(Cooperative Inversion of Reservoir Data)

The Effects of Reservoir Changes Associated with Cold Production on Seismic Response

Fereidoon Vasheghani
Larry Lines
Joan Embleton

SEG Development and Production Forum: Heavy Oils. Edmonton, Alberta, Canada • 29 July – 2 August 2007.

OUTLINE

- Introduction
- Theoretical Discussion
- Reservoir Simulation
- Simulator to Seismic
- Synthetic Seismograms
- Conclusions

INTRODUCTION

- cold production of heavy oil is a non-thermal process, in which sand and oil are produced simultaneously to enhance the oil recovery.

- Changes in reservoir during cold production
  - Porosity changes due to sand production
  - Fluid saturation changes due to changes in PVT conditions

- Porosity change:
  - Wormholes grow in the reservoirs which act as high permeability channels

- Saturation changes:
  - Pressure drops below the bubble point and gas come out of solution and foamy oil forms

INTRODUCTION

- Wormhole:
  - Coupled Geomechanical model
  - Static wormhole model
- Foamy Oil:
  - Based primarily on empirical adjustments to the conventional solution-gas-drive models.
  - Practical Adjustments:
    - Critical gas saturation
    - Oil/gas relative permeability
    - Fluid and/or rock compressibility
    - Pressure-dependent oil viscosity
    - Absolute permeability
    - Bubble point pressure

THEORETICAL DISCUSSION

- P-wave velocity:

$$v_p = \sqrt{\frac{1000\left(K_{sat} + 4/3\,\mu_{sat}\right)}{\rho_{sat}}}$$

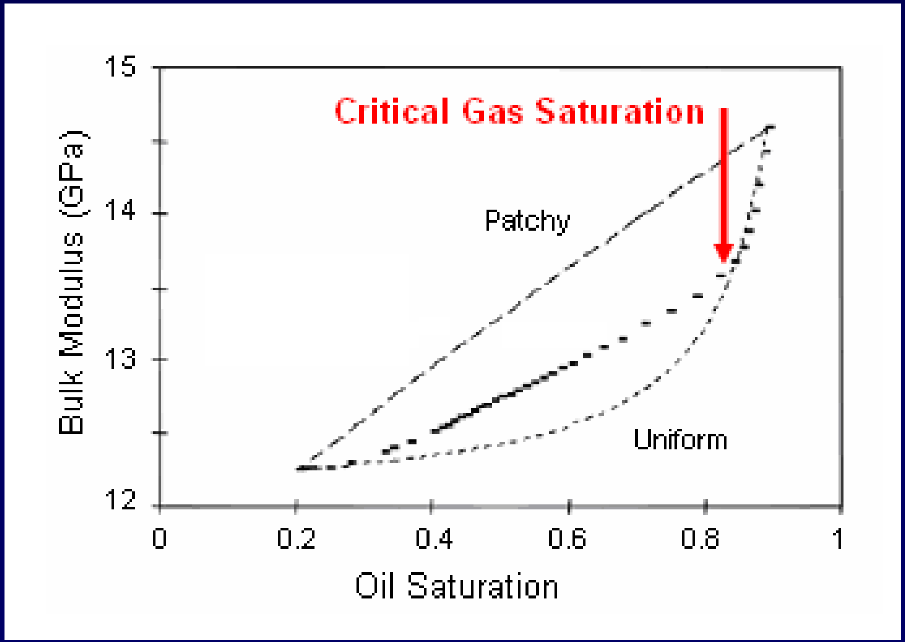
- Gassmann's equation:

$$K_{sat} = K_{dry} + \frac{\left(1 - \frac{K_{dry}}{K_m}\right)^2}{\frac{\varphi}{K_f} + \frac{1-\varphi}{K_m} - \frac{K_{dry}}{K_m^2}}$$

- K_f depends on:
  - Bulk modulus of each fluid constituent
  - Distribution of the fluids in the pore space

THEORETICAL DISCUSSION

- Uniform distribution: $$\frac{1}{K_f} = \frac{S_{oil}}{K_{oil}} + \frac{S_{br}}{K_{br}} + \frac{S_{gas}}{K_{gas}}$$
- Patchy distribution: $$K_f = S_{oil}K_{oil} + S_{br}K_{br} + S_{gas}K_{gas}$$
- Which averaging method to use?



