[AV]4-D Multi-component Seismic Modeling of CO_2 Fluid Substitution in the Redwater Devonian Reef, Alberta, Canada*

Taher M. Sodagar[1] and Don C. Lawton[1]

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[1]Geoscience, University of Calgary, Calgary, AB, Canada (taher.sodagsr@yahoo.ca)

Abstract

The Devonian Redwater reef in Alberta, Canada, 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 Leduc reef at Redwater is one of the largest Devonian reefs in the Western Canada sedimentary basin and is the third largest oil reservoir in Canada. The main objective of the study was to build a 3D geological model of the reef, from the reef interior to off-reef, and examine the seismic response of the reef to CO_2 saturation in the Leduc Formation. Fluid replacement and 3D seismic modeling were undertaken to generate PP and PS synthetic seismic data to study the consequences of CO_2 saturation on the seismic response of various reef facies and formations below the reef, based on seismic attributes.

Common shot multi-component 3D ray tracing modeling was undertaken to evaluate variations in the seismic response of the Redwater reef margin for CO_2 saturation in the Upper Leduc interval. The input geological model was based on well data and depth-converted seismic data from approximately 400-line-km of 2D seismic data were previously reprocessed and interpreted in the area. P-wave and P-S wave ray tracing synthetic seismic reflections demonstrate similar seismic attributes for the Mannville, Nisku, Ireton, Cooking Lake, and Beaverhill Lake formations, but with lower dominant frequency in PS data. Seismic sections and time structure maps display positive structure below the reef for both PP and PS, due to the lateral velocity change from on-reef to off-reef, but are compensated in the depth maps.

Terminations and the lateral position of the Upper Leduc and Middle Leduc events are obvious on the pre-stack time-migrated sections and improved on the depth-migrated section on PP data while it is less evident in PS data. 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 center of the reef for both PP and PS data. 4D seismic modeling predicts a sensible amplitude change and travel-time difference (4ms) for the seismic data before and after CO_2 saturation. High amplitude reflections occurring at the top of upper-Leduc, top of the rim, and base of upper-Leduc near the reef edge provide good markers to observe and monitor CO_2 saturation with 3D seismic data.

Reference

Bachu, S., and B. Bennion, 2008, Effects of in-situ conditions on relative permeability characteristics of CO_2 – brine systems, *in* J. Birkholzer, and C-F. Tsang, (Pref.) Site characterization for geological storage of CO_2: Environmental Geology Berlin, v. 54/8, p. 1707-1722.

4D multicomponent seismic modeling of CO_2 fluid substitution in the Redwater Devonian Reef, Alberta, Canada

Taher M. Sodagar

Don C. Lawton

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UNIVERSITY OF CALGARY

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Outline

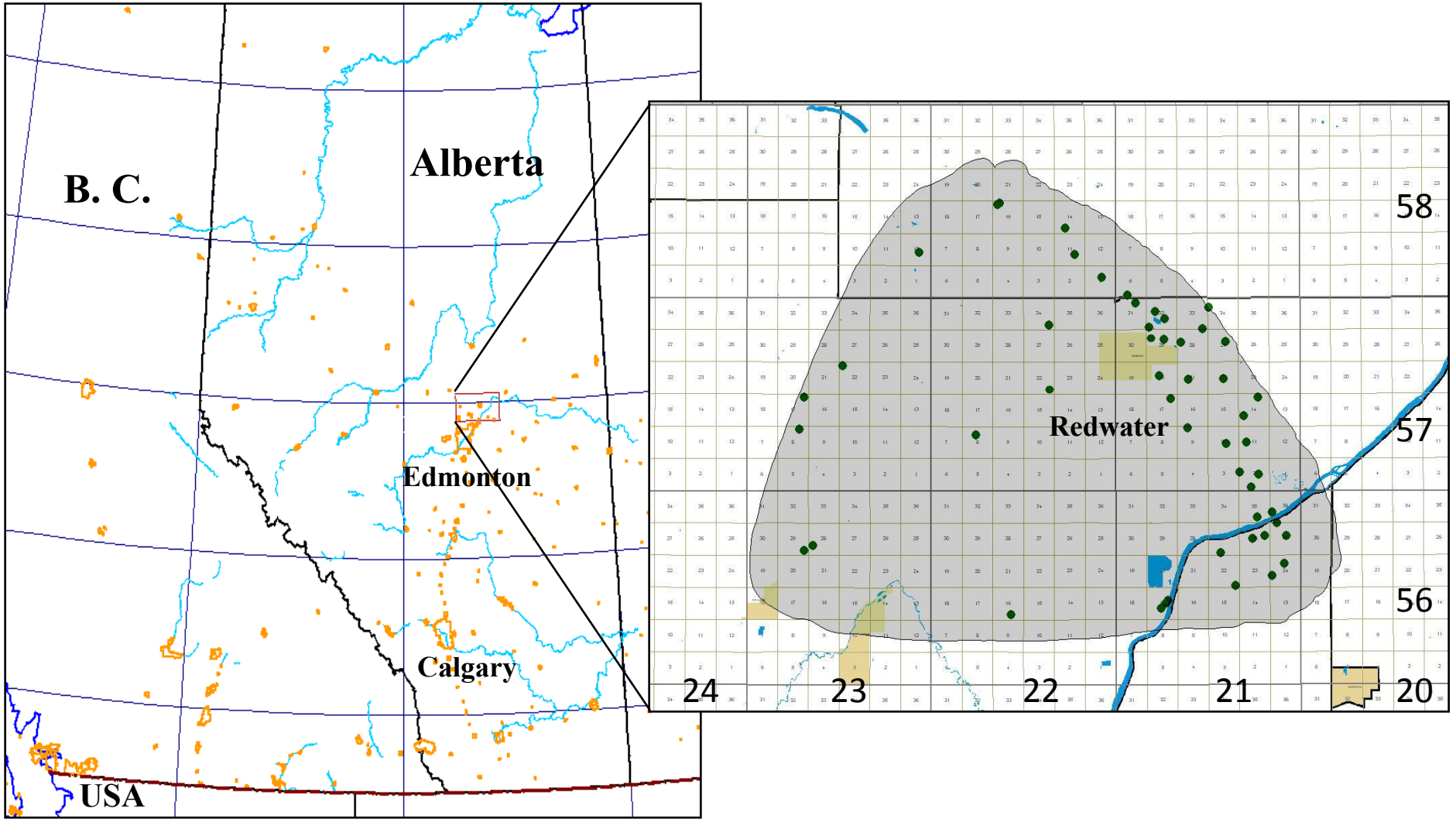
- **Objectives and Methods**
- **Geology and reef overview**
- **Results**
  - **Seismic modeling**
  - **Seismic section interpretation**
  - **Seismic map interpretation**
- **Conclusions**

Objectives/Methods

3D Seismic modeling and evaluation of the Devonian Redwater reef for geological storage of CO_2 and seismic monitoring

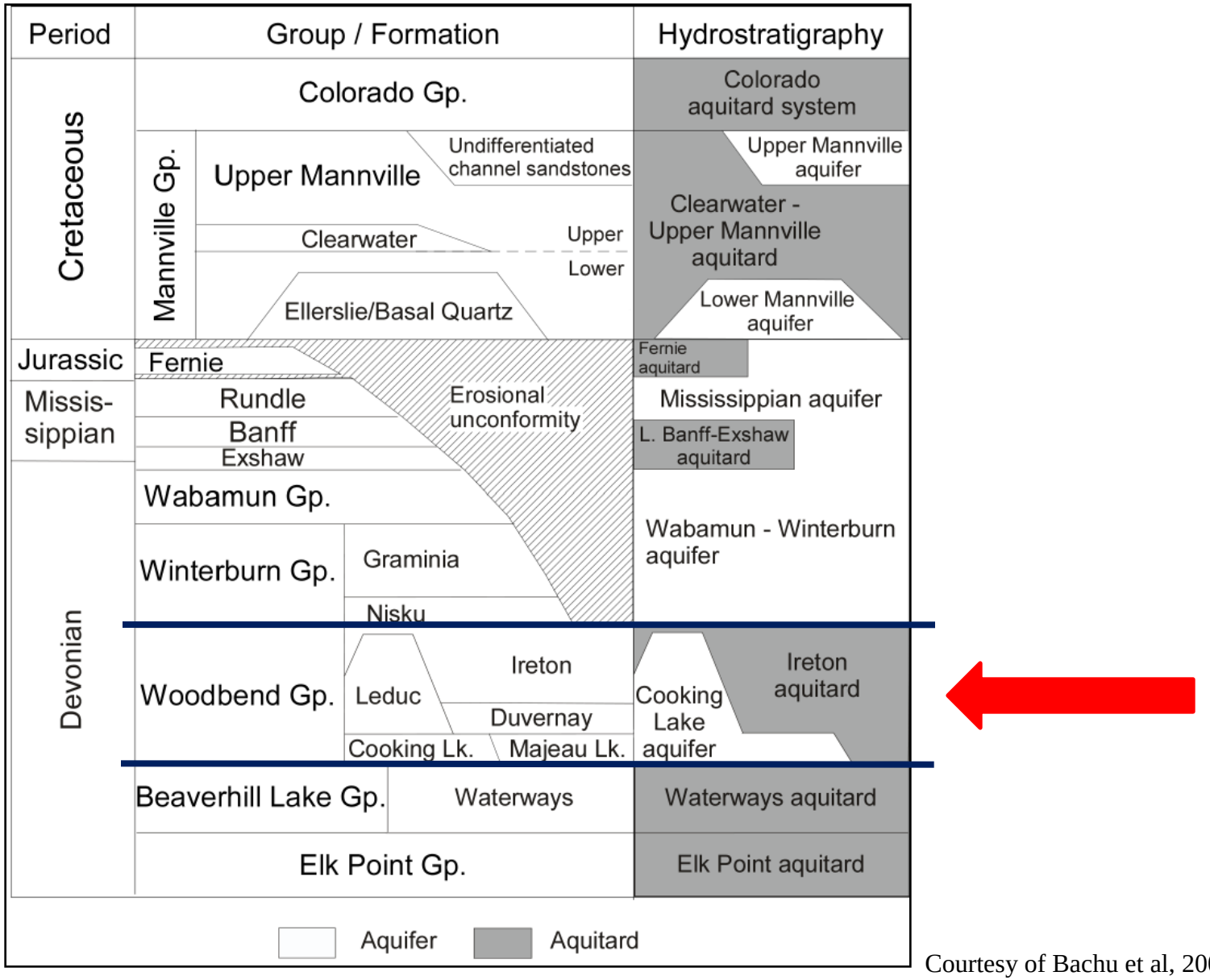
- **Evaluate 3D seismic modeling attributes and reflection character**
- **Determine Redwater reef litho-facies**
- **Multi-component ray tracing**
- **Gassmann fluid substitution**
- **Time-lapse seismology for CO_2 monitoring**

