2D Seismic Modeling of CO$_2$ Fluid Replacement of the Redwater Leduc Reef for CO$_2$ Storage Project, Alberta*

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Abstract

The Devonian Redwater Reef, northeast of Edmonton, Alberta, is being evaluated for geological storage of CO$_2$ for the Heartland Area Redwater CO$_2$ Storage Project. It is located close to large sources of CO$_2$ in the Redwater-Fort Saskatchewan-Edmonton region. The reef complex has a triangular shape with an area of about 600 km^2 and lies at depth of approximately 1000 m (-400 m elevation), and has a thickness of up to 300 m. The reef is underlain by the Cooking Lake carbonate platform and overlain by the Ireton Shale which forms the caprock to the proposed CO$_2$ storage. A shale embayment occurs around some parts of the reef margin at the Mid-Leduc level. The main objective of the study was to build a 2D geological model of the Redwater Reef, from the reef center to off-reef, with 40% CO$_2$ saturation in the entire Leduc Formation. Fluid substitution seismic modeling was then undertaken to generate a 2D synthetic seismic data to trace the consequences of CO$_2$ saturation on the facies within the reef and formations below the reef based on seismic attributes and characters.

Common shot ray tracing and finite difference modeling were undertaken to evaluate the variations in the seismic response of the Redwater Reef along a 2D line across the reef with 40% CO$_2$ saturation in the full Leduc Formation. The input geological model was based on well data and depth-converted seismic data from the interpretation of existing 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. 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 seismic sections. Terminations and the lateral position of the Upper and Middle Leduc events are obvious 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. Time-lapse seismology proved an enormous amplitude difference for the seismic data before and after 40% saturation. A high amplitude occurrence at the top of upper-Leduc, top of the rim, and base of Leduc was strong evident to monitor the saturation seismically.

Selected References

Bachu, S., and Bennion, 2008, Effects of in-situ conditions on relative permeability characteristics of CO_2-brine systems: Environmental Geology, v. 54/8, p. 1707-1722.

Lawton, T.F., 2008, Laramide sedimentary basins: Elsevier Amsterdam, Netherlands, v. 5, p. 429-450.

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Outline

- **Objectives and study area**

- **Geology and reef overview**

- **Methods**

- **Results**

- **Conclusions**

Objectives/Methods

Evaluate Devonian Redwater reef for geological storage of CO_2 and seismic monitoring

- **Evaluate 2D seismic modeling attributes and characters**
- **Determine Redwater reef litho-facies**
- **Ray tracing and finite difference**
- **Gassman fluid substitution**
- **Time-lapse seismology for CO_2 monitoring**

Redwater reef study area
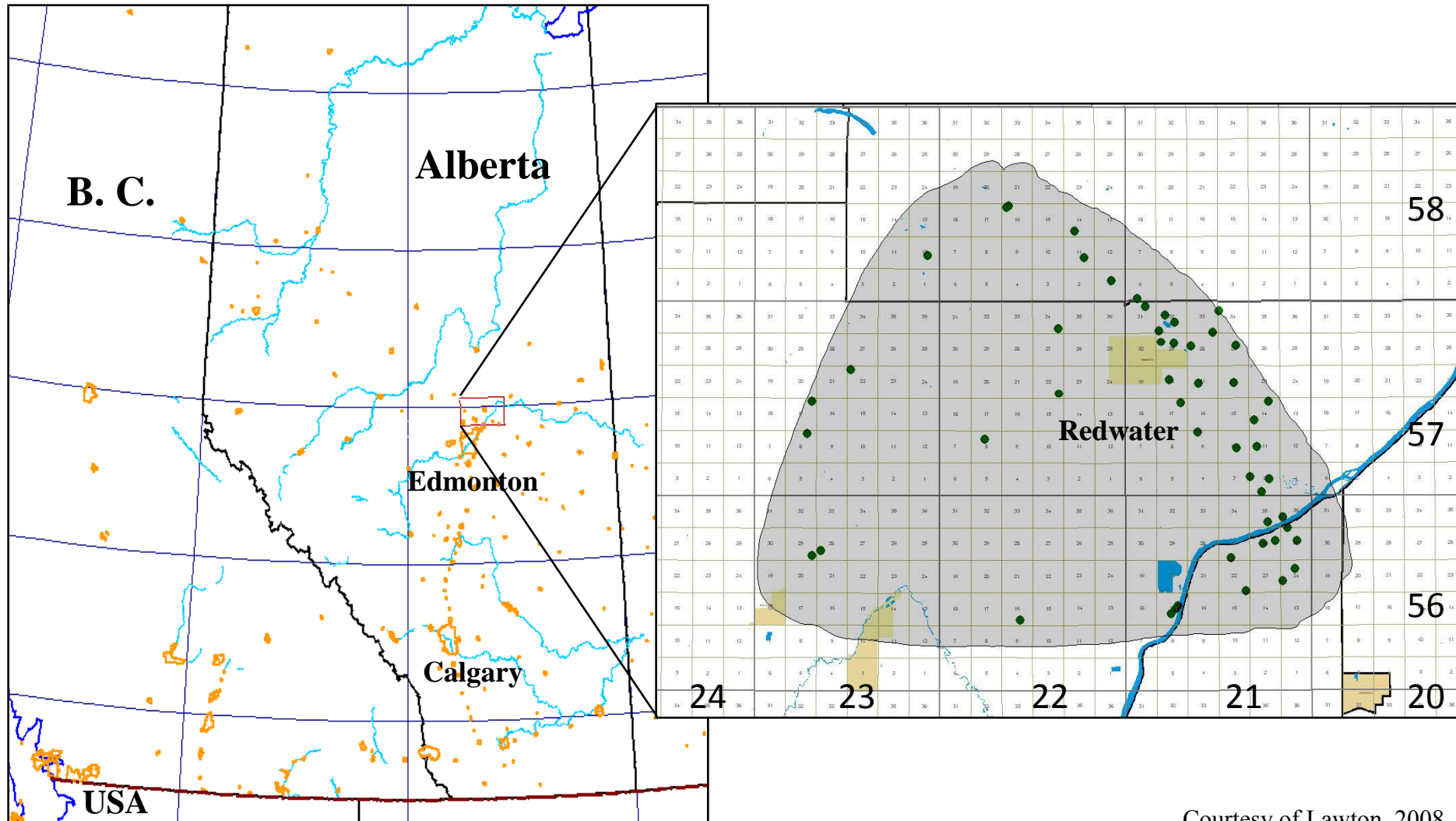
Geological setting

Courtesy of Bachu et al, 2008
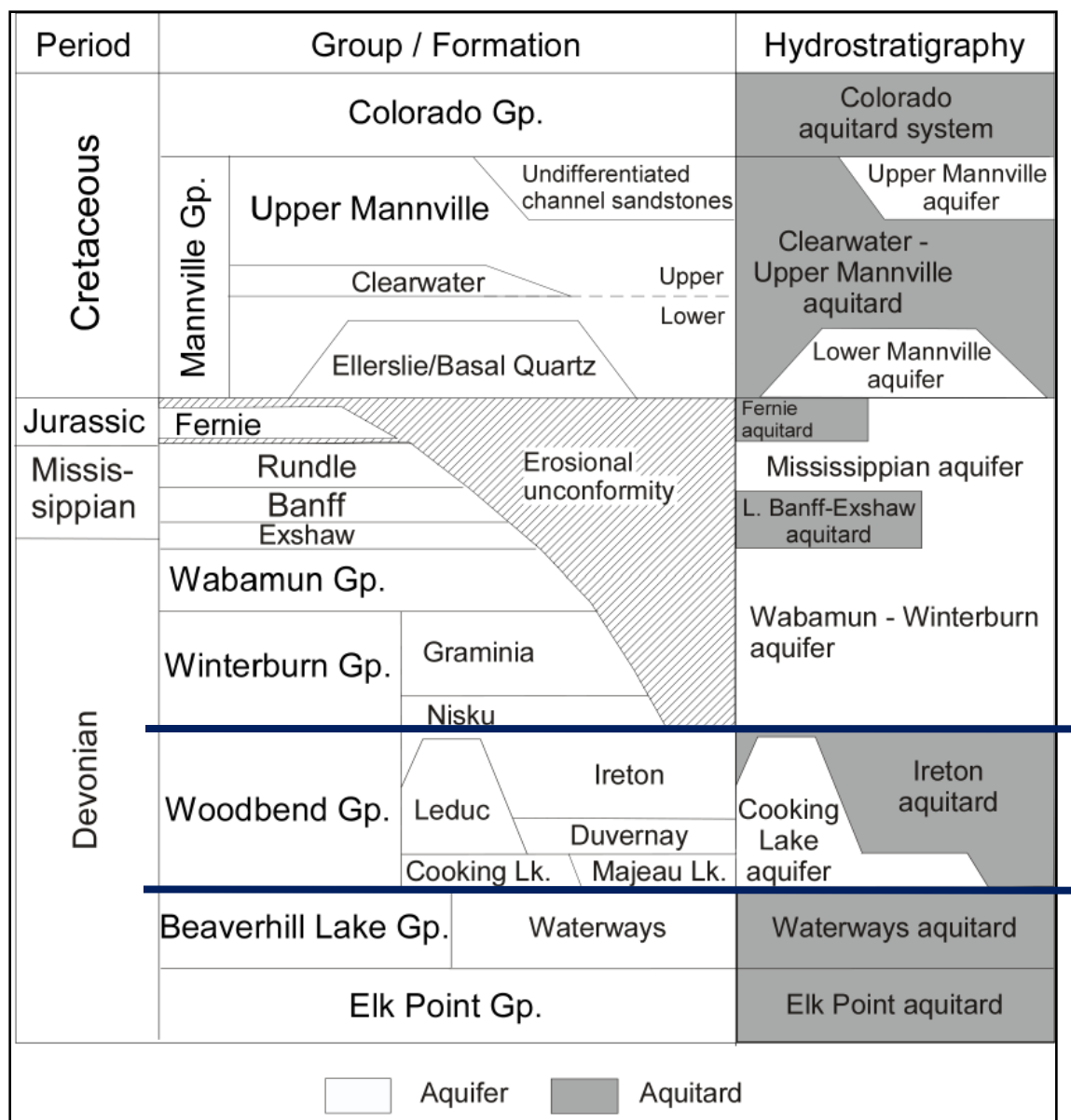
Reef Subdivisions and HC Migration

