2D Seismic modeling of the Redwater Leduc Reef, Alberta

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Summary

Common shot ray tracing and finite difference modeling were undertaken to assess variations in the seismic response of the Redwater reef along a 2D line across the reef. The input geological model was based on well data and depth-converted seismic data from the interpretation of 2D seismic lines in the area. Ray tracing and finite difference synthetic seismic sections demonstrate similar seismic attributes for the Mannville, Nisku, Ireton, Cooking Lake, and Beaverhill Lake Formations. There is a time difference of 45 ms between the events in the synthetic seismic data and those picked in the field surface seismic data, the difference being due to variation in the Seismic Reference Datum used for the two datasets. The Cooking Lake and Beaverhill Lake formations display positive structure below the reef in time sections due to the lateral velocity change from on-reef to off-reef, but corrected in the depth sections.

Terminations and the lateral position of the Upper Leduc and Middle Leduc events are clear on the post-stack time-migrated seismic section and are enhanced on the pre-stack time and depth-migrated sections. Higher amplitudes at the base of Upper-Leduc member are evident near the reef margin due to the higher porosity of the foreslope facies in the reef rim compared to the tidal flat lagoonal facies within the central region of the reef.

Introduction

The study area is located in the Redwater region of Alberta, northeast of Edmonton (Figure 1). The Redwater reef complex has an approximate triangular shape with an area of about 600 km^2. It occurs at a depth of about 1000 m (-400 m elevation sub-sea), and has a thickness of 160 to 300 m (Gunter and Bachu, 2007). The main objective of the study was to create a 2D geological model of the Redwater reef, from the reef center to off-reef. Seismic modeling was then undertaken to generate a 2D synthetic seismic data to map facies variations within the reef, based on seismic character, and to characterize the reef members and formations below the reef.

Method

Common Shot Surface Seismic Modeling

A 2D geological model of the Redwater reef area was constructed and 2D seismic modeling using common shot ray tracing and finite-difference methods were undertaken to produce field survey shot gather seismic data. The model section extends from the lagoonal facies within the central region of the reef to off-reef (Figure 1). The 2D geological model was extracted from the interpretation of the existing 2D surface seismic data, particularly 3D gridded time structure maps of geological formations including Mannville, Nisku, Ireton, Leduc, Mid-Leduc, Cooking Lake and Beaverhill Lake. These time structure maps were converted to depth maps using a gradient velocity at the well locations.

The 2D geological model developed is shown in Figure 2. Interfaces in depth were transformed to event blocks and then P-wave velocities and densities were assigned to these blocks using average values from the wells. The reef rim region was modeled as a separate block. In this block, the velocity and density values had a lateral gradient associated with an average porosity of 4% in the tidal flat lagoonal facies to an average porosity 9% in the foreslope facies at the rim of the reef (Figure 2). Common shot ray tracing and finite-difference for primary P-wave events were performed with a shot interval of 40 m and receiver interval of 10 m from a SRD (Seismic Reference Datum) of 750 m above sea-level. The survey was undertaken with 150 receivers each side of the source points. The shot gather seismic data was generated by convolving the computed arrival time with a zero-phase 40 Hz Ricker wavelet.

Seismic Data Processing

The synthetic shot gather seismic data were processed and migrated to improve the imaging of the reef margin and the internal reef facies. This processing involved converting the trace headers from shot point to CDP (Common Depth Point) domain, followed by Kirchhoff post-stack migration, pre-stack time migration, and pre-stack depth migration. The velocity model used for the migration was created by converting the interval velocities from the input geological model into rms velocities in time.

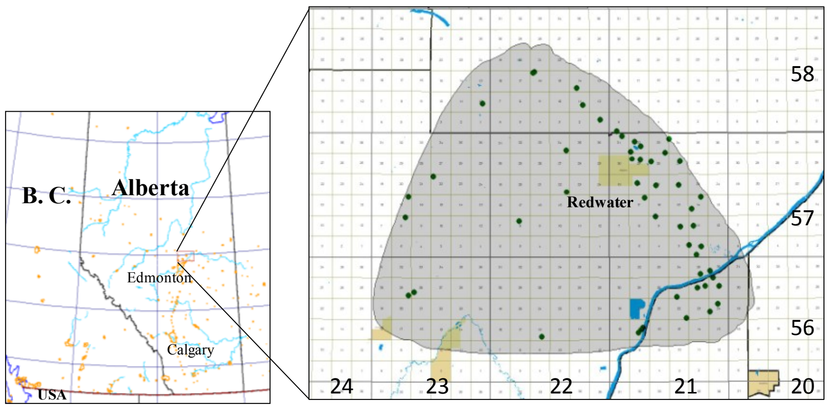

Figure 1: Alberta map showing the location and outline of the Redwater Reef, and wells penetrating the Lower Leduc Formation.

