Seismic Study of a Possible Eroded Impact Structure, Southern Alberta

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Summary

Bow City Structure, the remnant of a potential impact crater has been discovered near Bow City in southern Alberta. A high-resolution seismic survey was carried out in July 2013 in order to identify the abnormal features in the faulted rim and the central uplifted area. Processing methods focusing on removing the shallow subsurface noises have been applied to improve the imaging of the shallow reflectors in Upper Cretaceous. On the stacked seismic profiles, apparent structure characters including concentric normal faults in the outer rim and curved reflectors in the highly disturbed central peak are further enhanced. These observations reinforce the target structure to be a highly eroded impact crater. Currently, it is estimated to have a rim-to-rim diameter of 8 km with a grossly anticipated age of 73 Ma.

Introduction

Over the past 40 years, much work has been accomplished to investigate the impact processes around the world. According to the cratering statistics on fraction of the exposed surface in Western Canada Sedimentary Basin (WCSB), 500 impact craters greater than 1 km in diameter have been expected to form during the past 600 Ma in Alberta and it is likely that most of the impact structures have yet to be discovered (M.J. Mazur, 2000, CSEG Recorder). Due to the availability of the densely collected seismic data in Alberta, a number of craters have been found by examining the processed seismic images. More recently, a potential buried impact crater, Bow City Structure, centered at 50.45°N and 111.91°W in southern Alberta has been identified.

Glombick (2013) described the geological and geophysical evidences for the impact origin of this newly discovered possible impact crater. He presented an integrated study comprising of the geological mapping, well logs analysis and seismic reflection imaging. A circular depression with the central uplifted region was observed on the geological structure maps. Moreover, the preliminary examination of the legacy 2D seismic data revealed three listric normal faults in the west out rim and a seismic transparent peak in the central region. However, it is difficult to indicate the shallow subsurface targets in details because the optimized goal of these donated data was the deeper petroliferous formations. As such, a high-resolution 2D seismic profile was acquired across the estimated impact disturbed region to further display the complex features in 2013.

Seismic Acquisition

The new seismic survey has a total length of 5 km across the expected faulted rim and the central uplifted area of the buried structure (Figure 1). To characterise the near surface targets in the upper 500 m subsurface, high frequency (40Hz) geophones were planted at every 4 m and a 240-channel seismography was utilized with 960 m maximum offset. This strategy of shooting at every field station was used to get a good signal to noise ratio (S/N) through the whole profile. The University of Alberta Minivib® (IVI, Tulsa) generated the linear seismic sweeps from 15 to 180 Hz in a period of 14 s and a sample interval of 1 ms. Therefore, an average fold of 400 was maintained in this survey which was much higher than the 12 fold from the old data. Far offset data was also collected to facilitate the seismic refraction tomography modelling.