Courtesy of Stoakes and Foellmer, 2008
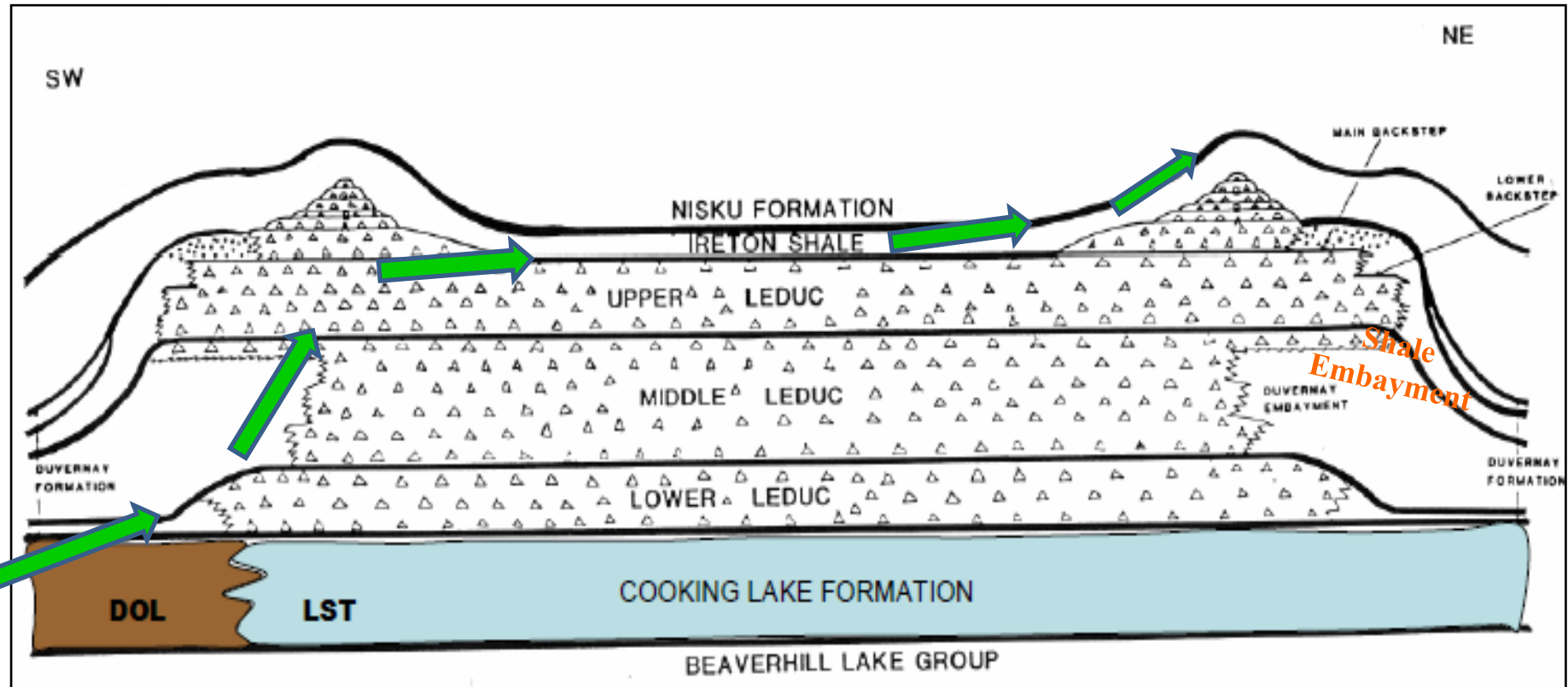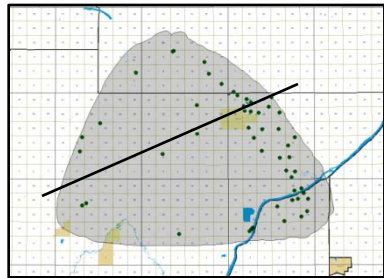
Leduc Formation properties

- **Porosity: 1-17% (Avg. 7%)**
  - **Intercrystalline, molding, and fractur**

- **Permeability**:
  - **Horizontally: 0.01-4000 md**
  - **Vertically: 0.02-670 md**
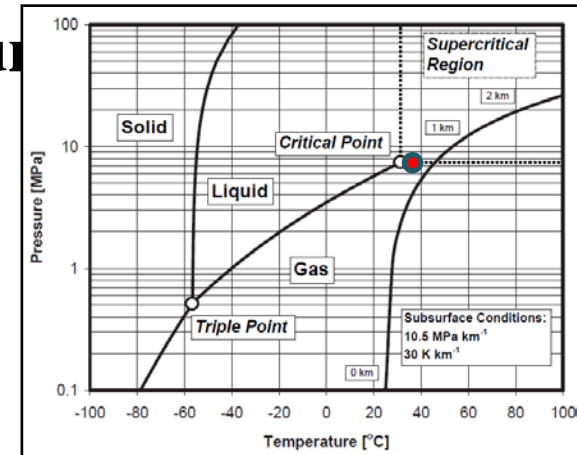
- **Pressure 7.4 MPa and Temperature 34°C**