(modified from Kristetter et al, 2006)

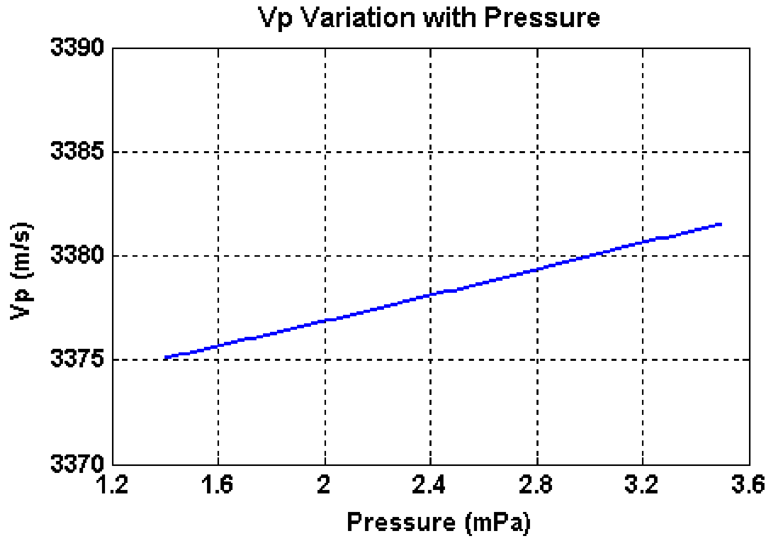
THEORETICAL DISCUSSION

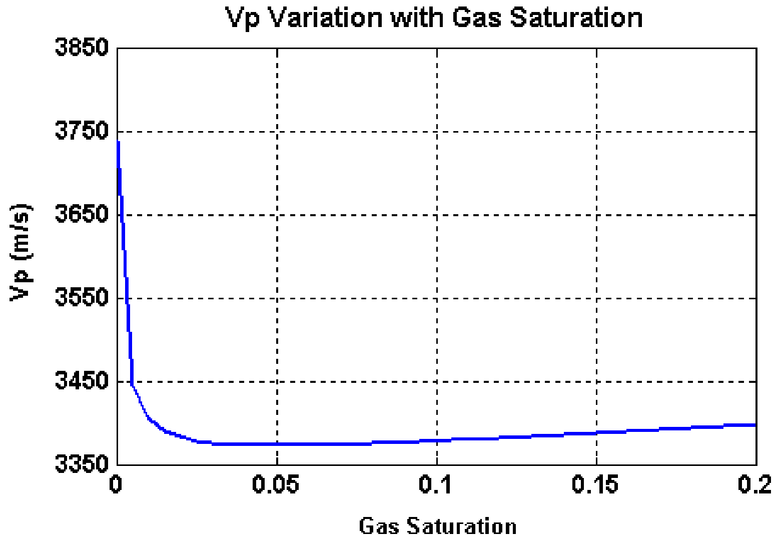
- Bulk modulus of each fluid depends on:
  - Reservoir pressure
  - Reservoir temperature

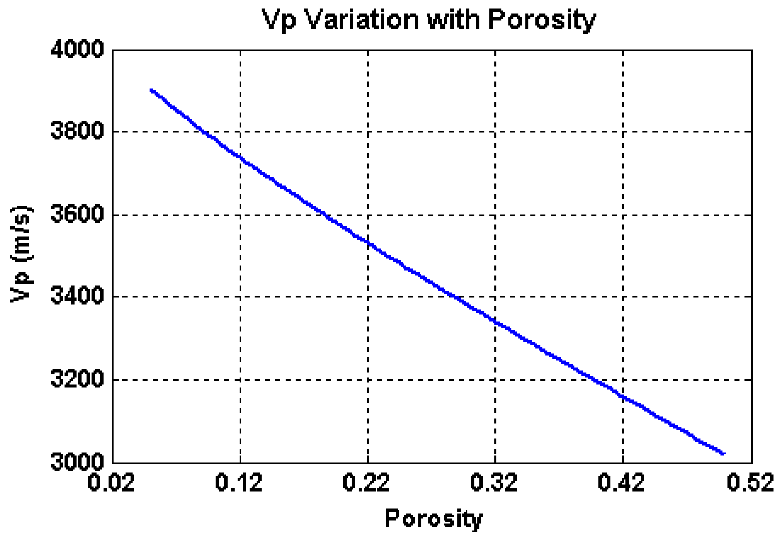
- P-wave velocity:
  - A sophisticated function relates V_p to reservoir parameters