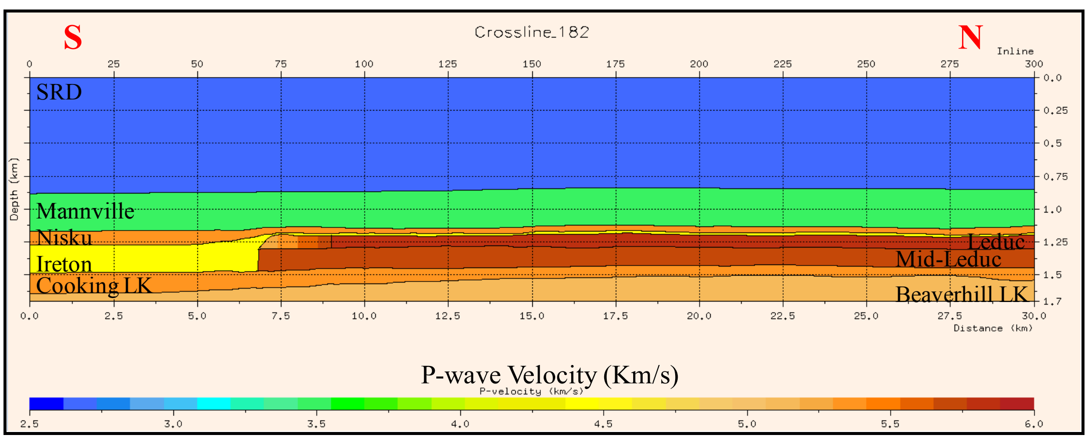

Figure 2: 2D geological model across the margin of the Redwater reef, showing P-wave interval velocities of the various formations.

Results

Figures 3 and 4 demonstrate the seismic shot gathers of ray tracing and finite difference modeling methods respectively. Figures 5 and 6 illustrate the pre-stack time-migrated and depth-migrated seismic sections respectively using the ray tracing method. In these sections, the Mannville event is a strong peak, the Nisku event is also a moderate amplitude peak, the Ireton shale event is a trough and the Cooking Lake Formation correlates to a moderate amplitude trough on-reef but has higher amplitude peak off-reef. This is because the Cooking Lake carbonates, when overlain by Ireton shale, yield a large impedance contrast and a high-amplitude reflection. The Beaverhill Lake event is fairly weak trough due to the small impedance contrast at the interface between the two carbonate units.

Reflections from the Cooking Lake and Beaverhill Lake formations exhibit positive time structure below the reef at the time section. This velocity pull-up is due to a lateral velocity change from the on-reef carbonate strata (Leduc Fm.) to the adjacent, lower velocity off-reef shale strata (Ireton Fm.). Both formations are essentially flat in the depth model (Figures 2). This velocity pull-up is corrected to nearly flat in the pre-stack depth-migrated data (Figure 6).

Terminations of the Upper Leduc and Middle Leduc events are clear on the 2D synthetic seismic sections with some enhancements on the depth section at the reef margin, and the Upper Leduc event shows the rim build-up (Figures 5 and 6). A high- amplitude reflection at the base of upper-Leduc member is evident near the reef margin and but this event becomes weaker toward the interior facies. This is because of the porosity differences and consequently velocity and density differences between the foreslope facies in the reef rim and lagoonal facies within the central region of the reef. It is noteworthy that this event on the modeled seismic data is similar to that observed on the processed field data in this part of the reef (Figure 10), and thus may be a possible higher porosity indicator.

Figures 7 and 8 present the pre-stack time-migrated and depth-migrated seismic sections respectively using finite difference method. All the formations display basically the same seismic attributes as the ray tracing modeling sections. Also, Positive time structure corrected to nearly flat in the pre-stack depth-migrated data. Figure 9 illustrates the velocity model in color super-imposed by pre-stack depth migration seismic section where it shows the perfect match between the original model and the depth seismic model.

Conclusions

The 2D ray tracing and finite difference synthetic seismograms demonstrate similar seismic attributes for the Mannville, Nisku, Ireton, Cooking Lake, and Beaverhill Lake Formations. The Cooking Lake and Beaverhill Lake formations display positive structure below the reef in time sections due to a lateral velocity change. This structure is apparent on time section and both formations are corrected to nearly flat in the depth model.

Terminations and the lateral position of the Upper Leduc and Middle Leduc events are obvious on the 2D post-stack time migration synthetic seismic line and are enhanced on the 2D pre-stack time and depth-migrated seismic sections. The reef rim is observed at the reef margin. High amplitudes at the base of upper-Leduc member are evident at the reef edge due to porosity differences between the foreslope facies in the reef rim and tidal flat lagoonal facies within the central region of the reef. There is an ideal match between the original model and the depth seismic model which gives more confident in the experimental results.

Acknowledgements

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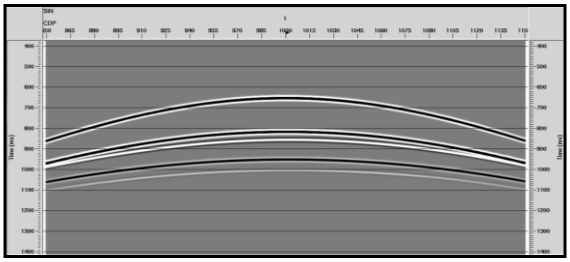

Figure 3: Ray tracing numerical seismic shot gather from the Redwater Reef model.