Redwater reef study area



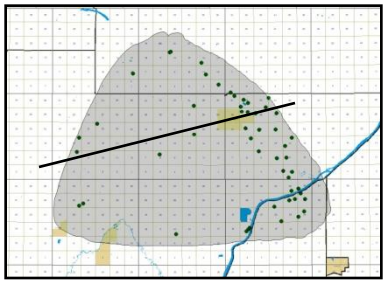
Courtesy of Lawton and Sodagar, 2009

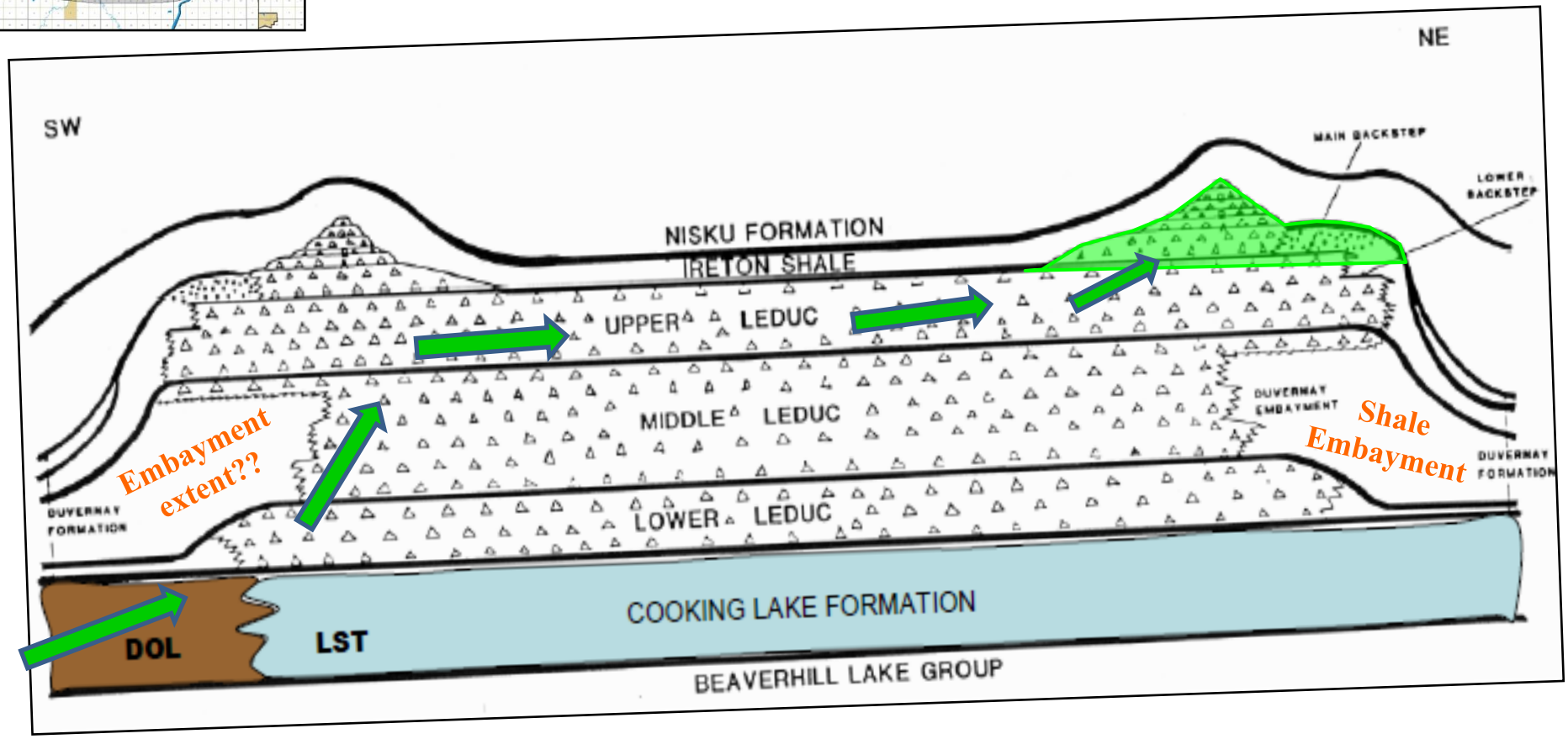
Geological setting



Courtesy of Bachu et al, 2008

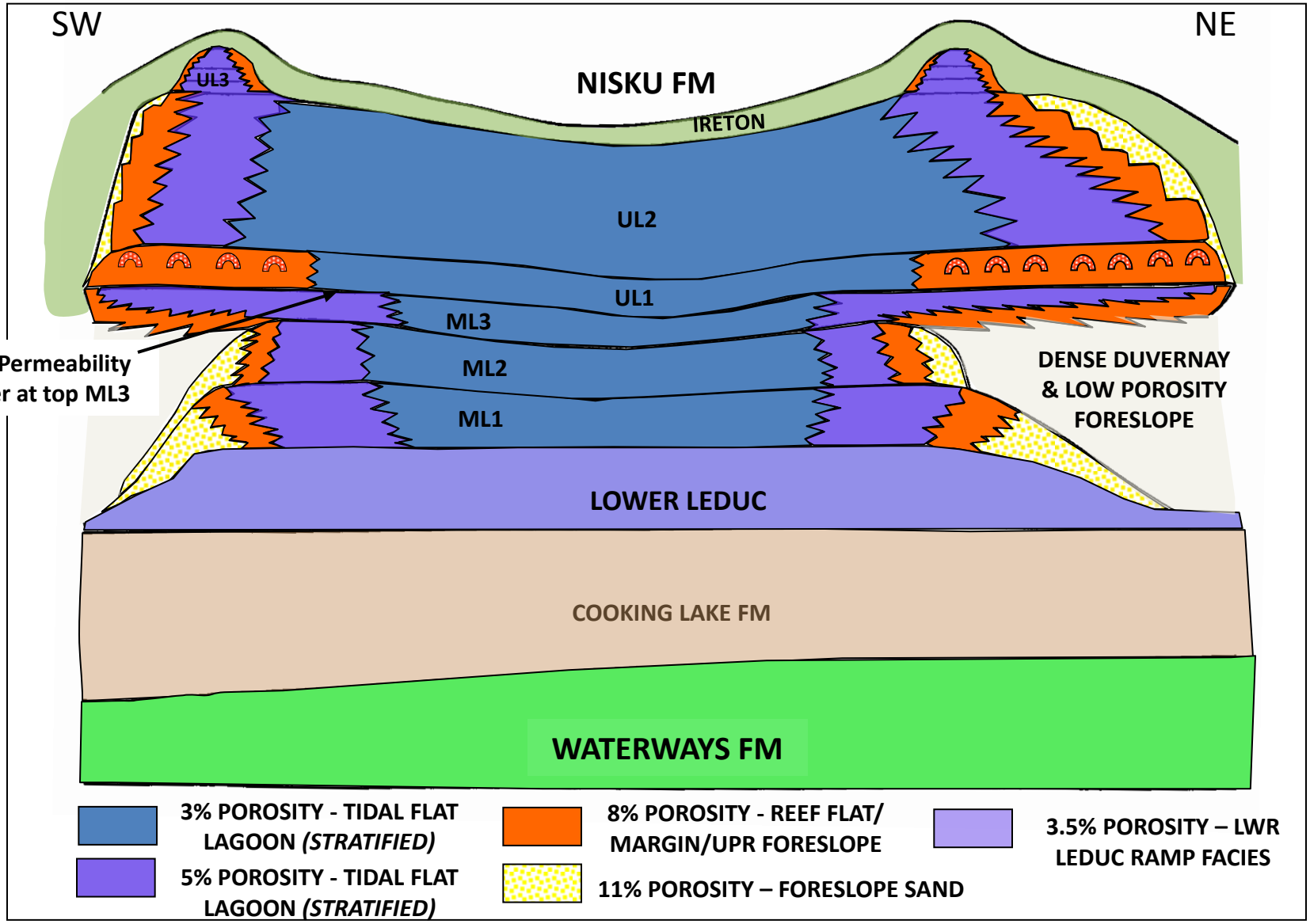
Reef subdivisions and HC migration





Courtesy of Stoakes and Foellmer, 2009

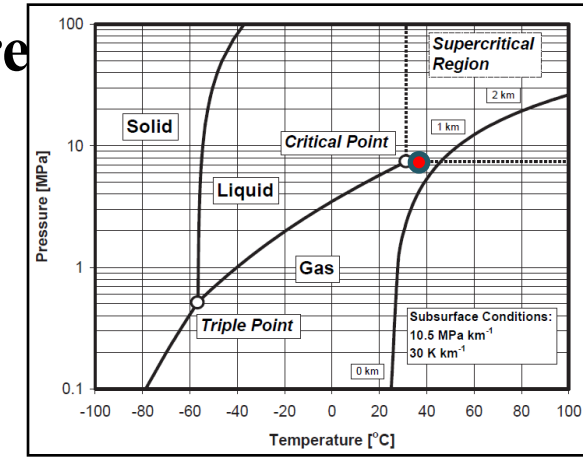
Reef porosity and facies distribution



Courtesy of Stoakes and Foellmer, 2009

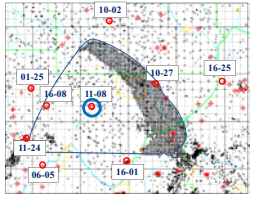
Leduc Formation properties

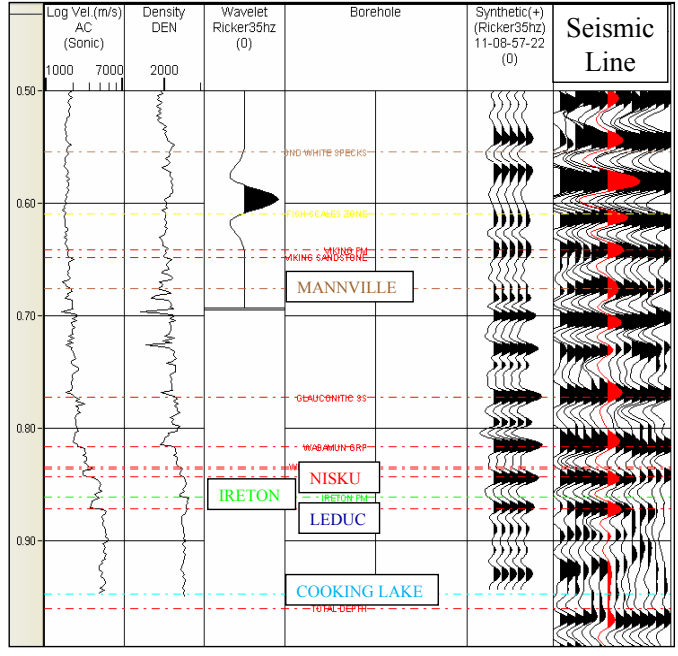