  - Pressure
  - Temperature
  - Fluid saturations
  - Fluid distribution
  - Porosity
  - …

THEORETICAL DISCUSSION







Reservoir Properties, Reference Values	
Porosity	0.3
Pressure (mPa)	2.3
Temperature (°C)	35
Water Saturation	0.2
Oil Saturation	0.7
Gas Saturation	0.1
Water Salinity (ppm)	350 000
Oil Gravity (API)	10
Gas Specific Gravity	0.56
Matrix Bulk Modulus (mPa)	40 000
Matrix Shear Modulus (mPa)	30 000
Dry Bulk Modulus (mPa)	3 250
Matrix Density (g/cc)	2.71

RESERVOIR SIMULATION

Reservoir Simulation

Reservoir Geometry

Size (m)	1010 x 1010 x 30
Grid size (m)	10 x 10 x 10

Vertical Well Properties

Perforation (m)	30
Radius (m)	0.0762

Horizontal Well Properties

X direction

Length (m)	620
Radius (m)	0.0672

Y direction

Length (m)	330
Radius (m)	0.0672

Reservoir Properties

Porosity	0.3
HorizontalPermeability (md)	2000
Vertical Permeability (md)	200
Initial Pressure (kPa)	3200
Temperature (°C)	35

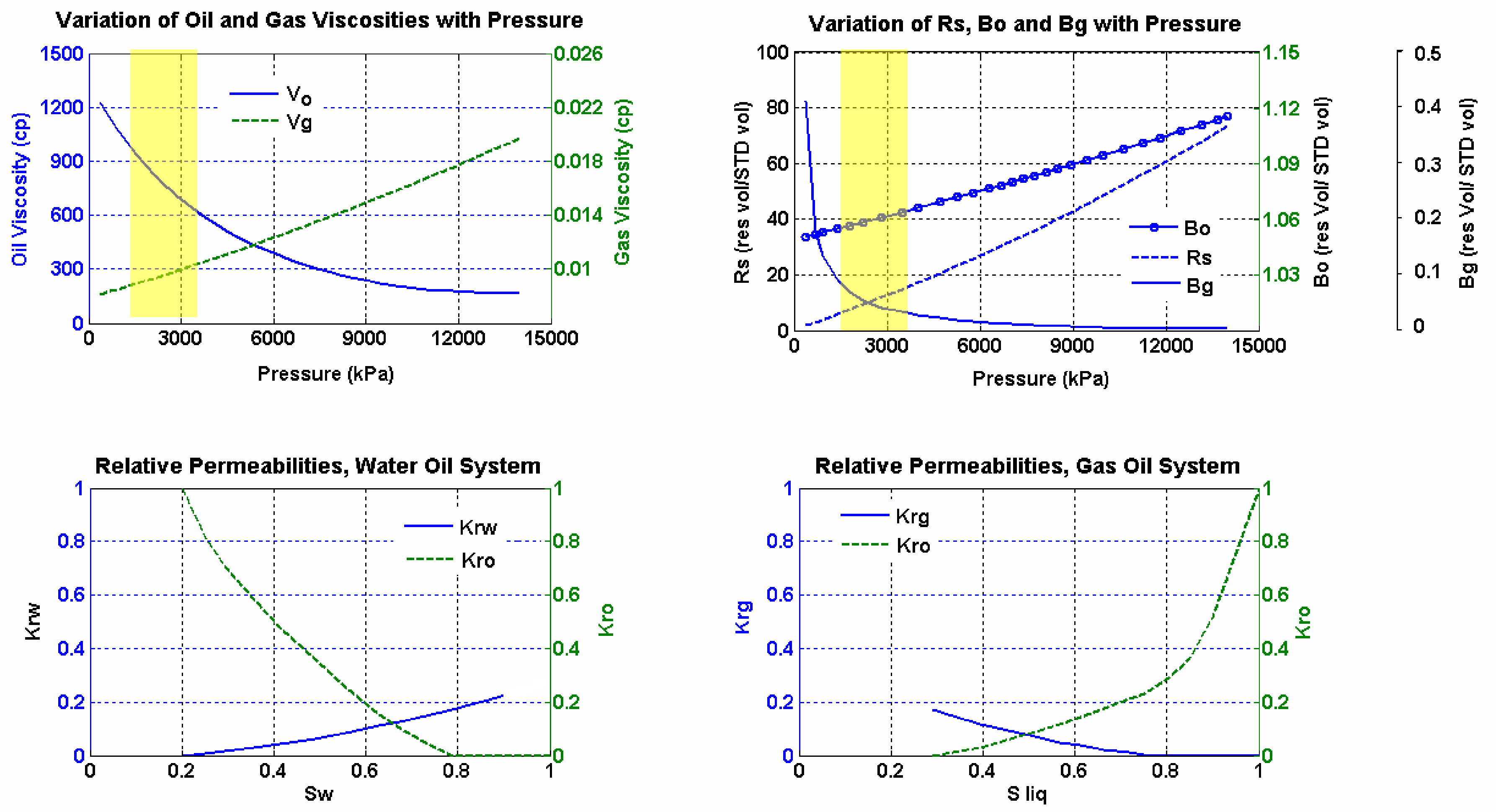
Production Parameters

Duration (days)	720
Min BHP (kPa)	500

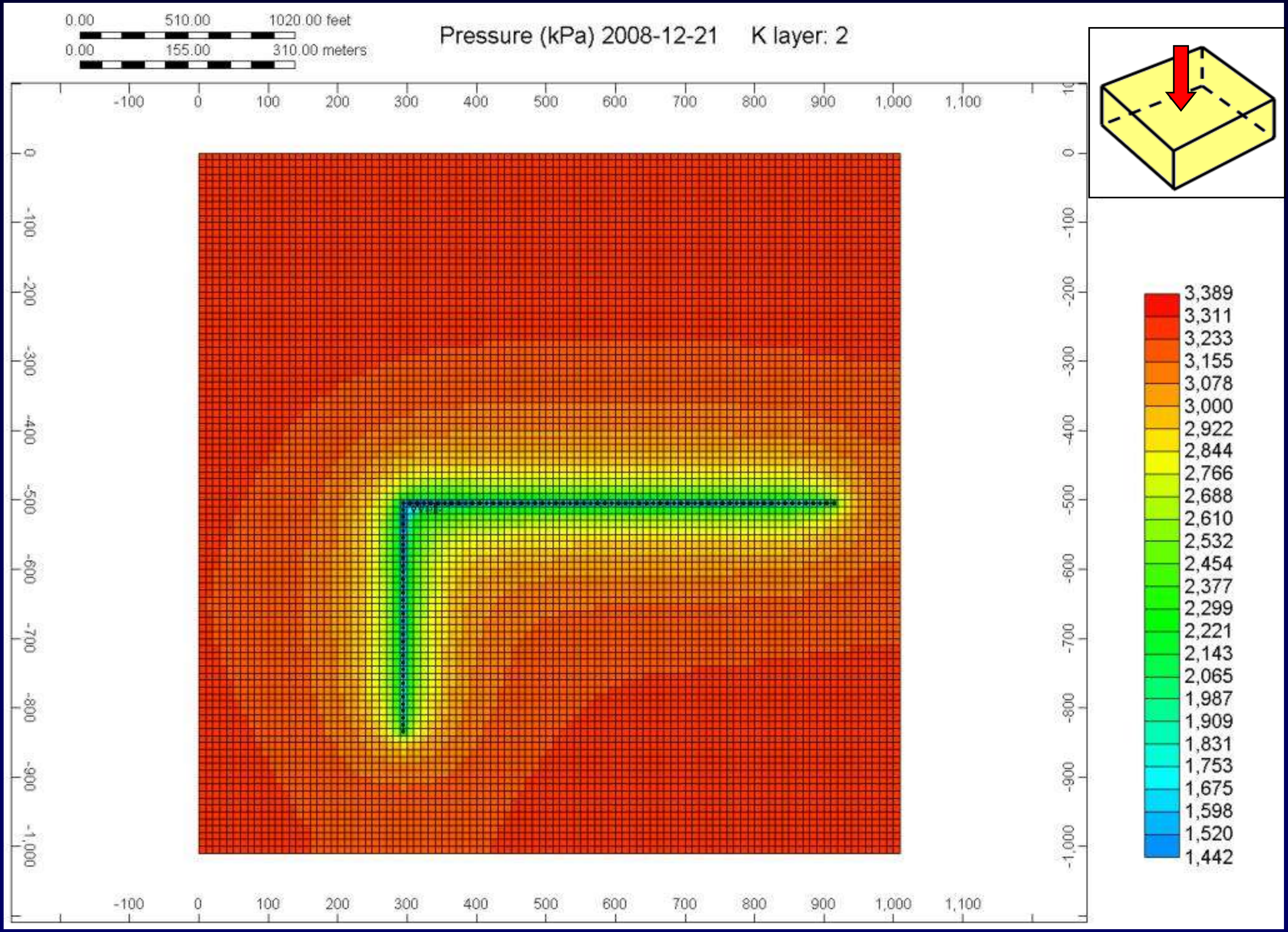
Oil Properties

Gravity (API)	10
Bubble Point Pressure (kPa)	3200
Oil Compressibility (1/kPa)	1.091×10^{-6}
CVO	0