- **Formation water NaCl, salinity 107 mg/l**

- **Leduc depth: 994 - 1120 m**
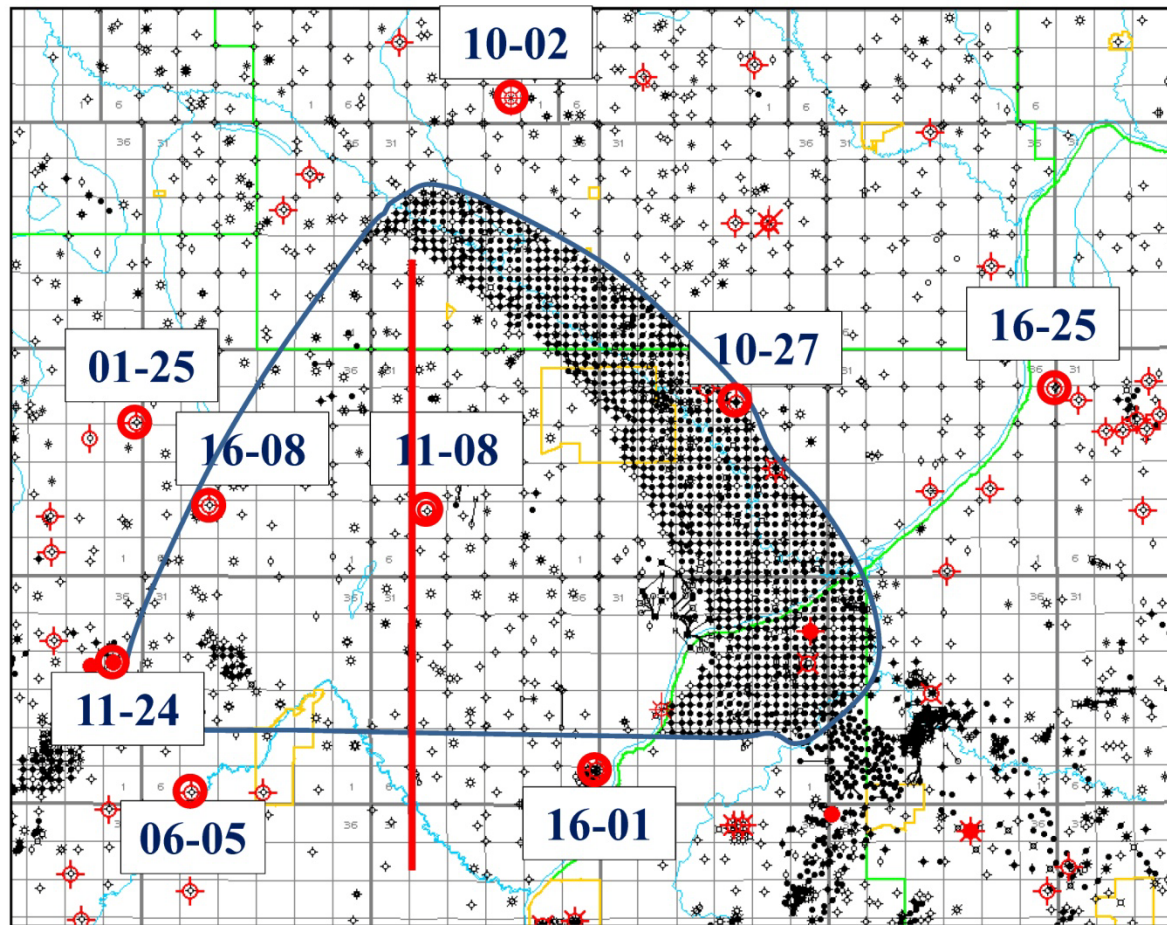
Notes by Presenter: Redwater Map with all wells and Sonic logs & COOKLK and below in red color

2D geological model (P-wave velocity)
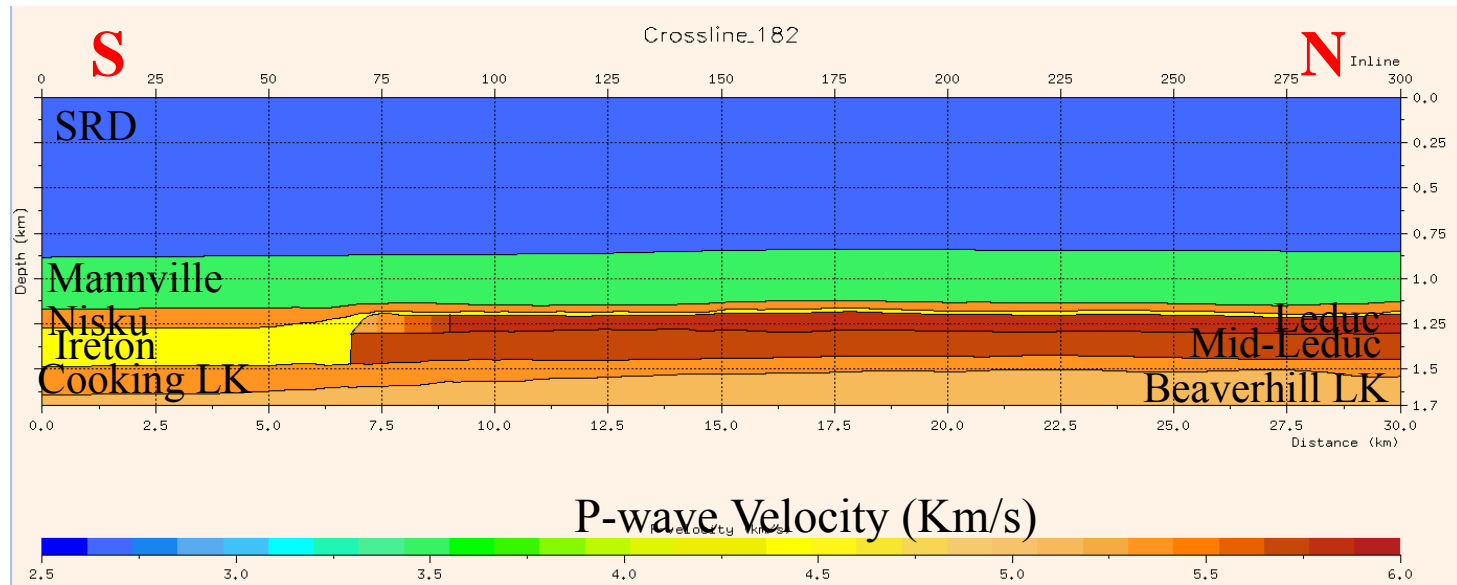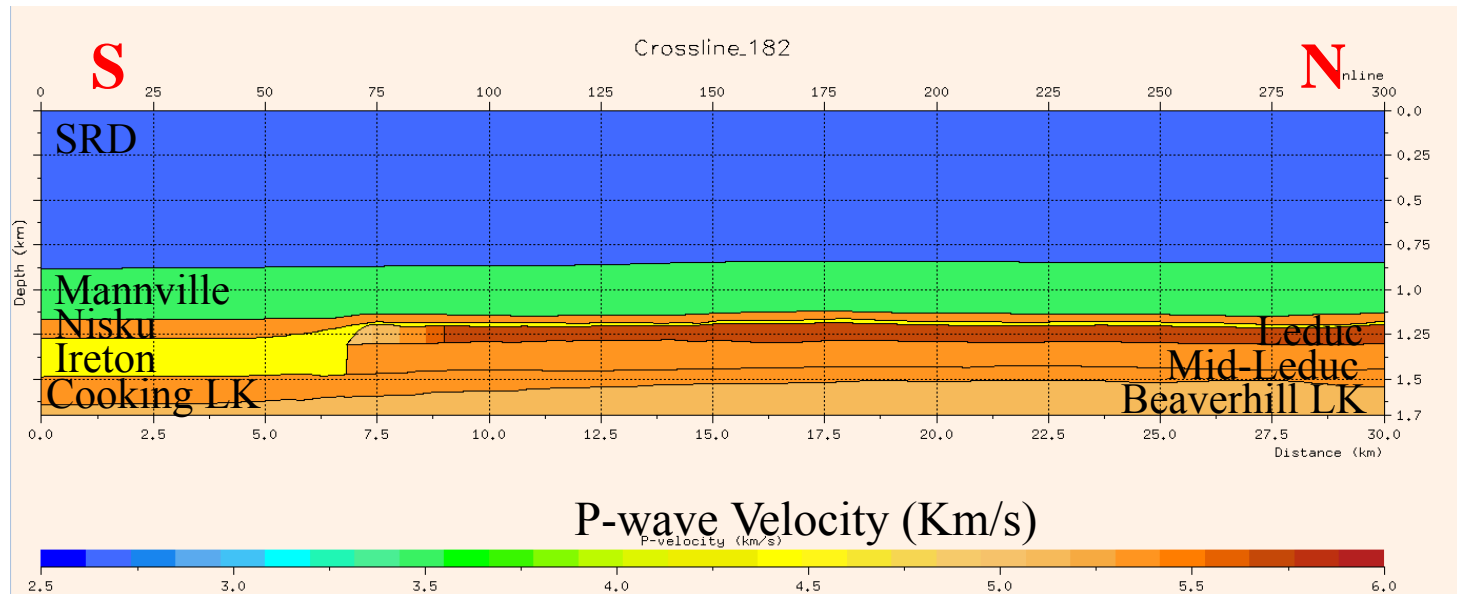
2D geological model (Density)
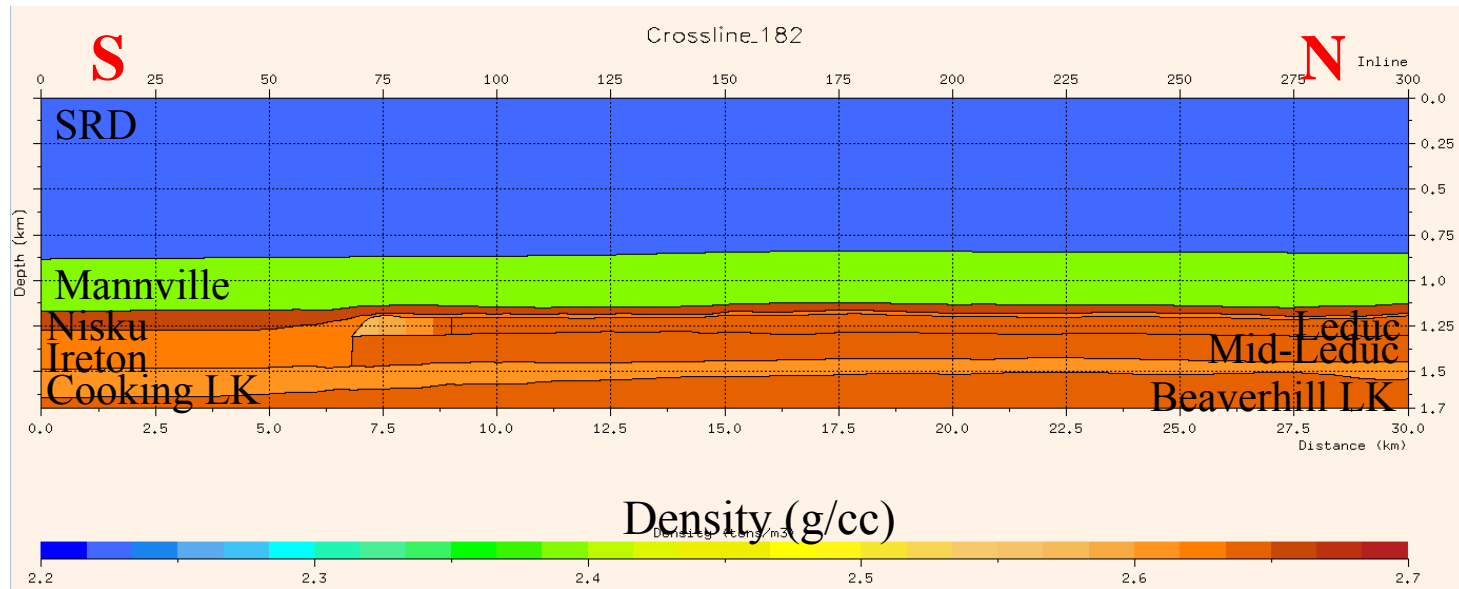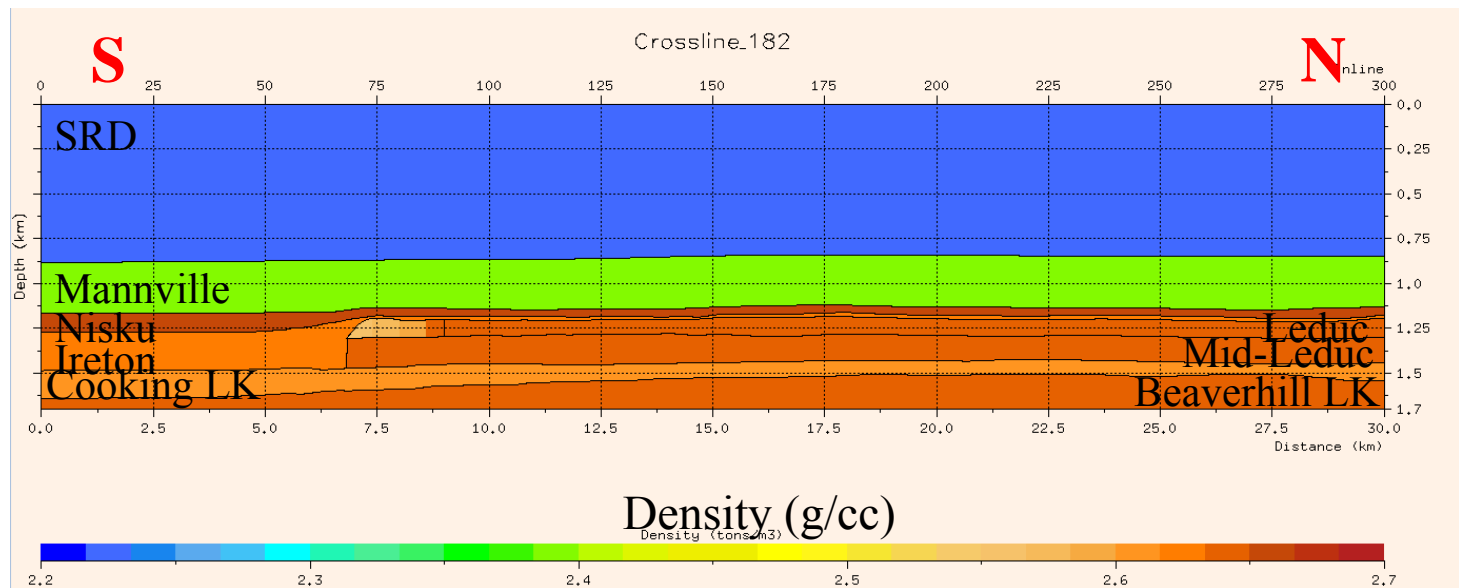
Common Shot Modeling Shot Gather

