Processing and interpretation of 2D seismic data from Inglewood Park, Calgary, Alberta

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ABSTRACT

Significant rainfall and rapid snowmelt occurred in June of 2013 in Southern Alberta. The largest flood, on record, of the Bow River and its tributaries was triggered from the heavy rainfall and snowmelt. Following the flooding event, several 2D seismic lines were recorded on a point bar near the intersections of the Bow and Elbow Rivers in Calgary Alberta. Several seismic data processing steps were used to attempt to create an image, representative of geology, of the subsurface beneath Calgary. The near surface was searched for signs of fluvial geomorphology and two subtle drape structures were identified from the seismic data. The seismic line processed for this paper shows a complex near-surface geomorphology

URBAN SEISMOLOGY

Introduction

The June floods in Southern Alberta were the largest in recent history for the region. The estimated costs of the damages in Southern Alberta are around $5 billion CDN. Due to the extreme cost of the flooding event it is worthwhile to study the frequency of flooding events using shallow subsurface seismic interpretation along the Bow River. Identifying the risk of flooding in the future is of importance to the region. During the 2013 University of Calgary geophysics field school, 5 2D seismic lines were recorded in Inglewood Park, a point bar along the Bow River. In this project one of these 2D seismic lines is studied in detail. Different processing steps will be tested on the line in order to try to best image the subsurface at Inglewood Park.

Figure 1 depicts the Saskatchewan River Basin, including the Bow River drainage system and Calgary. The 2D seismic line is along a point bar within the City of Calgary near the confluence of the Bow and Elbow rivers. A more detailed plan-view map of the seismic line is shown in Figure 2. The line studied in this paper is Seismic line 3. Line 3 is a 2D line running North-South in the project area. This line was chosen because the raw data appeared to have the best signal to noise ratio of the 5 lines. Also, line 3 is the longest of the lines recorded in Inglewood. The line runs parallel to the river trajectory on the point bar.

Single-component, P-wave, geophones were used to record the dataset. The geophones were placed at 5 meter intervals along the line. The energy source was an Envirovibe with a sweep from 10 Hz to 200 Hz over 20 s, with a listen time of 3 seconds on the line. A 600 channel ARIES seismic acquisition system was used. The time sample rate of the dataset was 1 ms. Shots were placed at each geophone location on the line with the exception of phones placed near fragile plant life and infrastructure (such as pipelines). The seismic data was processed with Vista seismic processing software version: 12.000.2847.

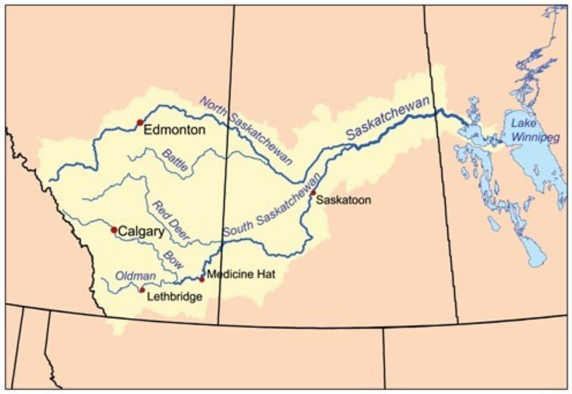

FIG. 1. Map of the Saskatchewan River Basin. The location of Calgary and the Bow River are labelled.

FIG. 2. The project area, the study focusses on line 3.

Data Processing

The raw seismic dataset for line 3 consists of 12240 seismic traces, distributed amongst 102 shot points. Each trace extends from 0 seconds to 3 seconds. An image of the raw shot gather for shot number 323, at geophone location number 44, is displayed in Figure 3. There is a clear energy concentration near the shot point in figure 3. That is, the largest amplitudes visible in the raw seismic data are concentrated close to the energy source. To correct for this energy distribution and to make a more interpretable raw shot gather, automatic gain correction (AGC) was applied.