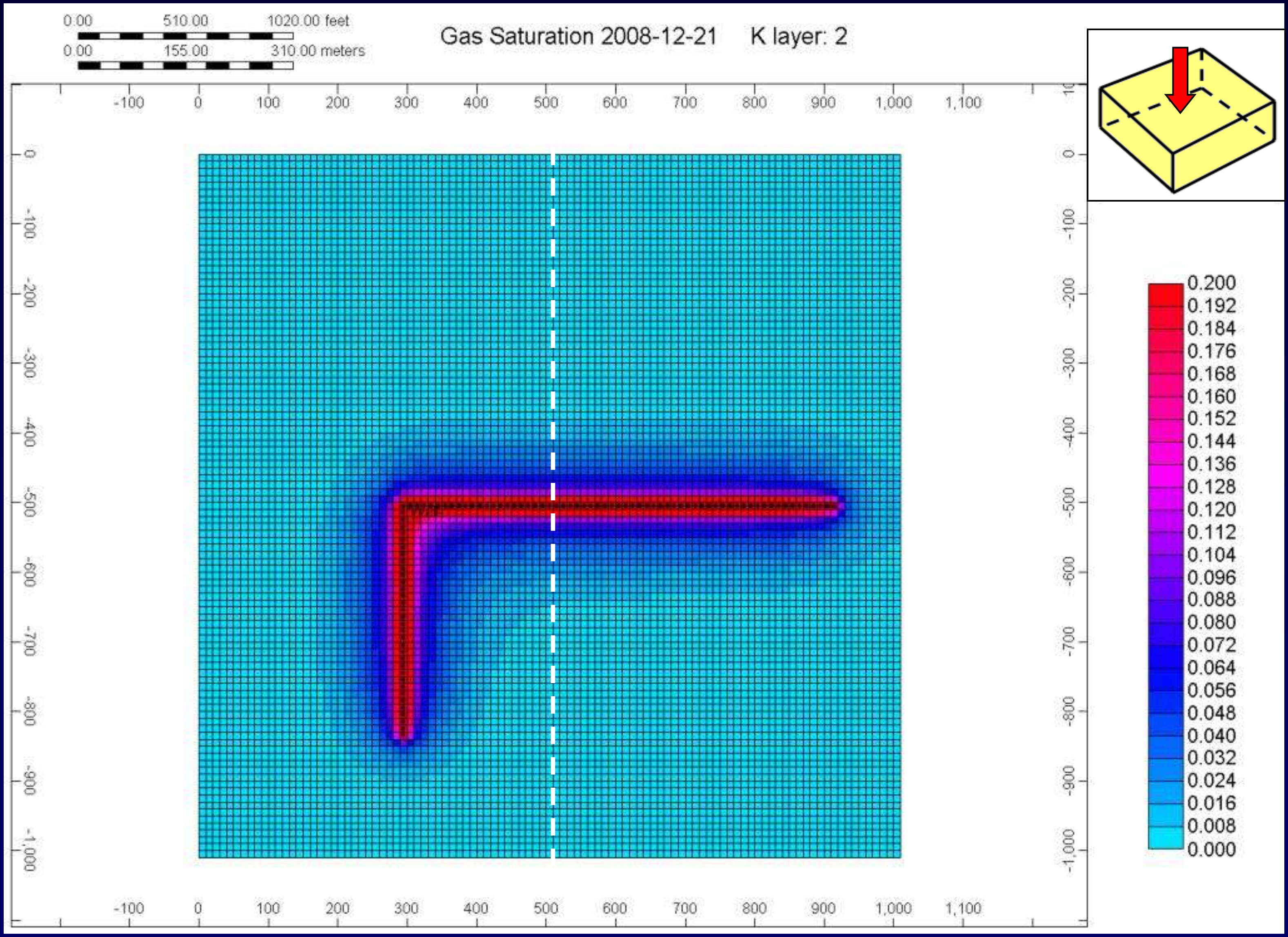
RESERVOIR SIMULATION