Ray tracing
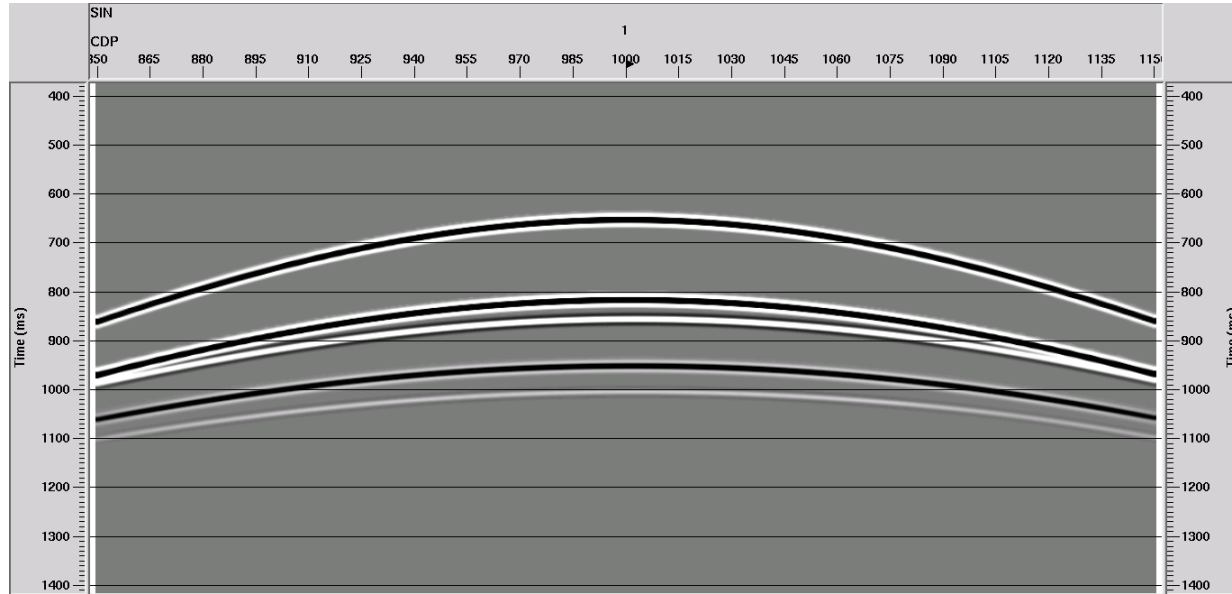
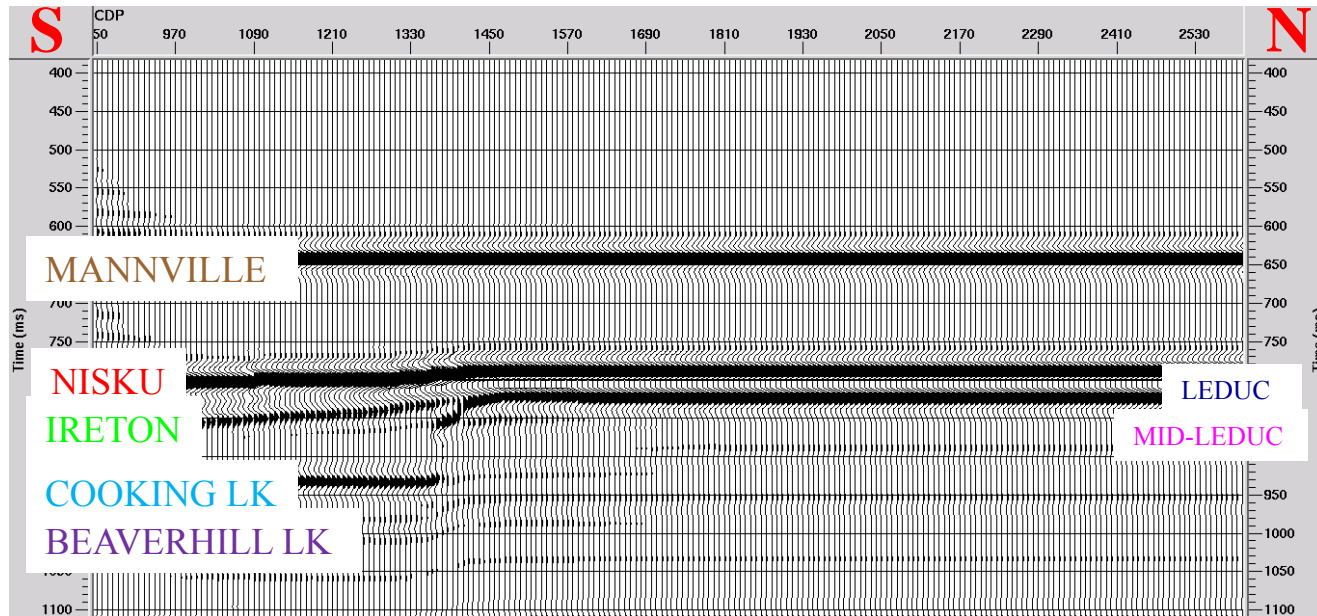**Finite difference**
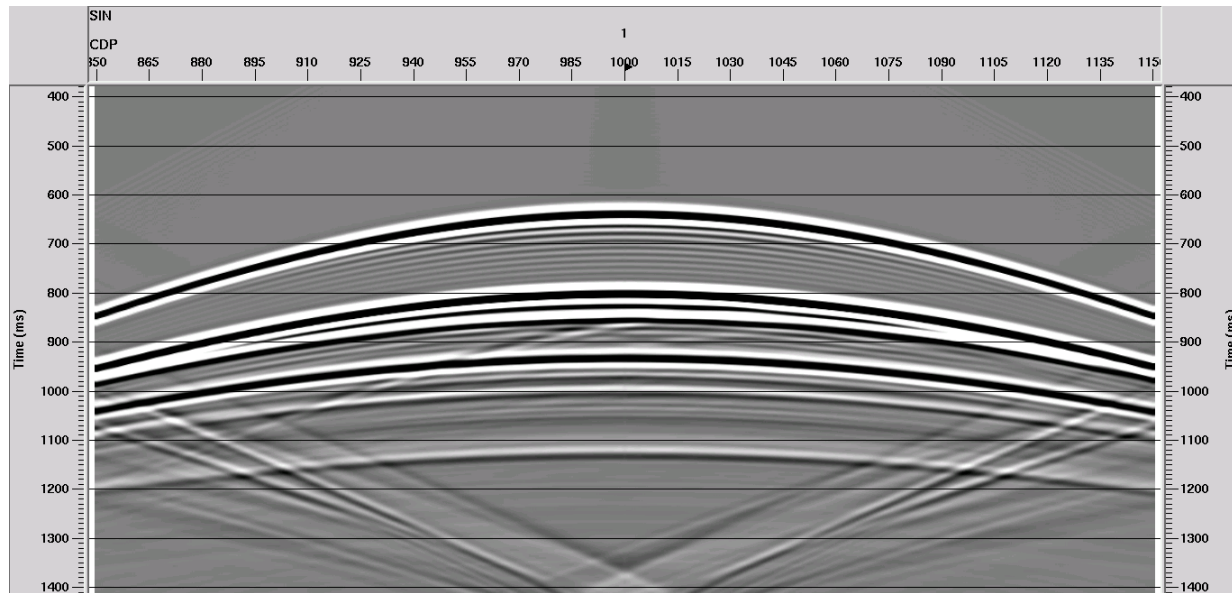