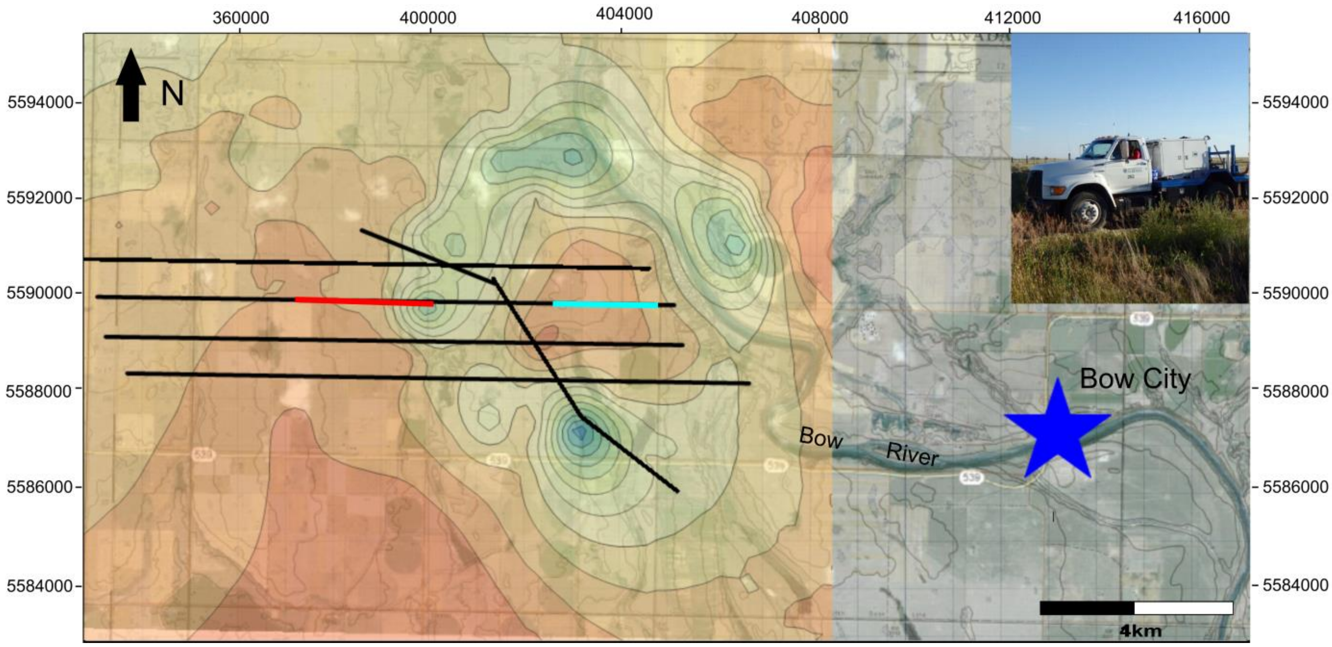

Figure 1. Location map of the seismic surveys. Coordinates are given in UTM Zone 12N NAD83. Red and blue lines are the new data acquired in July, 2013. Black lines represent the legacy 2D dataset. The colored contour map of the top of Belly River Group (BRG) in Upper Cretaceous is generated from well logs data. Image of vibroseis is shown in the right upper corner.

Seismic Processing

The seismic reflection data was processed in Vista® software (Gedco, Calgary) with a work flow designed for shallow subsurface imaging. As the primary focus of this study is the reflections in the upper 500 m of the shallow subsurface, the near surface noises including refracted waves, guided waves, ground rolls and multiples have been largely eliminated and the shallow S/N ratio has been significantly improved. Table 1 summarises the complete procedures employed for data processing.

Table 1. Seismic processing workflow.

Processing Steps
Data Conversion and Geometry Input
Trace Editing (Kill and mute)
First-break Picking
Elevation/Refraction Static Corrections
Exponential Gain (Time Power) /AGC
Time Variant Band-Pass Filter
Predictive Deconvolution
Spiking Deconvolution (Different window length)
CMP Binning/ Initial Velocity Analysis /NMO Correction
Residual Statics Corrections
Surface Consistent Spiking Deconvolution

Zero Phase Deconvolution
Predictive Deconvolution
Second Velocity Analysis /NMO Correction
Residual Statics Corrections
Predictive Deconvolution/Time Variant Band-pass Filter/Scaling
Final Velocity Analysis/ NMO Correction/ CMP Stacking
FD Migration
Post Stack Predictive Deconvolution /Spiking Deconvolution
FX Deconvolution/White Noise Suppression

Seismic Interpretations

Figure 2 is the seismic profile showing the uninterpreted (top) and interpreted sections (bottom) for line 1 and line 2. The geophysical well information (sonic and density logs) near the seimsic lines were utilised to generate the synthetic seismograms. Good correlation was obtained to tie the seismic horizons with the interpreted geological units in the Upper Cretacesou. In these profiles, a number of key features is worthy to be pointing out.

The line on the left of figure 2 is located in the faulted zone and the most obvious feature is the four listric normal faults with significant displacement and tilting. The uniform Belly River Group reflector (light blue) significantly drops to 200 ms at the common midpoint position (CMP) 400 which is interpreted as a normal fault on the outer edge (blue tilted line). Moving into the structures easterly, the reflector gets more complicated and interrupted by the other three such faults displacements (draw by green, purple, yellow lines) from CMP 400 to CMP 200. The reflections in the faulted area between the Belly River Group reflector (light blue) and the McKay Coal reflector (blue) are not continous and the seismic energy beneath the faulted zone are under light disruption as well.