The raw shot gather plus AGC has a lot more interpretable character than the completely raw shot gather. The seismic refraction can be seen near the top of the section. A closer view of the seismic refraction for shot 323 is shown in Figure 5. In Figure 4 there appears to be a lot of low velocity, low frequency signal. This signal is mostly a result of ground roll. Ground roll is considered noise for seismic imaging methods. Generally, ground roll is made up mostly of Rayleigh waves which are guided surface waves that have retrograde elliptical particle motion. One of the traces seen on shot 323 is clearly not receiving signal and is completely noise-dominated. The trace is just to the right of the shot point and was likely unplugged during the recording of this shot. This trace was muted before proceeding through seismic processing. On the raw plus AGC record it is difficult to identify pervasive reflections. Significant processing will be necessary to image the subsurface in

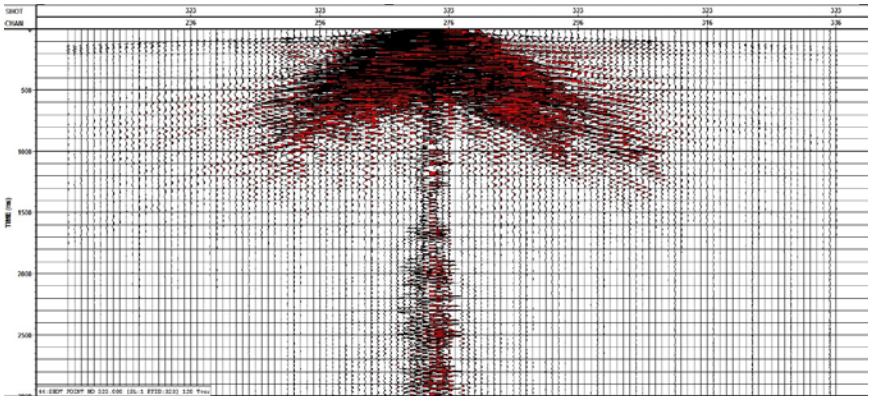

FIG. 3. Raw seismic at shot 323

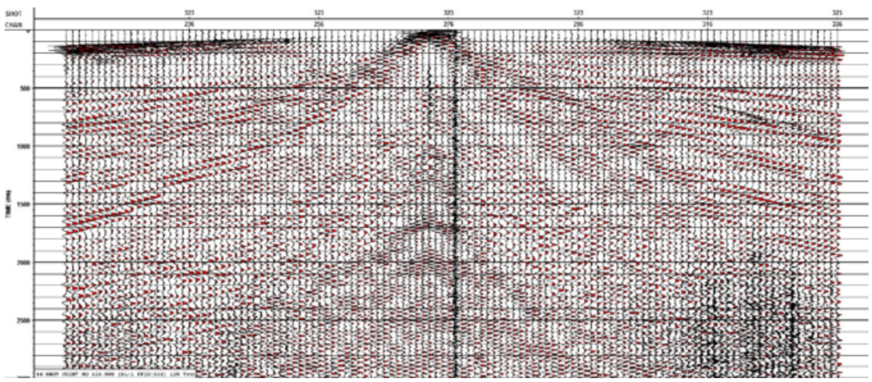

FIG. 4. Shot 323 plus automatic gain correction

this case. Figure 5 depicts the first 600 milliseconds of shot 323. It is easier to interpret some characteristics of raw seismic on this section. The refraction (first breaks) of the seismic wave can be identified clearly at the top of the section. It is the linear event of shortest time at the top of the shot gather labelled 1. The ground roll, or Rayleigh wave, is labelled 2 on the section. The events near label 3 are reflections on the section; the goal of seismic processing is to preserve these reflection events. Again the noise-dominated trace can be seen to the right of the shot point.