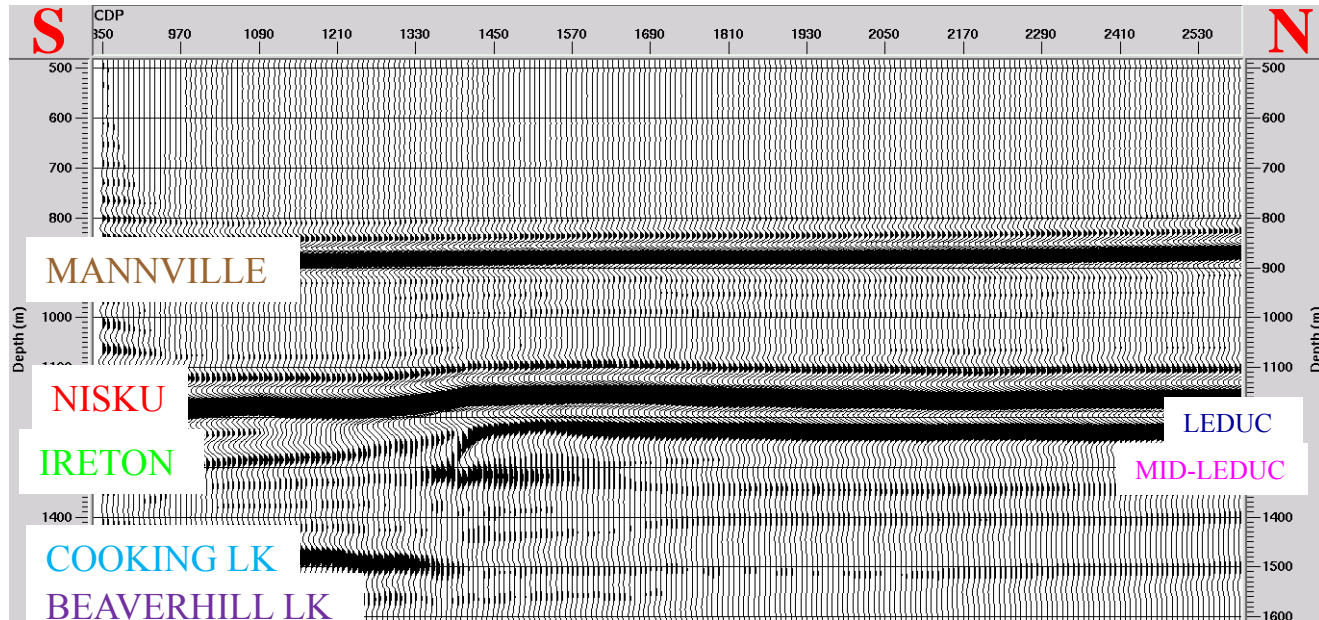# Ray Tracing Post Stack Time Migration
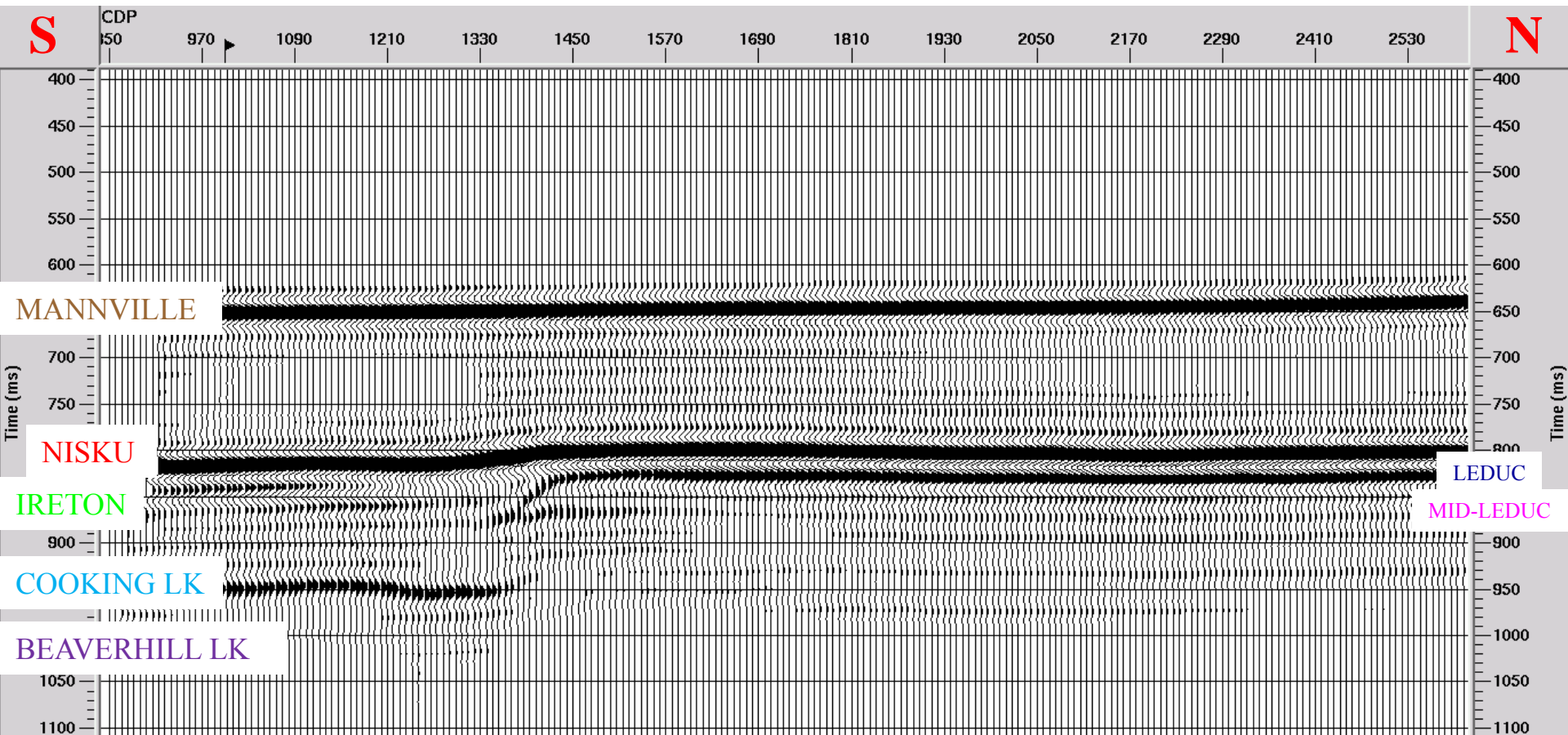
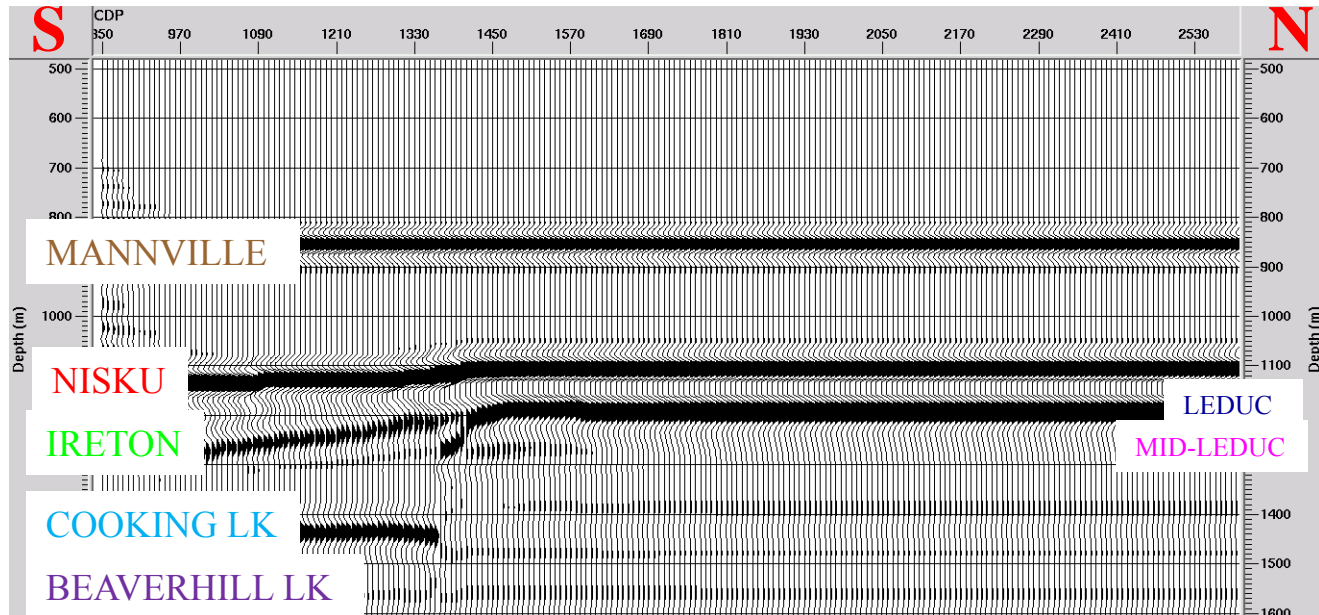# Pre Stack Time Migration Seismic Section