- **Porosity: 1-17% (Avg. 7%)**
  - **Intercrystalline, moldic, and fracture**
- **Permeability:**
  - **Horizontal: 0.01-4000 md**
  - **Vertical: 0.02-670 md**
- **Pressure 7.4 MPa and Temperature 34°C**
- **Formation water NaCl, salinity 107 mg/l**
- **Leduc depth: 994 - 1120 m**



Courtesy of Bachu et al, 2008

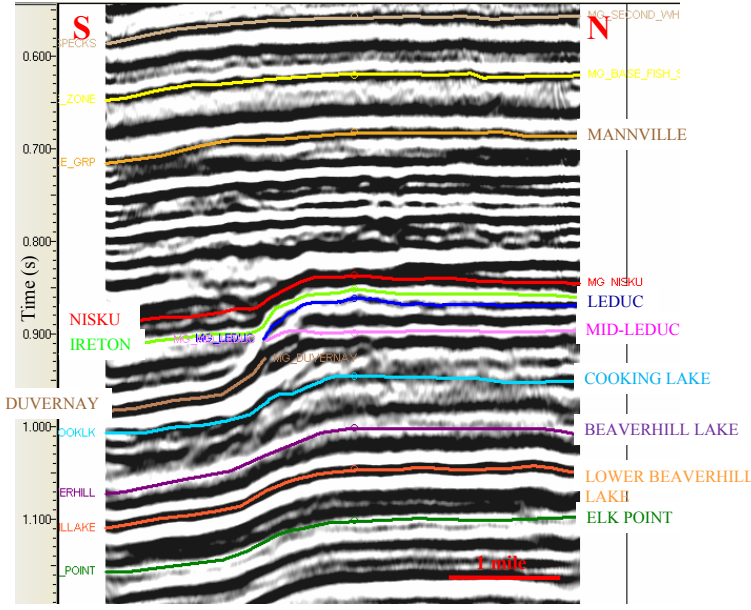
Well 11-08 synthetic tie to seismic data





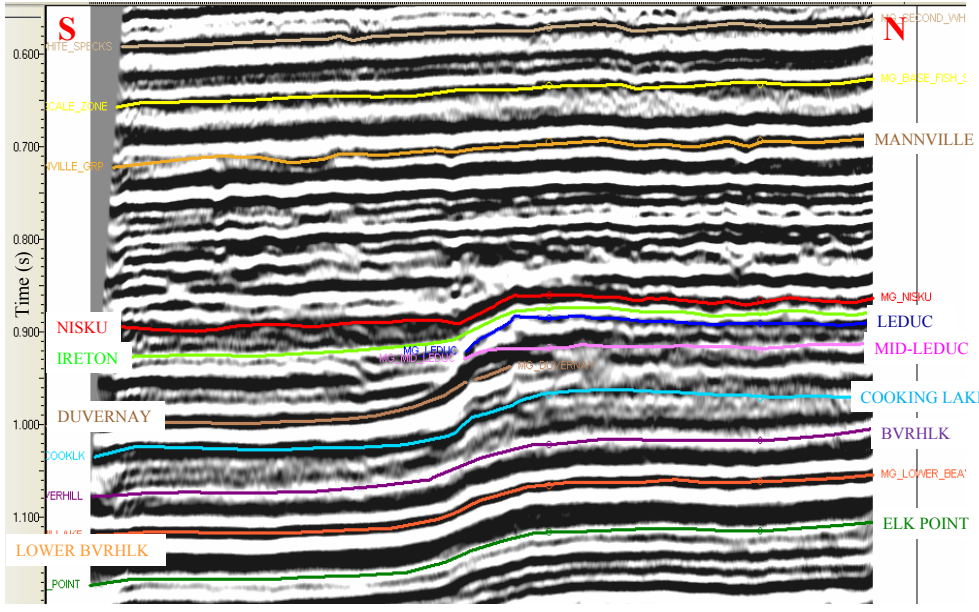
Presenter's notes: Synthetics of Well 11-08 Correlated with Line BD9.