The line on the right of figure 4 covers the estimated central uplifted area. A pronounced disruptive zone (highlighted by yellow shading) is seen to the west of CMP 71. The seismic events in this area are barely visible which means the energy is scattered and the reflectors are broken into small pieces. This seismic ‘transparent’ zone (lack of seismic coherency) might result from the severe disruption of the impact material. Also, the curved behavior of the Belly River reflector (light blue) between CMP 300 and CMP 71 reveals a significant uplifted feature. Indeed, the three underlying reflectors, the McKay Coal (blue), the Lea Park (green), and the Milk River (orange) indicate an obvious raised area, but with less discontinuity. These bending horizons display the anticlinal uplift in the disruptive area which suggest the central uplift of a complex crater.

Furthermore, a 3D structure model (Figure 3) has been created with the travel times of each interpreted horizon to represent the complex features. The nearly flat mapping surfaces show a general dipping trend from west to east in agreement with the geological well tops mapping. Clearly, the Belly River horizon has more time perturbations than the layers below which means it is more damaged by the hypervelocity event, especially in the faulted rim and raised central peak area.

Conclusion

High-resolution seismic reflection study has been conducted to detect the structure features of the deep roots of a possible highly eroded impact crater near Bow City in southern Alberta. Processing work flow that is suitable for imaging near-surface structure has been utilised to distinguish the detailed features. In this new survey, detailed features that are barely visible in the legacy dataset including enhanced shallow seismic reflectors, distinctive concentric normal faults and central interuptive area with curved reflectors have been improved. Currently, based on the underlying disturbed seismic horizons, the structure is recognized to be a complex structure with grossly 8 km in diameter and 400 m in depth from current surface. The ongoing work of seismic velocity tomography analysis and interpretaion of the migrated profile in depth domain would provide additional information for measuring the damaged structural features.