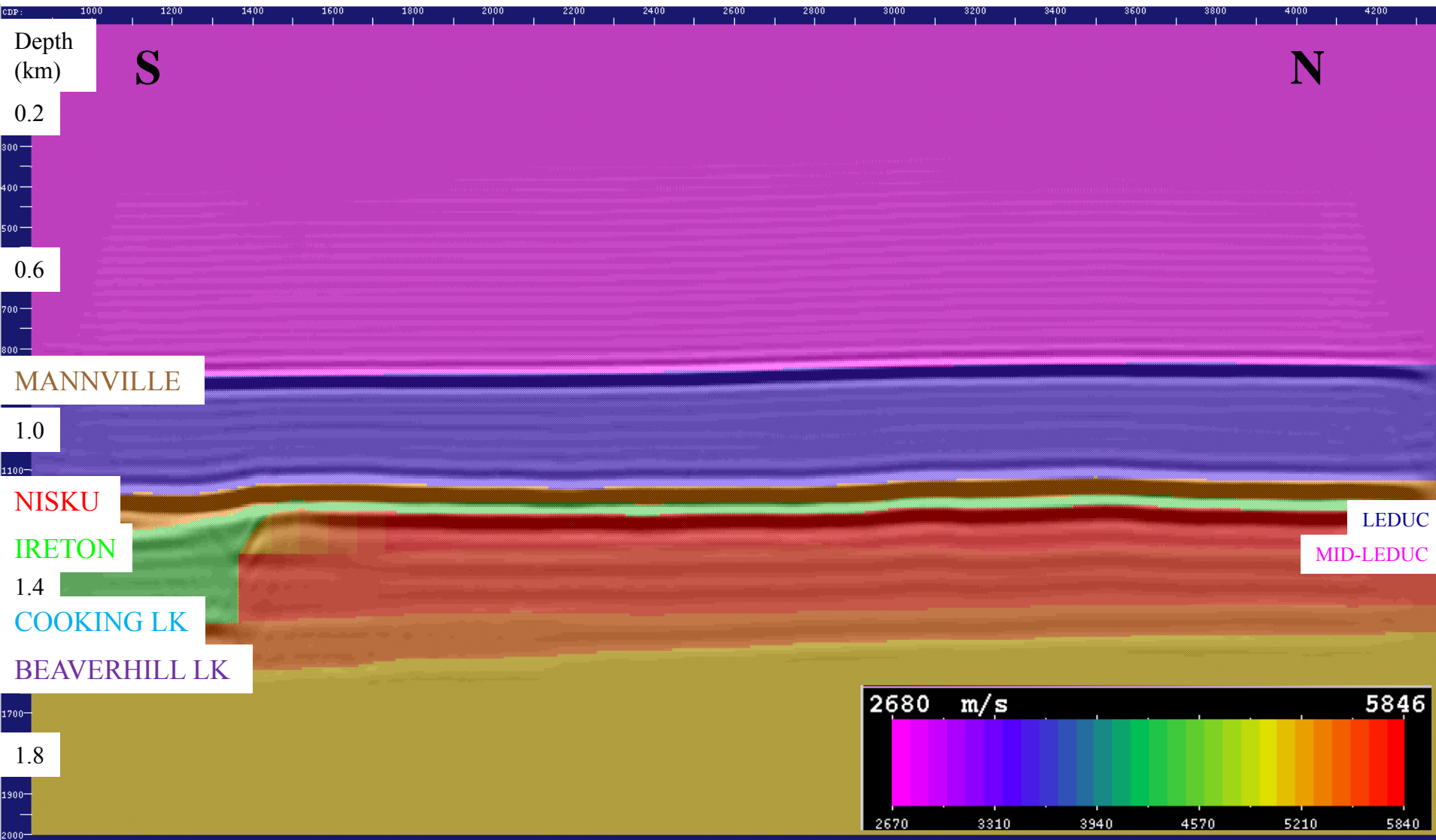# Pre Stack Depth Migration Seismic Section
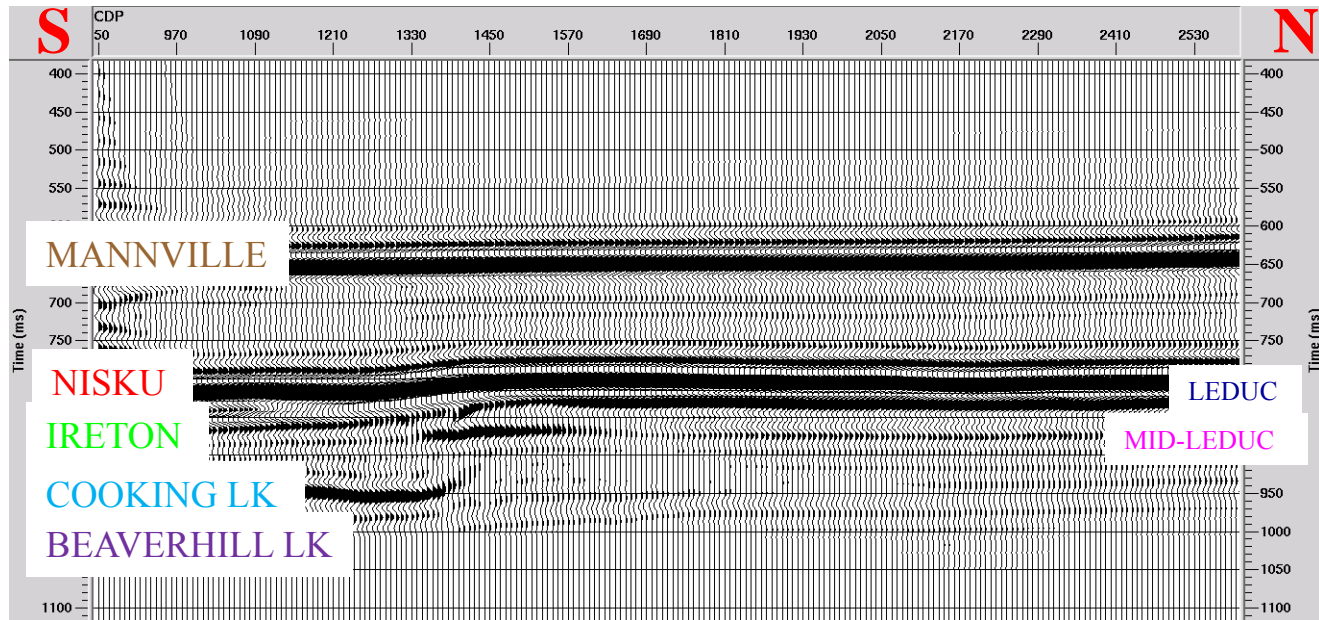
Ray tracing