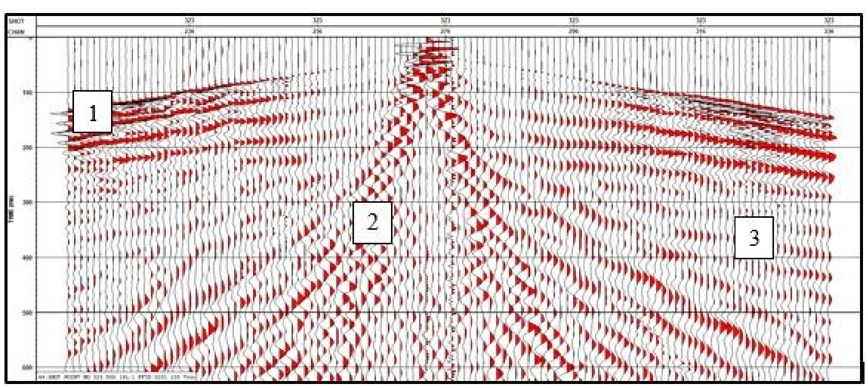

FIG. 5. First 600 ms of shot 323 with AGC applied

The steps from raw seismic data to a fully processed image of the subsurface are outlined in this section. The first processing step performed was the pre-processing. In this step trace kills were selected, that is, traces that have no signal are muted. Also part of preprocessing, all signals above the first breaks were muted as these are undesirable noise. The geometry is quality controlled and the chaining notes from acquisition are reviewed. Following preprocessing, gain corrections were made. Corrections for the effects of spherical spreading are made. Spherical spreading is the effect of energy loss with increased distance travelled in acoustic waves. Specifically for the processing of line 3, a time-variant scaling function was used to correct for amplitude. After correcting amplitude effects, static corrections are applied. Statics account for the effects of the near surface in seismic surveying. To better estimate true reflectivity, wavelet deconvolution was performed on the seismic data after statics corrections. Next, coherent noise was filtered using F-K spectral analysis and filter. The Rayleigh wave, ground roll, is removed with this filtering step. Following noise filtering velocity analysis was performed. From velocity analysis a velocity profile along the line was generated, followed by normal moveout (NMO) to flatten hyperbolic reflections. Following normal moveout corrections, a surgical mute was used to null the air-wave. This completely eliminates the high frequency air-blast noise. Next, residual statics solutions are found for and applied to the pre-stack dataset. A common mid-point stack was then made for the dataset. Random noise was attenuated with FX deconvolution, a spatial filtering process. Finally, a post-stack time migration algorithm was used to complete the processing of the seismic data.

Interpretation

A variable density plot of the first 1000 ms of the line 3 seismic data from Inglewood Park in Calgary is depicted in Figure 6. At first glance, the most significant events in the section occur at about 500 ms and 80 ms. Generally, these two events are the highest amplitude and most laterally pervasive reflections on the section. At 260 ms, there is a higher frequency, lower amplitude event that spans across most of the section. The near surface, up to about 150 ms, appears complex. The lateral extent of seismic events in the near surface region is fairly discontinuous; however there are some events that do span much of the section. As travel time increases the quality of the image decreases, that is, the signal to noise ratio of deeper events is much lower than more shallow events. Interpretable reflections only exist on line 3 up to about 1 second. The seismic data below this point is noise dominated and is not useful to draw geologic conclusions from. The challenges of collecting seismic data in an urban setting are highlighted by the processed section.

In attempt to quality control the seismic data, we considered the interface between the two layers found from the refraction analysis (Figure 7). It was found that the velocity of the first layer was 2500 m/s and that the velocity of the second layer was 3000 m/s. Structurally the interface between these two layers is slightly anticlinal, and is about 30-40 meters below the fixed datum used for seismic processing. From typical convention for the reflection coefficient an amplitude peak would be expected for a velocity increase over an interface, also assuming relatively constant density over the interface. Using the first layer velocity, 2500 m/s, and the fact that the interface is around 30-40 meters depth, the two-way-time of the event should be around 12-16 ms. Figure 8 shows the very shallow seismic data, including the 12-16 ms section. In the middle of the section around 5-15 ms there is a feature that appears to be slightly anticlinal, annotated on Figure 8 in yellow. The anticlinal event is also an amplitude peak, which may further suggest that it is the interface between the two layers found in the refraction analysis.