Reef margin seismic line



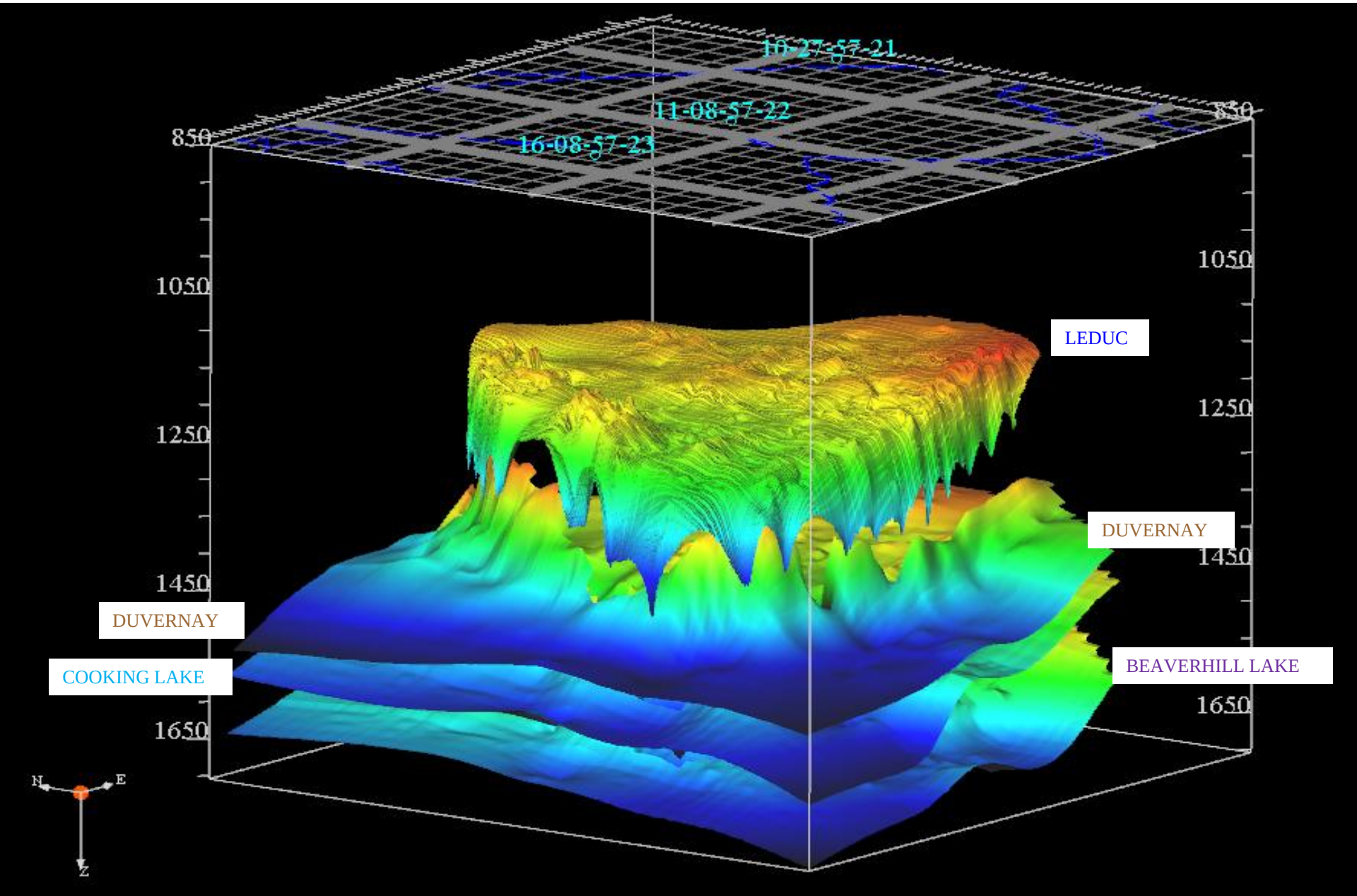
Presenter's notes: Line 83-R13, with interpretations (L5).

Reef margin with embayment

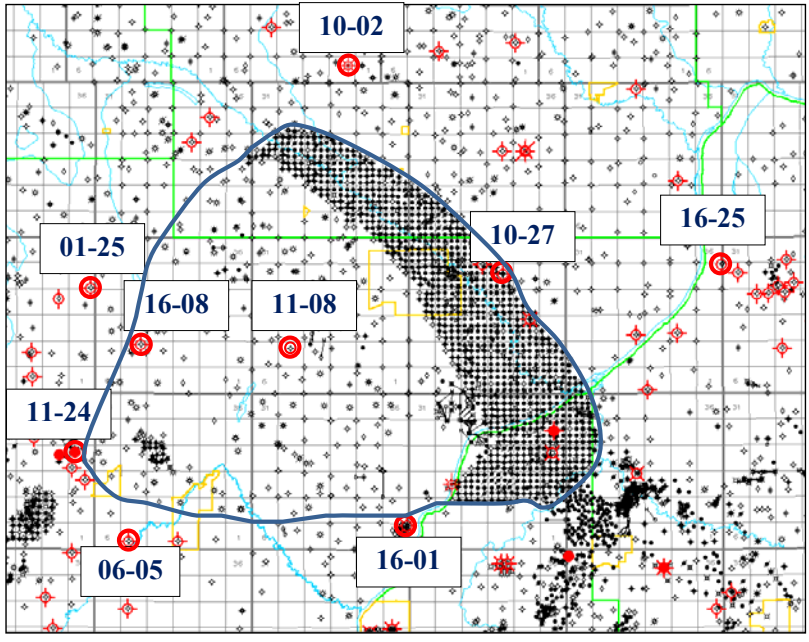


Presenter's notes: Line 83-R9, with interpretations (L13).