Finite difference
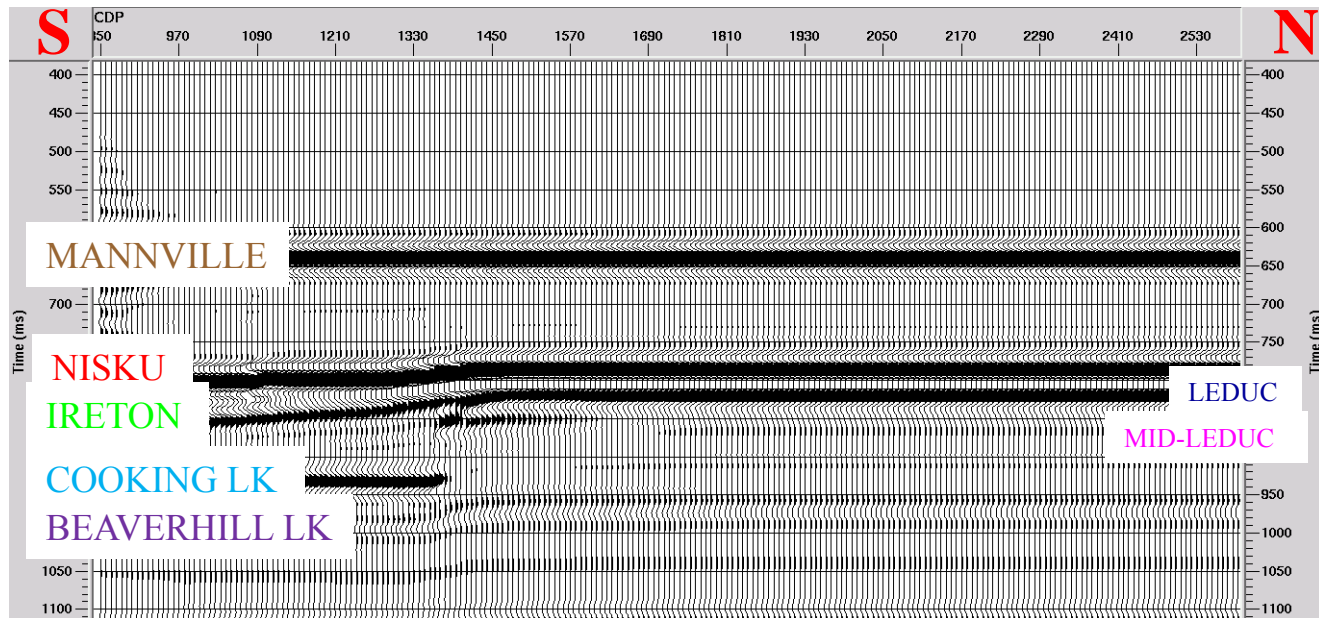
PSDM Stack with original Velocity
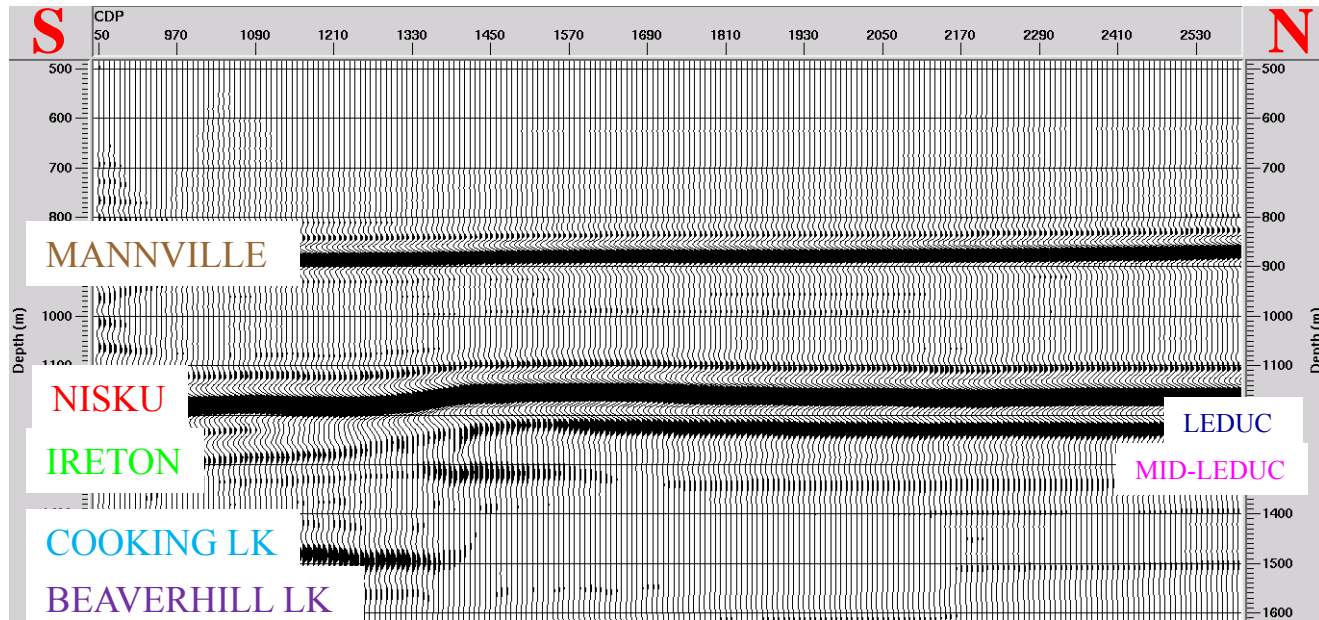
PSTM Seismic Section (CO₂ FRM)