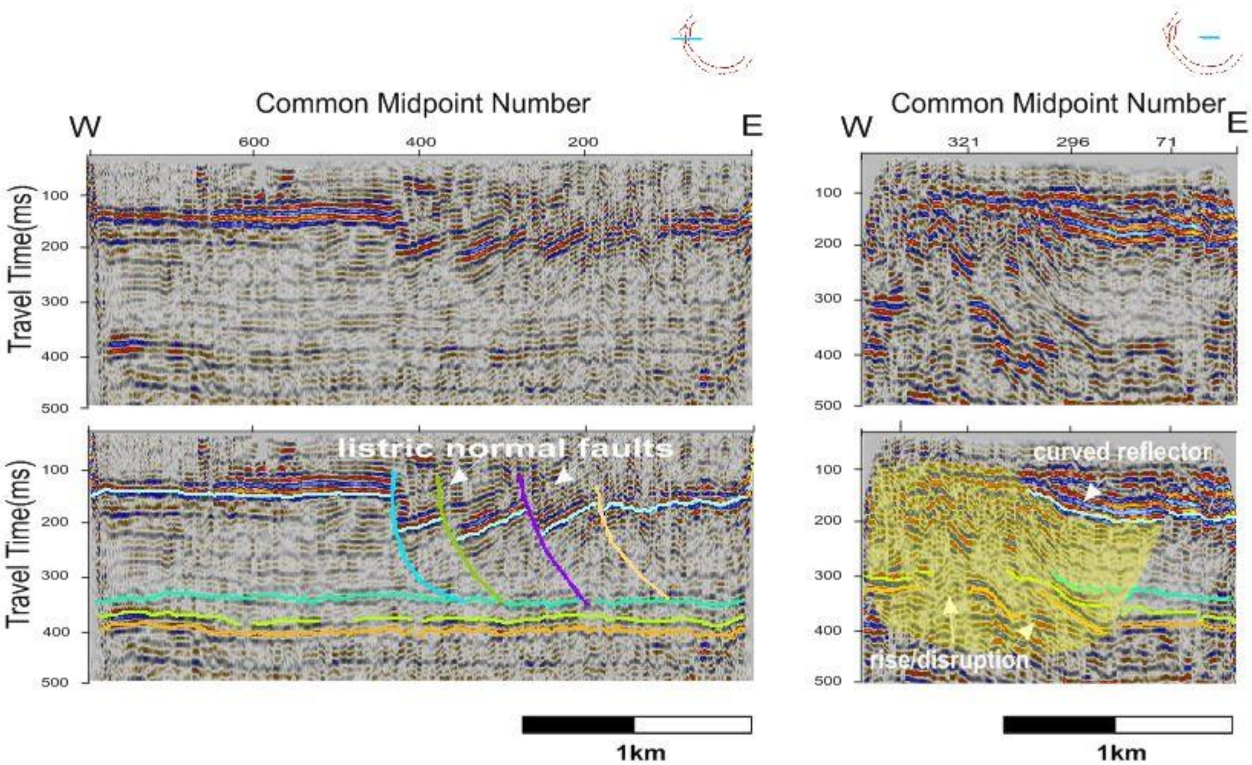

Figure 2. Stacked section of seismic profiles for line1 (left) and line2 (right). The top and bottom are the uninterpreted and interpreted images respectively. The light blue line represents top of Belly River formation, blue line represents base of McKay Coal formation, green line represents top of Lea Park formation and orange represents Milk River shoulder. The image in the right upper corner shows the line location. The tiltied lines in line 1 (left) colored by blue, green, purple and yellow show the interpreted rim faults. The yellow shading area in line 2 (right) shows the center disruptive zone.

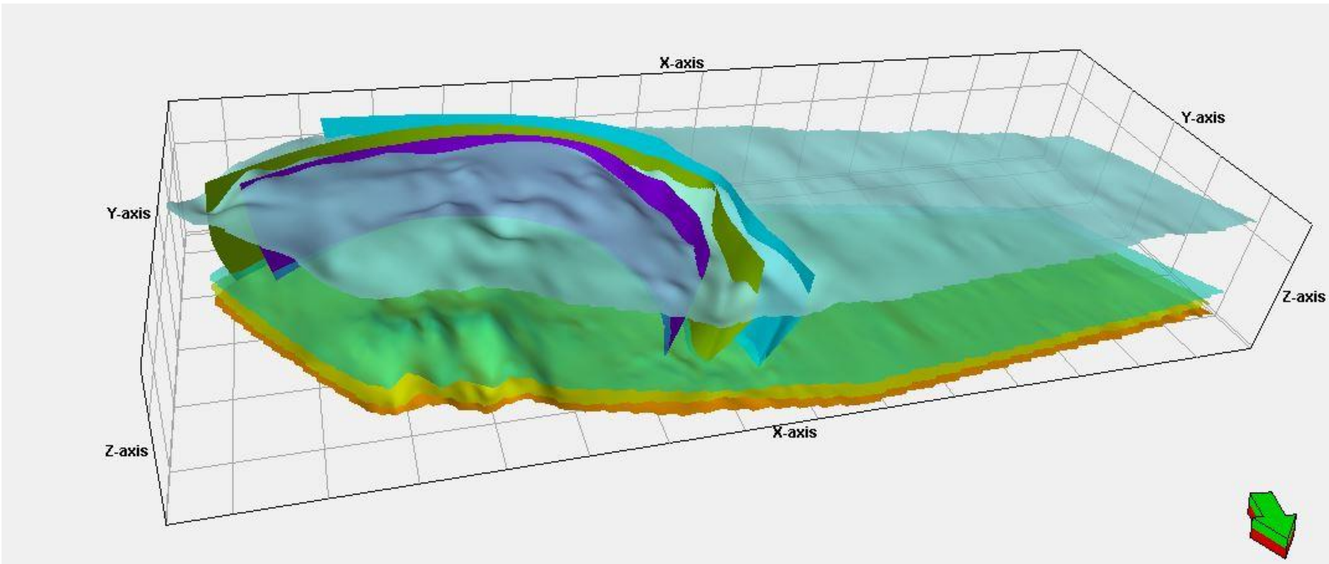

Figure 3. 3D model showing the interpreted faults and horizons from seismic dataset. Layers are mapped with sesmic travel times of Belly River (light blue), Mckay Coal (green), Lea Park (yellow),Milk River (orange). View is looking towards the southwest.

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