Redwater reef 3D view in depth

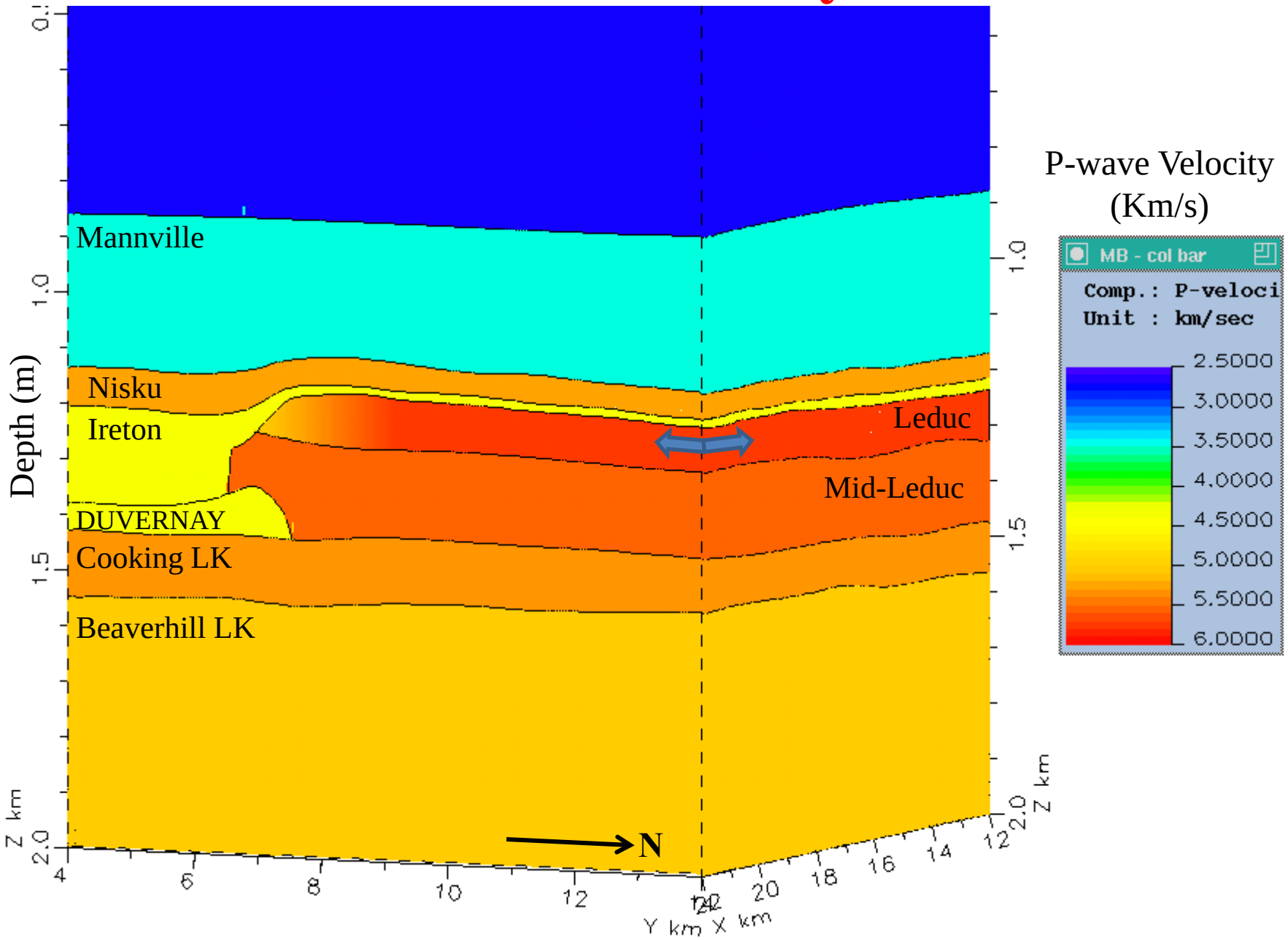


3D seismic survey in Redwater reef

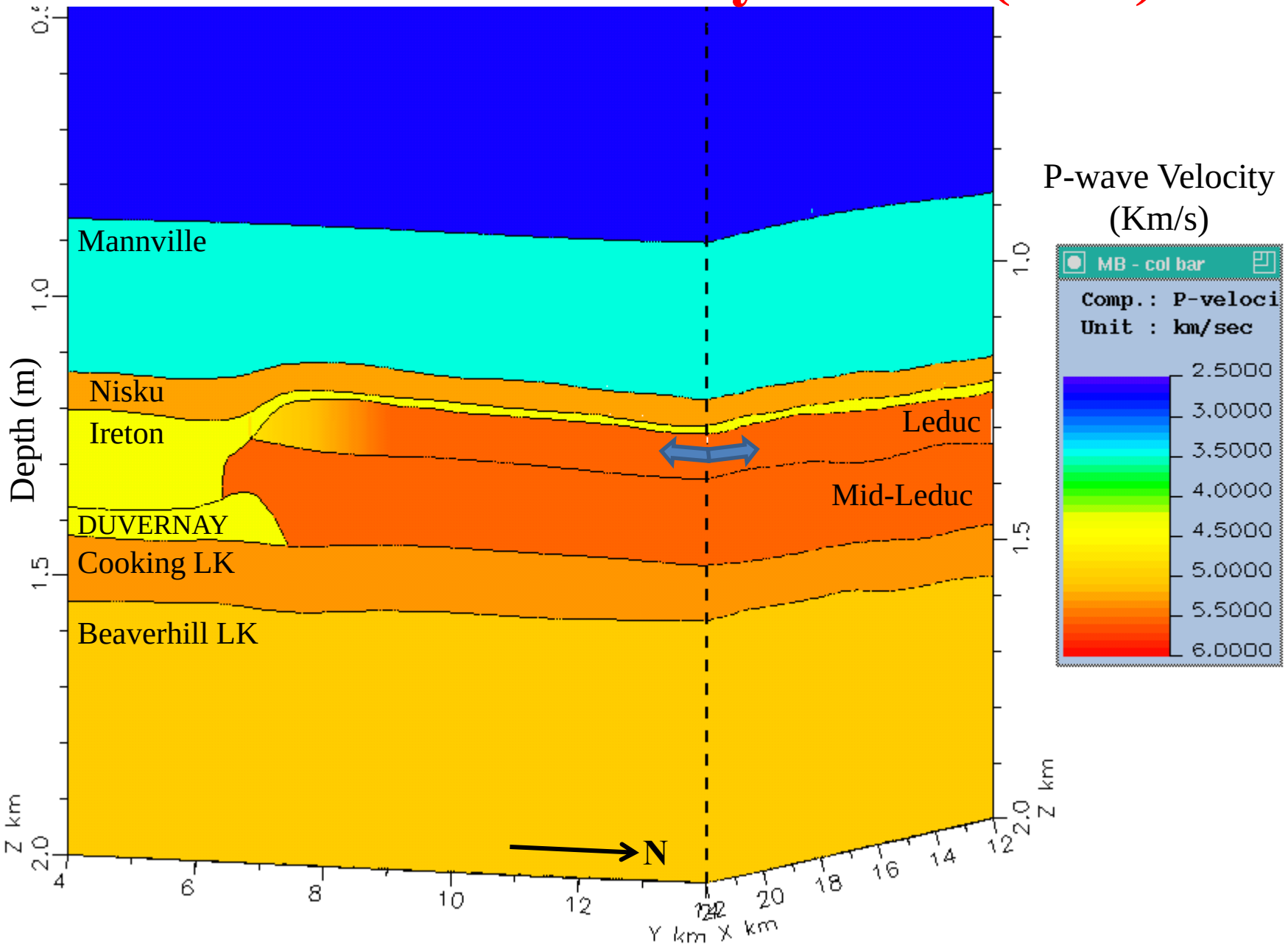


Redwater Map with all wells, those with sonic logs, and reef outliine.

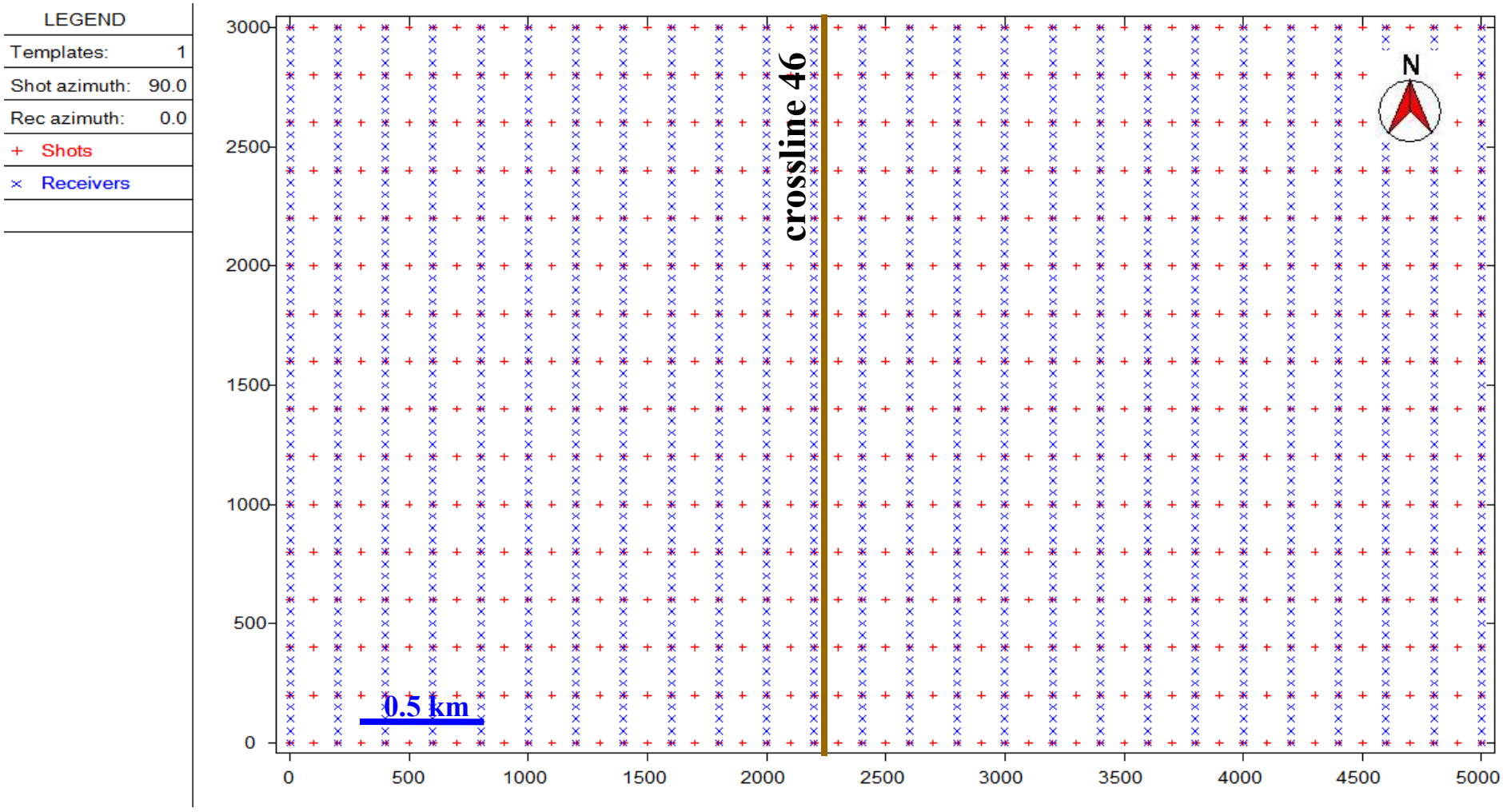
3D P-wave velocity model



3D P-wave velocity model (CO_2)



