of the area. The small spacing between receivers and sources was not an advantage for a geologically complex area as this one; instead a more powerful vibroseis source is suggested as well as a bigger spacing between receivers. Explosive sources might be a good idea for this area because it might help on eliminating some of the noise that is being generated by the vibroseis source.

Future work for this line will involve pre-stack depth migration and processing of the line in straight segments trying to overcome the limitations of crooked line acquisition geometries.

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