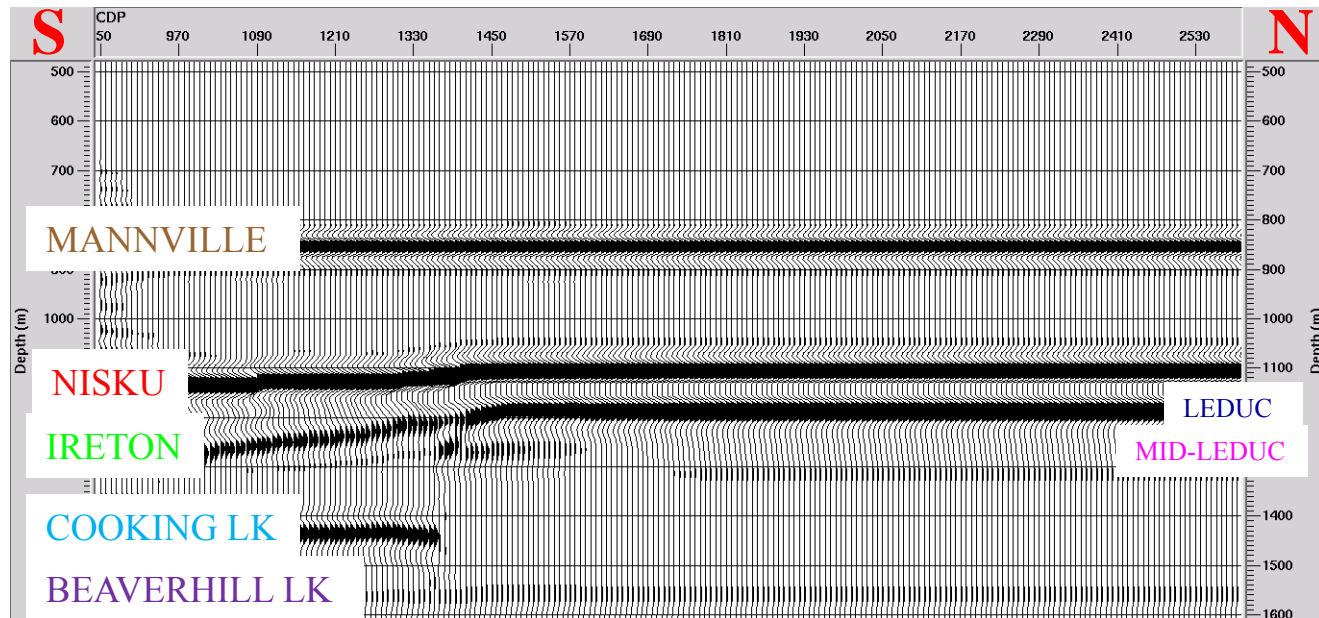**Ray tracing**

Finite difference

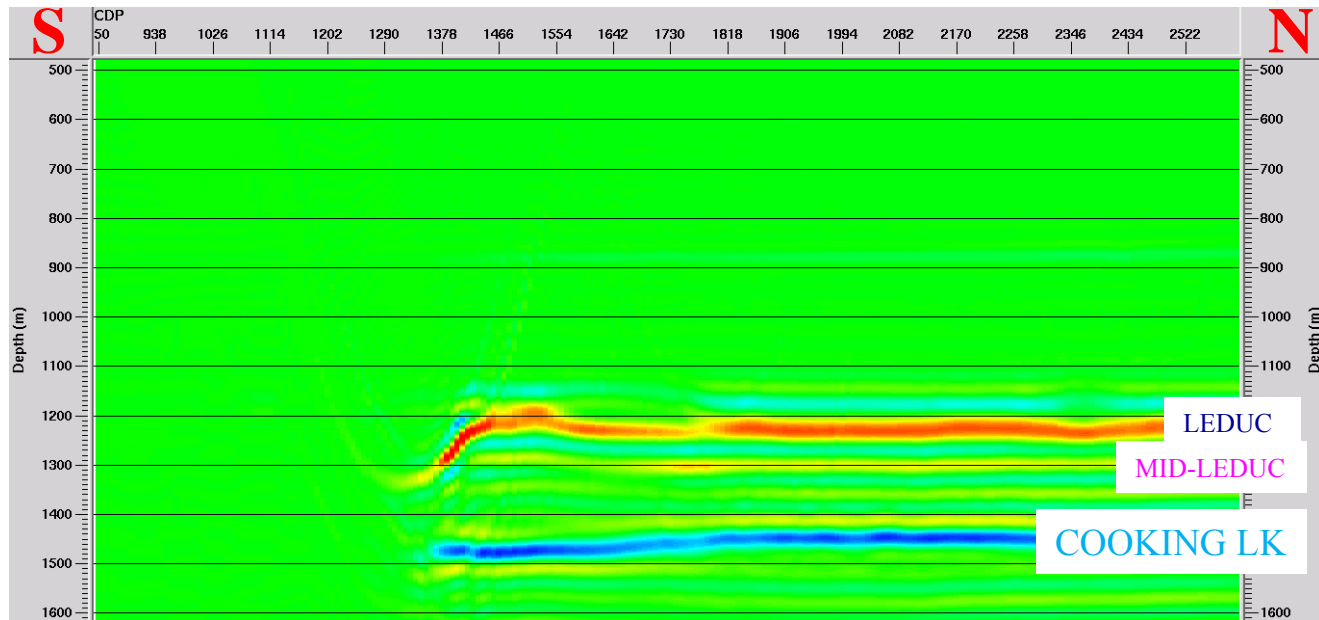# PSDM Seismic Section (CO₂ FRM)

Ray tracing
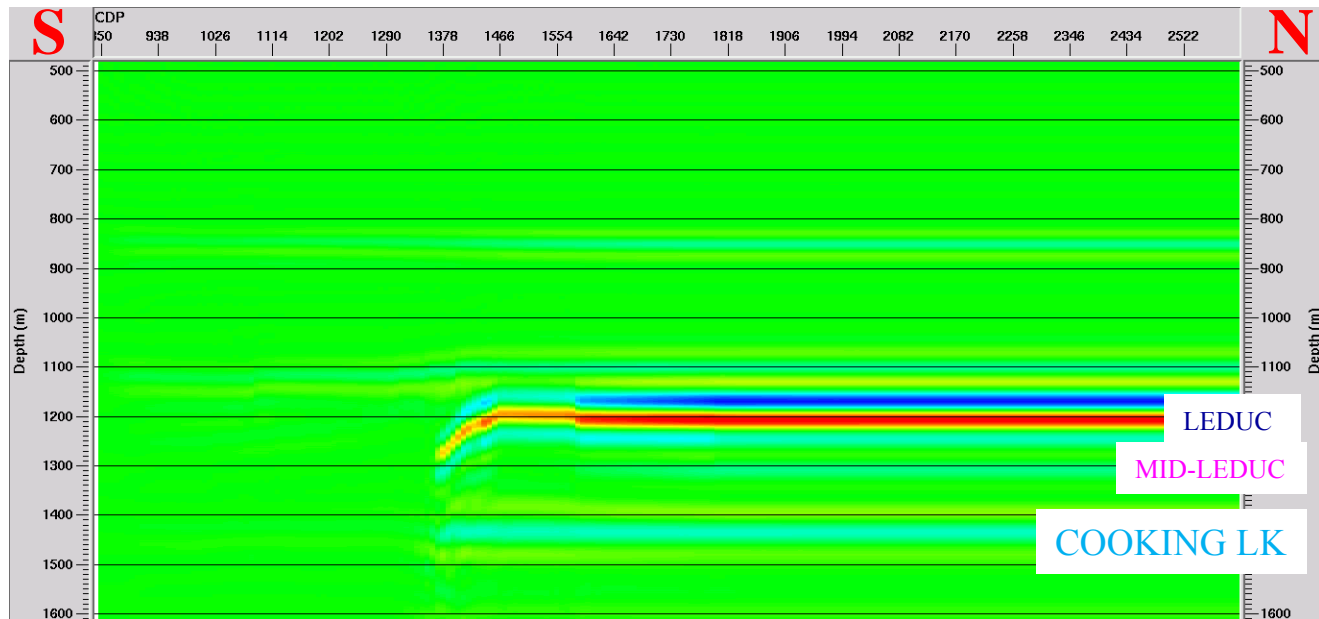
Finite difference

PSDM Time-Lapse Seismic Section

Ray tracing

Finite difference

Conclusions

- Ray tracing and finite difference synthetic seismograms demonstrate similar seismic attributes

- Cooking Lake and Beaverhill Lake Formations display positive structure below the reef

- Reef rim, termination and lateral position are observed seismically at the Redwater Leduc reef margin

- Reef litho-facies are recognized by seismic characters

- High amplitude reflections are strong evident to detect the CO_2 saturation geophysically

- Time-lapse seismology shows a great amplitude difference for the seismic data

Acknowledgements

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CREWES sponsors

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