3D seismic survey design

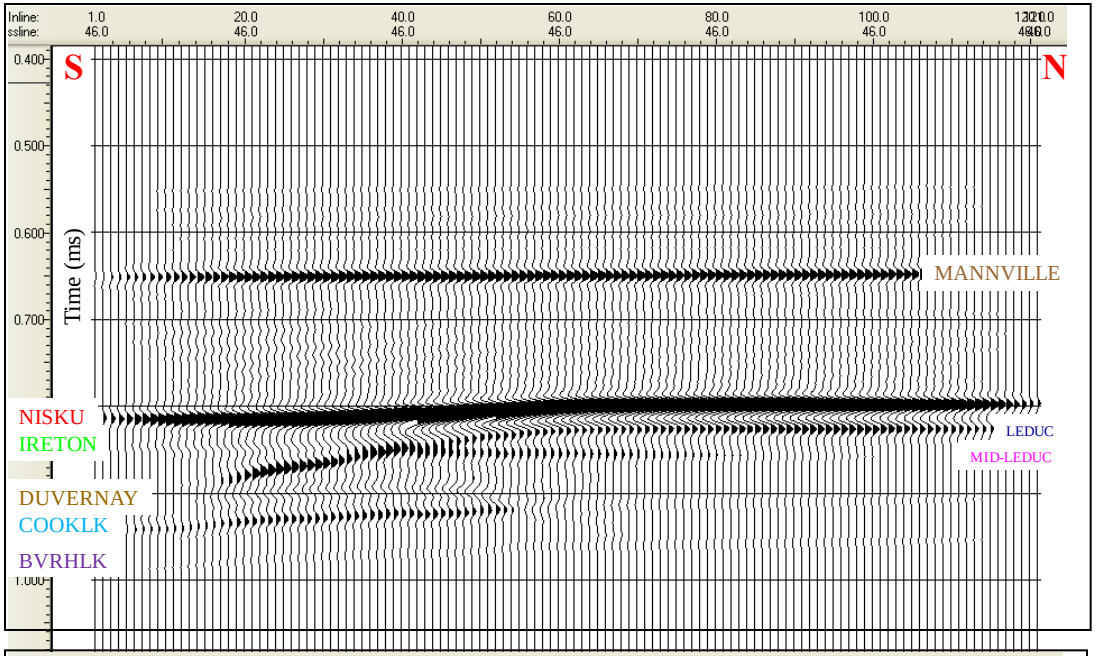


Source interval = 100m
Source line interval = 200m

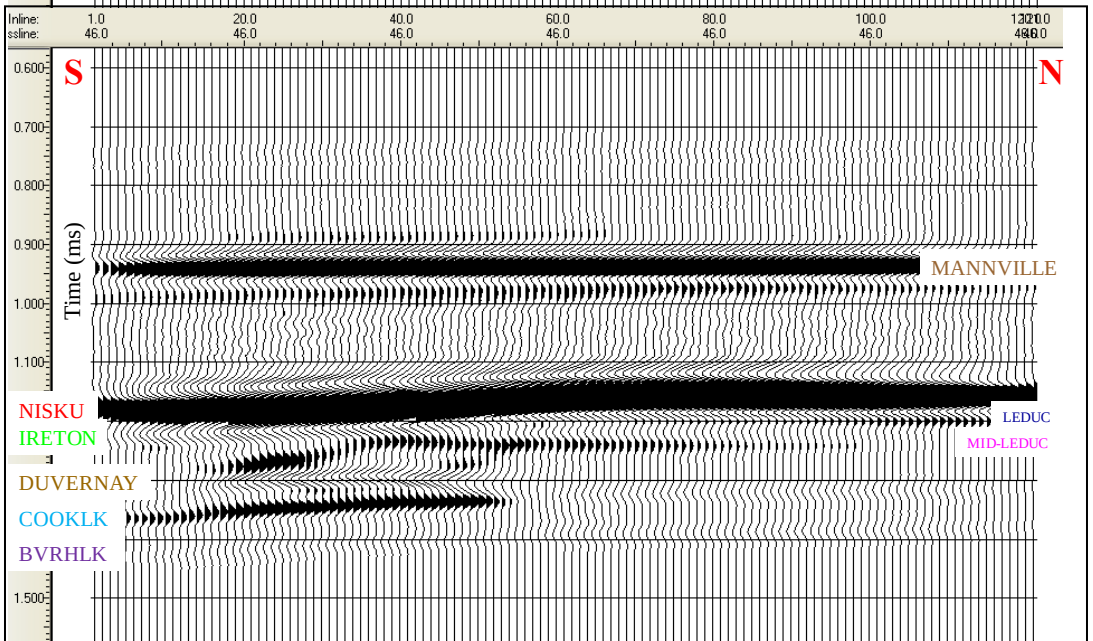
Receiver interval = 50m
Receiver line interval = 200m

Pre-stack time migrated seismic section

PP

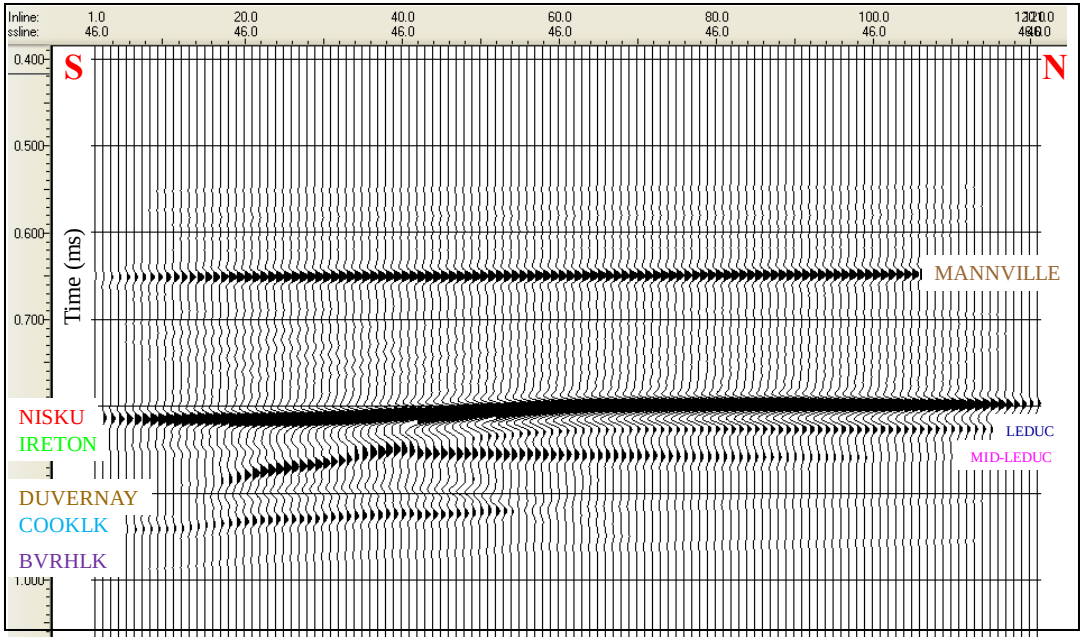


PS

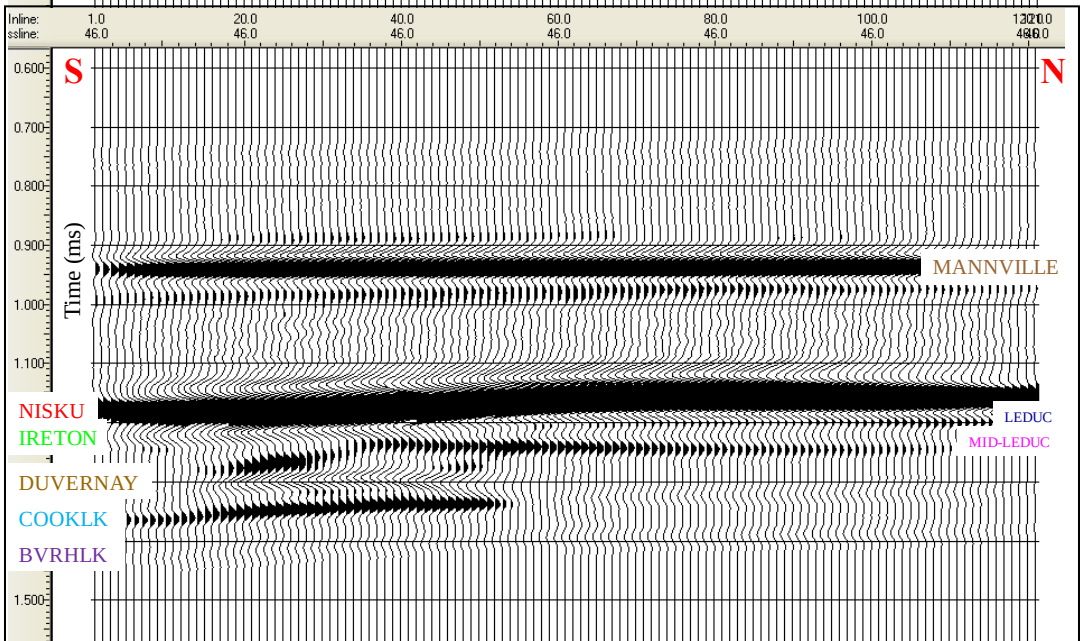


PSTM seismic section (Monitor)