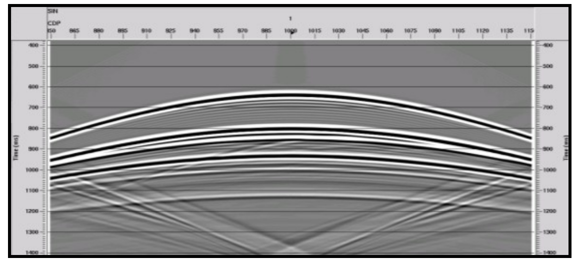

Figure 4: Finite difference numerical seismic shot gather from the Redwater Reef model.

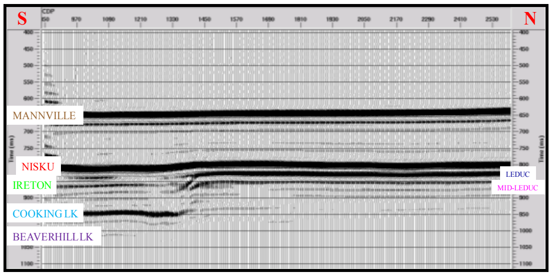

Figure 5: 2D ray tracing numerical seismic data after pre-stack time migration from the Redwater Reef model, with interfaces identified.

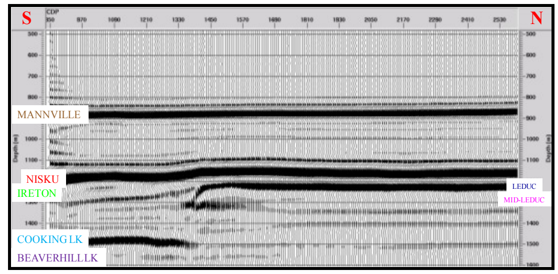

Figure 6: 2D ray tracing numerical seismic data after pre-stack depth migration from the Redwater Reef model, with interfaces identified.

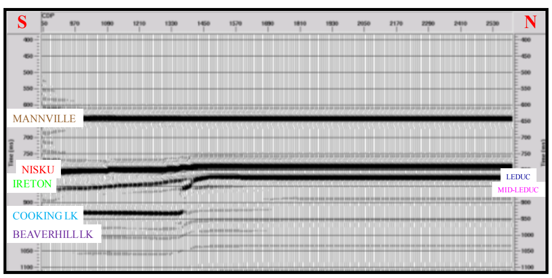

Figure 7: 2D finite difference numerical seismic section after pre-stack time migration.

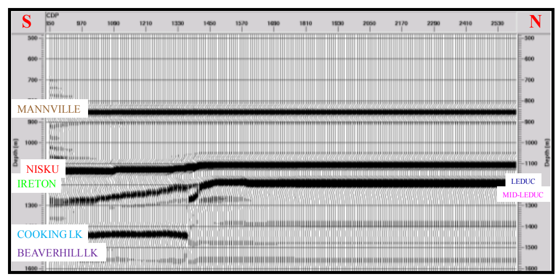

Figure 8: 2D finite difference numerical section after pre-stack depth migration.

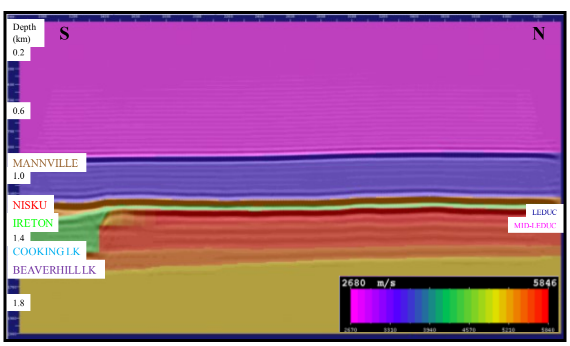

Figure 9: colored velocity model super-imposed by pre-stack depth migration seismic section.

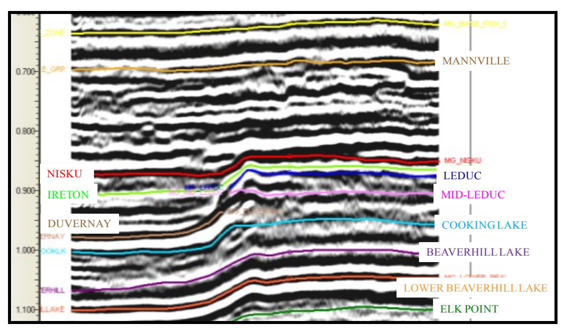

Figure 10: Interpreted seismic section across the reef margin.

References

Gunter, B., and Bachu, S., 2007, The Redwater Reef in the Heartland Area, Alberta; A Unique Opportunity for Understanding and Demonstrating Safe Geological Storage of CO_2: ARC and AEUB Document on Heartland Redwater CO_2 Storage opportunities.