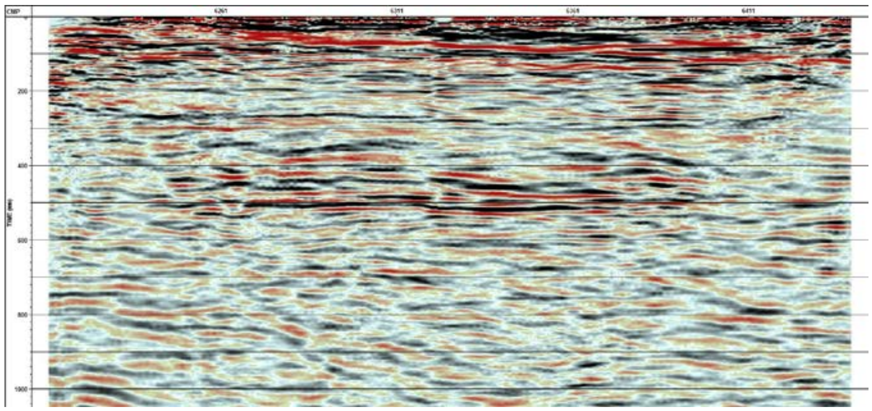

FIG. 6. Variable density seismic, 0-1000 ms, note that peaks are black

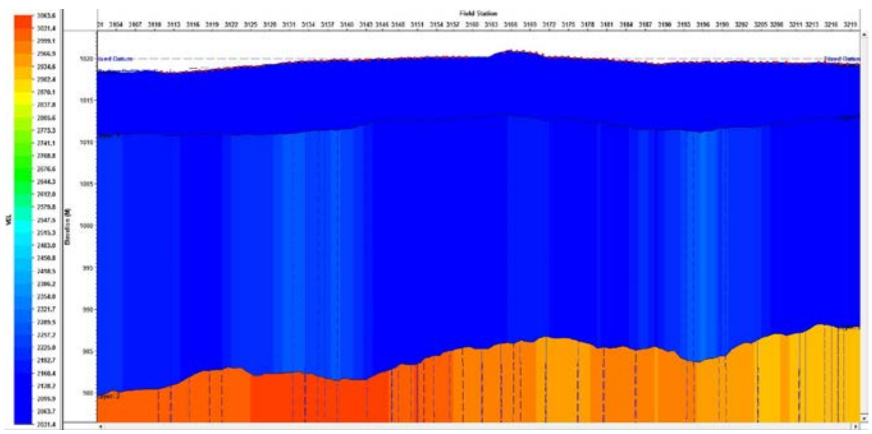

FIG. 7. Near surface velocity model from refraction analysis

Relationship between flood risk and seismic

Figure 9 depicts our interpreted at-risk region within the City of Calgary for flooding. There exists significant industrial, commercial and residential development within the neighborhoods between the Bow and Elbow rivers in this region. It would be worthwhile to understand the history of the Bow and Elbow rivers in this area. If the rivers' channels have changed significantly due to major flooding events in recent geological time the highly developed region between the Bow and Elbow is at a major risk of being damaged. The seismic data is analyzed for signs of near surface channelization or any fluvial activity. Figure 10 shows the first 100 ms of the Inglewood seismic. Fluvial geomorphology, if present, should be easily interpretable from a 2D seismic image, given that the channelization crosses the line orthogonally or obliquely. At first glance, there does not appear to be any easily identifiable fluvial incisions or seismic characteristics of point bar accretion.