PP

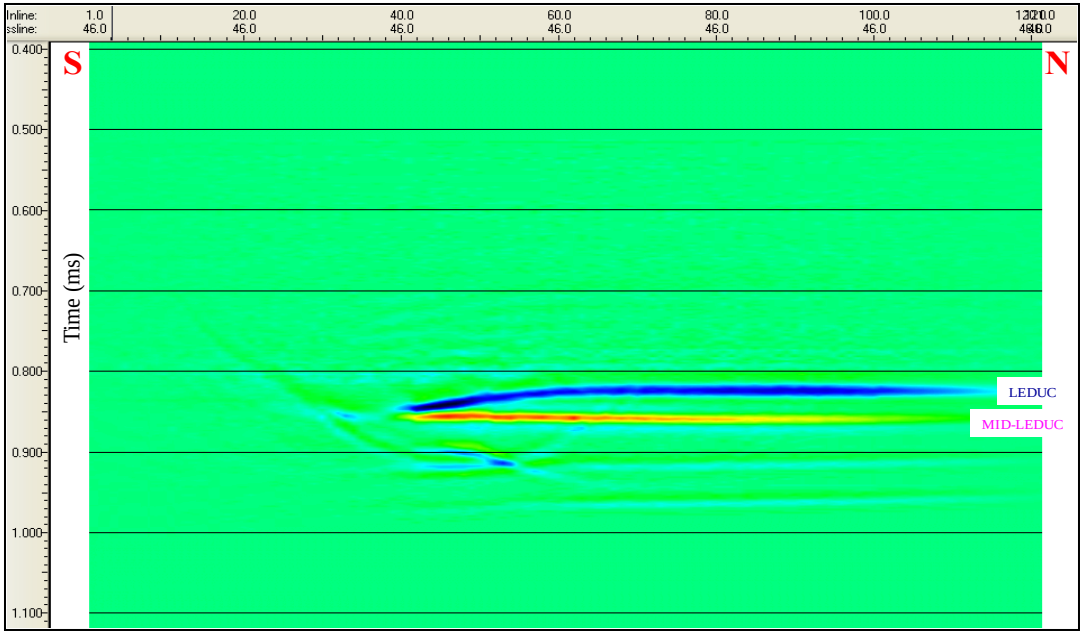


PS



PSTM difference sections

PP



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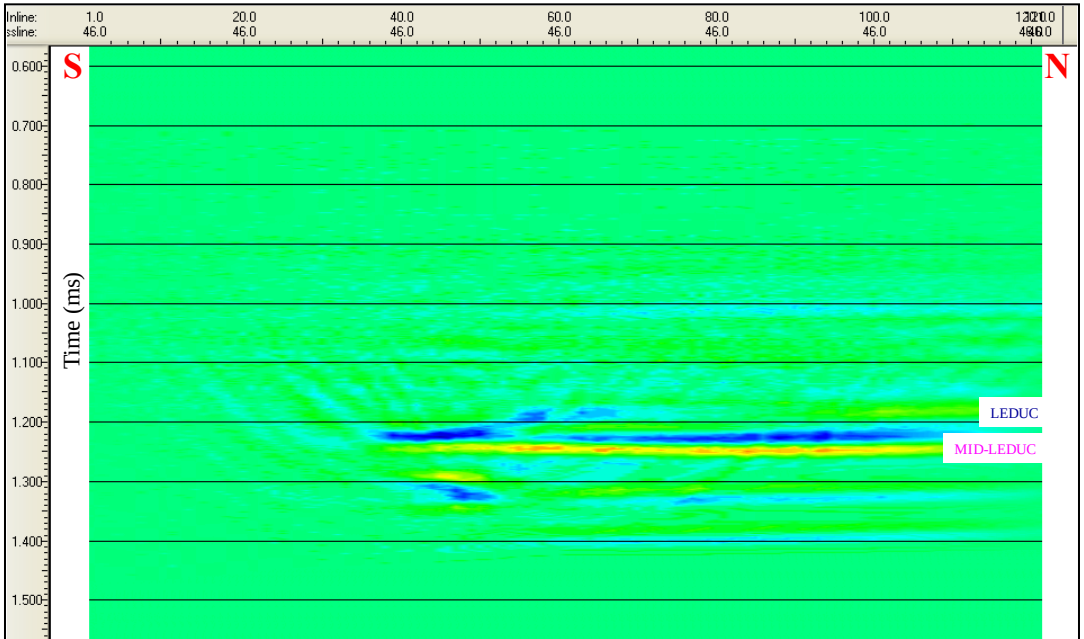
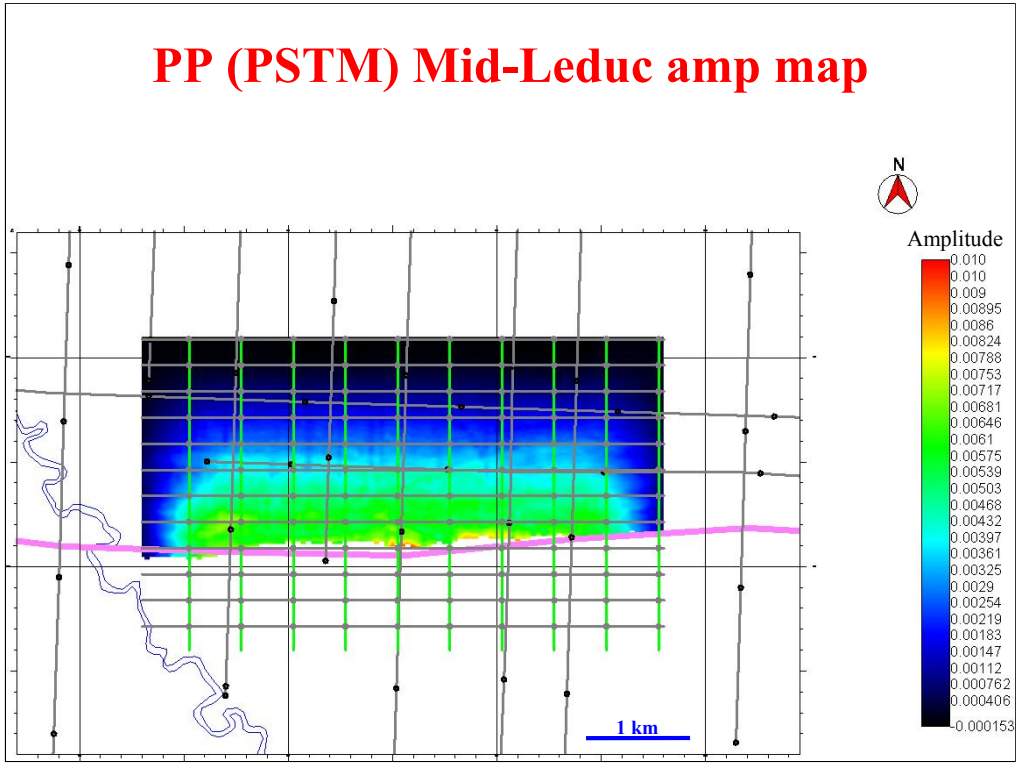
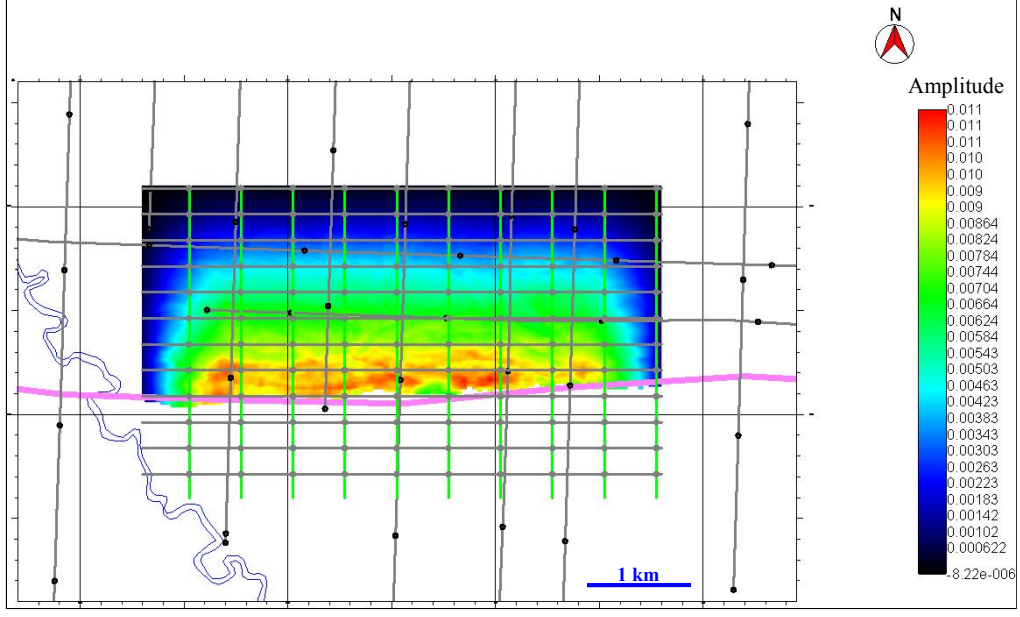


PP (PSTM) Mid-Leduc amp map



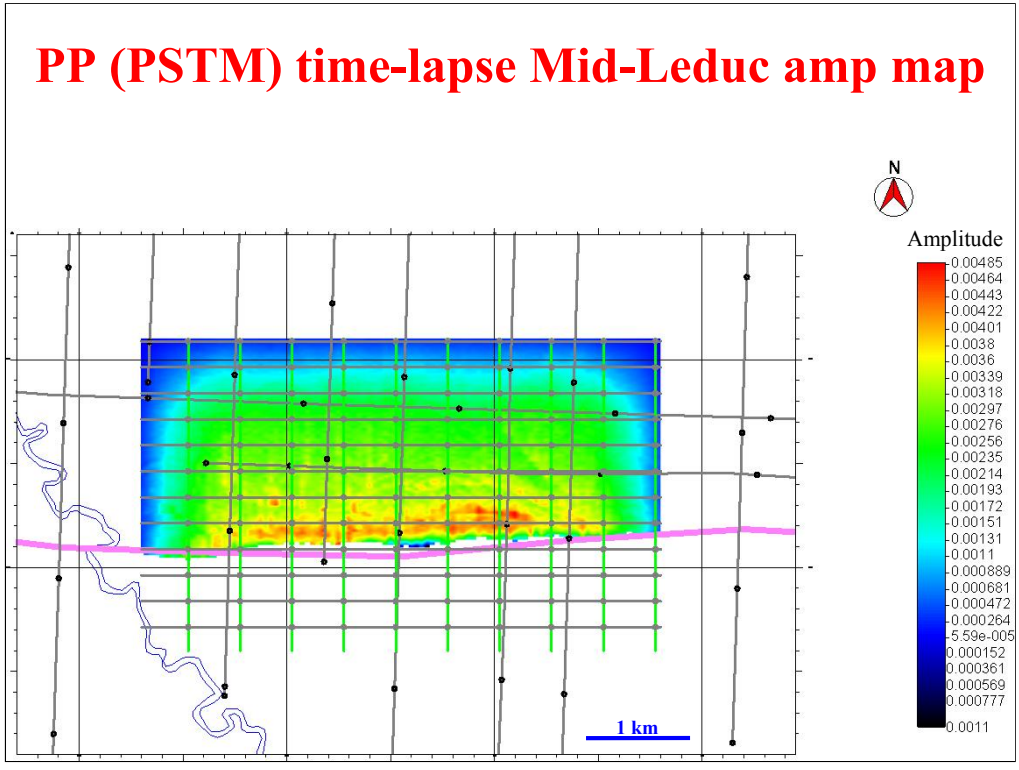
Presenter's notes: After CO_2, XL-46.