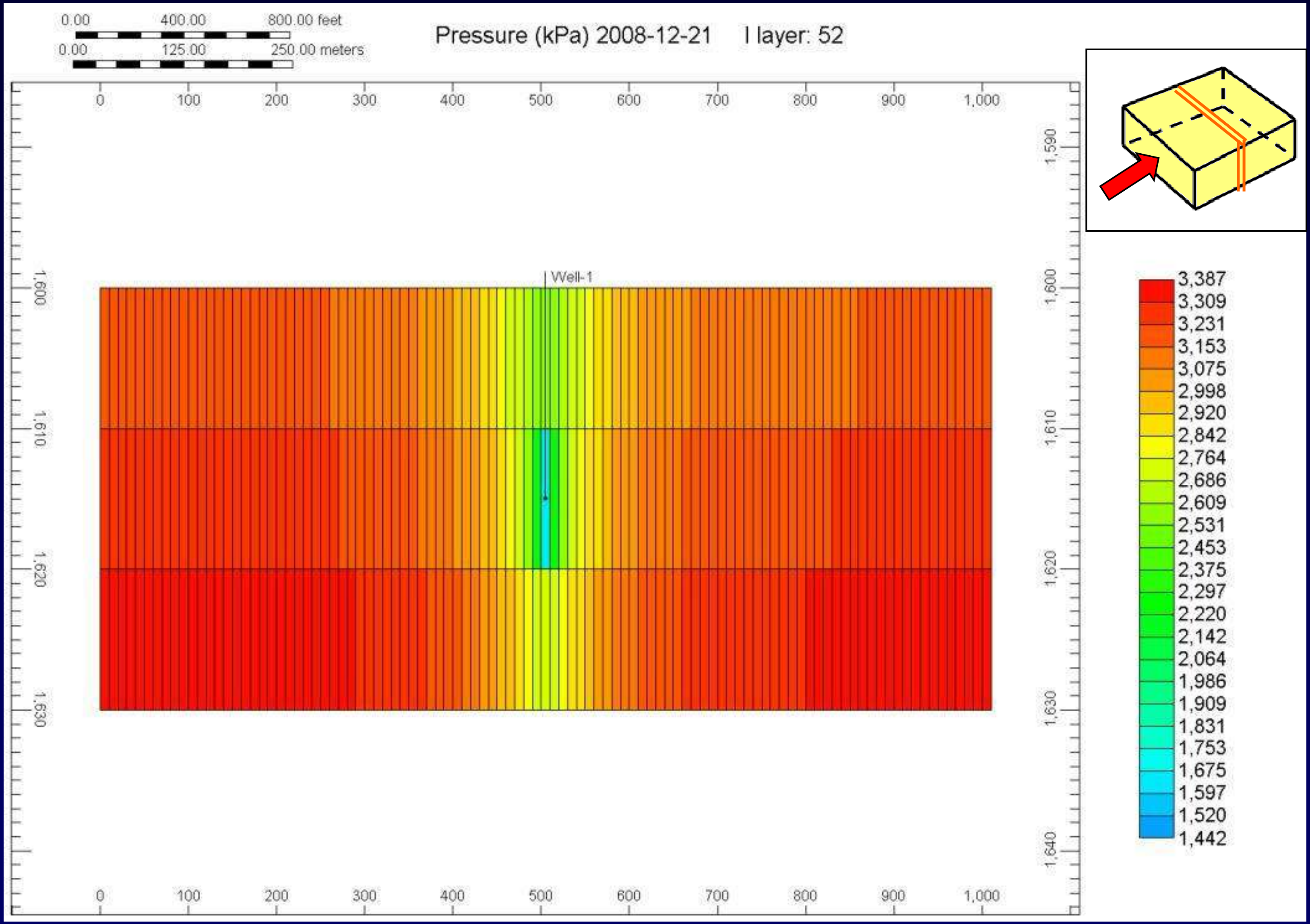
RESERVOIR SIMULATION