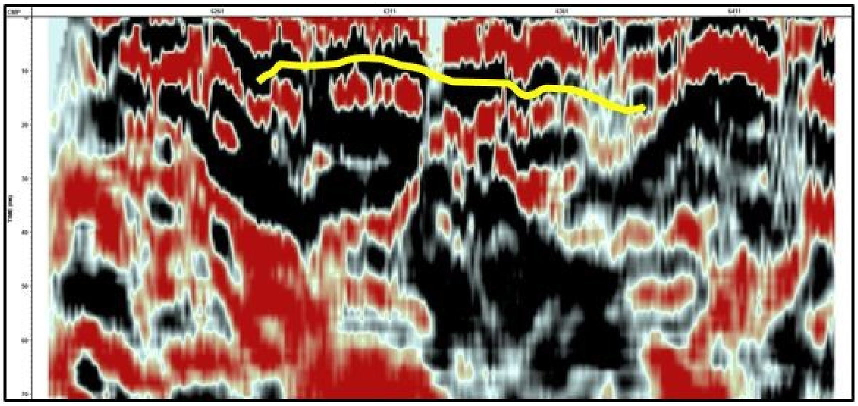

FIG. 8. First 70 ms of the seismic line

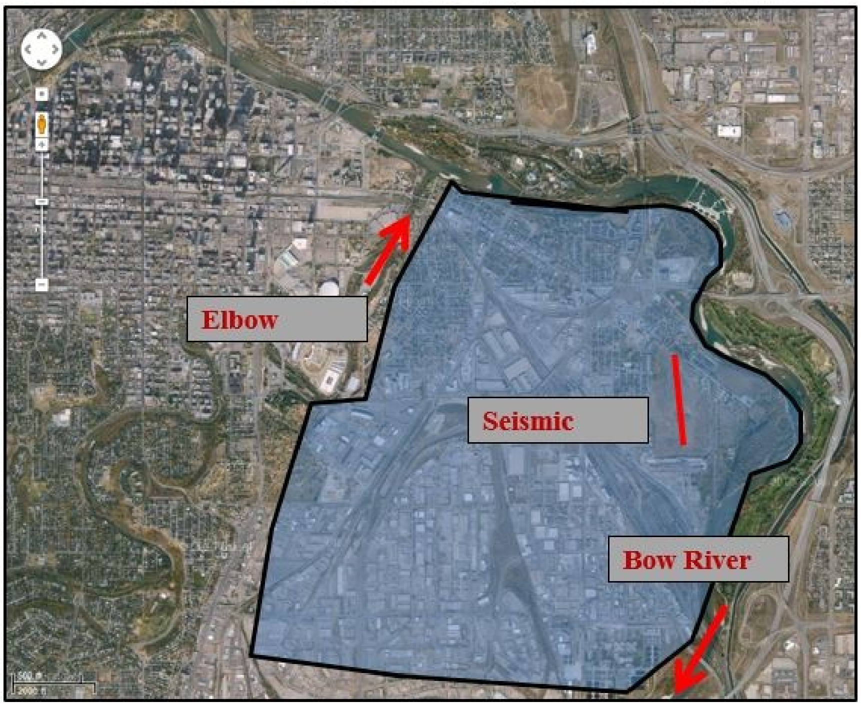

FIG. 9. The Bow and Elbow rivers, the seismic line, and a flood risk area between therivers. Arrows indicate flow direction. Image courtesy of Google Maps 2014

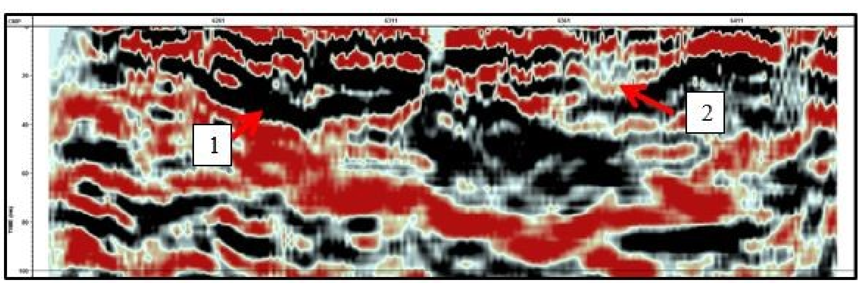

FIG. 10. First 100 ms of the dataset. Annotations indicate possible drape features

CONCLUSIONS AND RECOMMENDATIONS

The 2D seismic data from Inglewood Park in Calgary, Alberta was acquired with single component geophones placed at 5 meter intervals, parallel to the Bow River flow direction on a point bar. The project area is between the Bow and Elbow rivers near downtown Calgary. The seismic data was processed using Vista seismic processing software to best represent the geology beneath the project area. Several processing methods were used to take the raw data and convert it into an image representing geology, some of the major processing steps include: gain correction, statics, deconvolution, noise attenuation, normal moveout correction, common midpoint stacking and post stack time migration. The fully processed seismic data was interpreted, without the assistance of well control, and the near surface seismic was analyzed. The horizons inferred from the fully processed seismic data are not necessarily representative of the actual geologic features in the section due to the lacking geologic controls for the project area. Two structures in the near surface exhibiting drape were identified. In order to conclude whether or not these drape structures are a result of channelization or are seismic processing artifacts or other, additional geologic control would need to be included. In the future, the other seismic lines shot during geophysics field school should be processed and interpreted with emphasis on the near surface, to study flooding and the Bow-Elbow fluvial system. No conclusions on the frequency of flooding events in the project area can be made from the seismic data alone.

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