PP (PSTM) Mid-Leduc amp map (monitor)



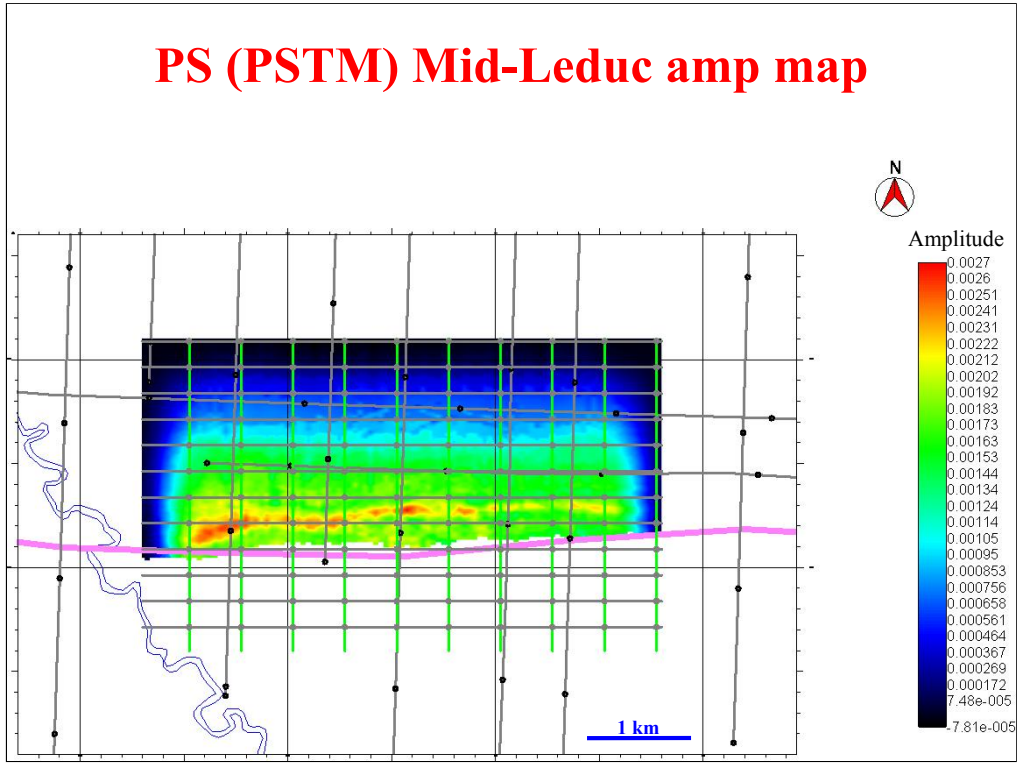
Presenter's notes: After CO_2, XL-46.

PP (PSTM) time-lapse Mid-Leduc amp map



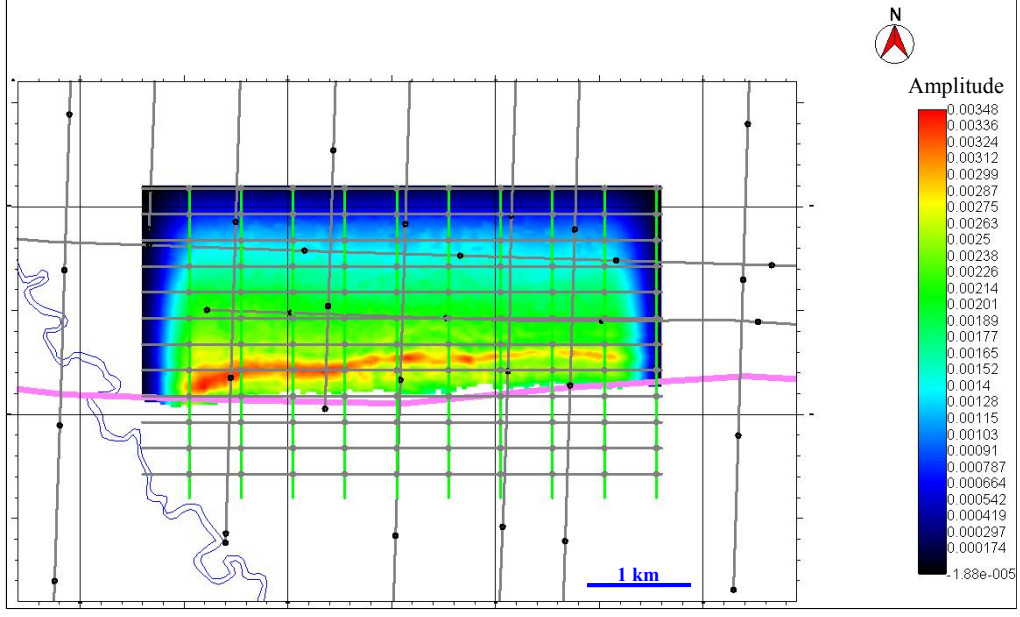
Presenter's notes: After CO_2, XL-46.

PS (PSTM) Mid-Leduc amp map



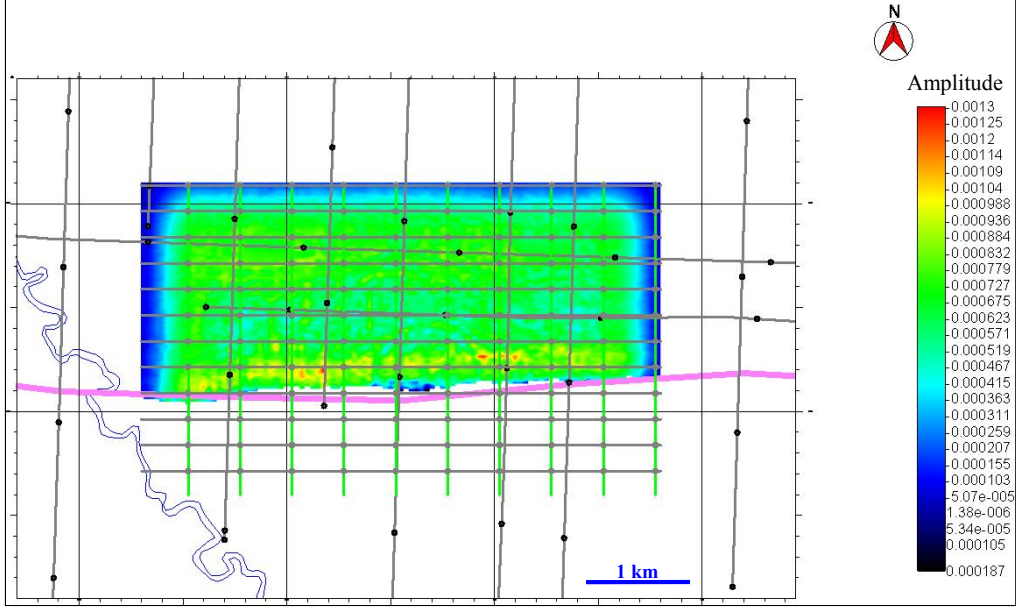
Presenter's notes: After CO_2, XL-46.

PS (PSTM) Mid-Leduc amp map (monitor)



Presenter's notes: After CO_2, XL-46.

PS (PSTM) time-lapse Mid-Leduc amp map



Presenter's notes: After CO_2, XL-46.

Conclusions

- Cooking Lake and Beaverhill Lake Formations display positive time structure below the reef
- Reef rim, termination and lateral position are observed seismically at the Redwater Leduc reef margin
- PP and PS synthetic seismograms demonstrate similar seismic attributes
- Reef litho-facies are recognized by seismic character particularly on PS data
- Time-lapse PP reflections show strong evidence to detect CO_2
- Time-lapse PS reflections show weaker evidence to detect CO_2

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