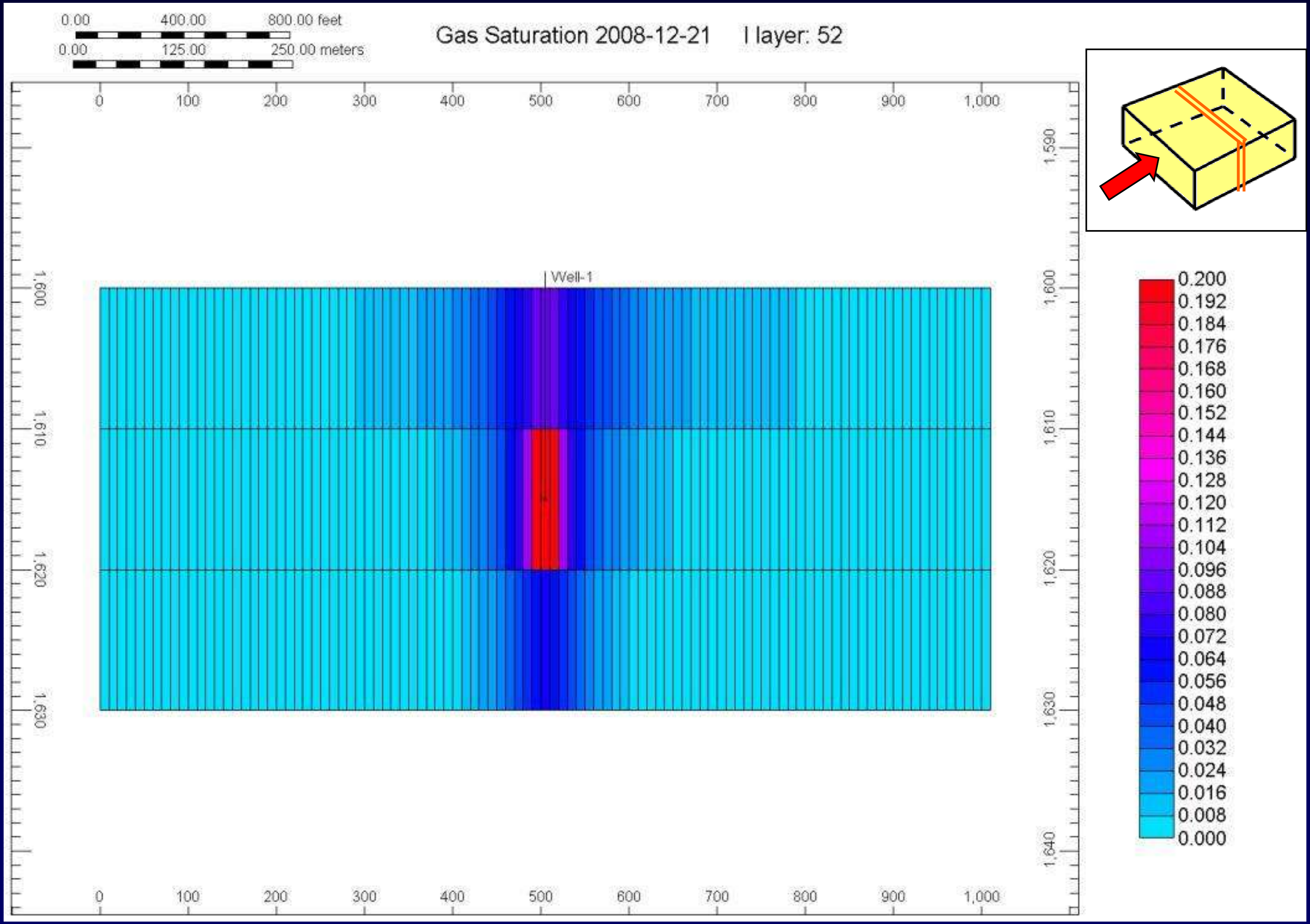
RESERVOIR SIMULATION



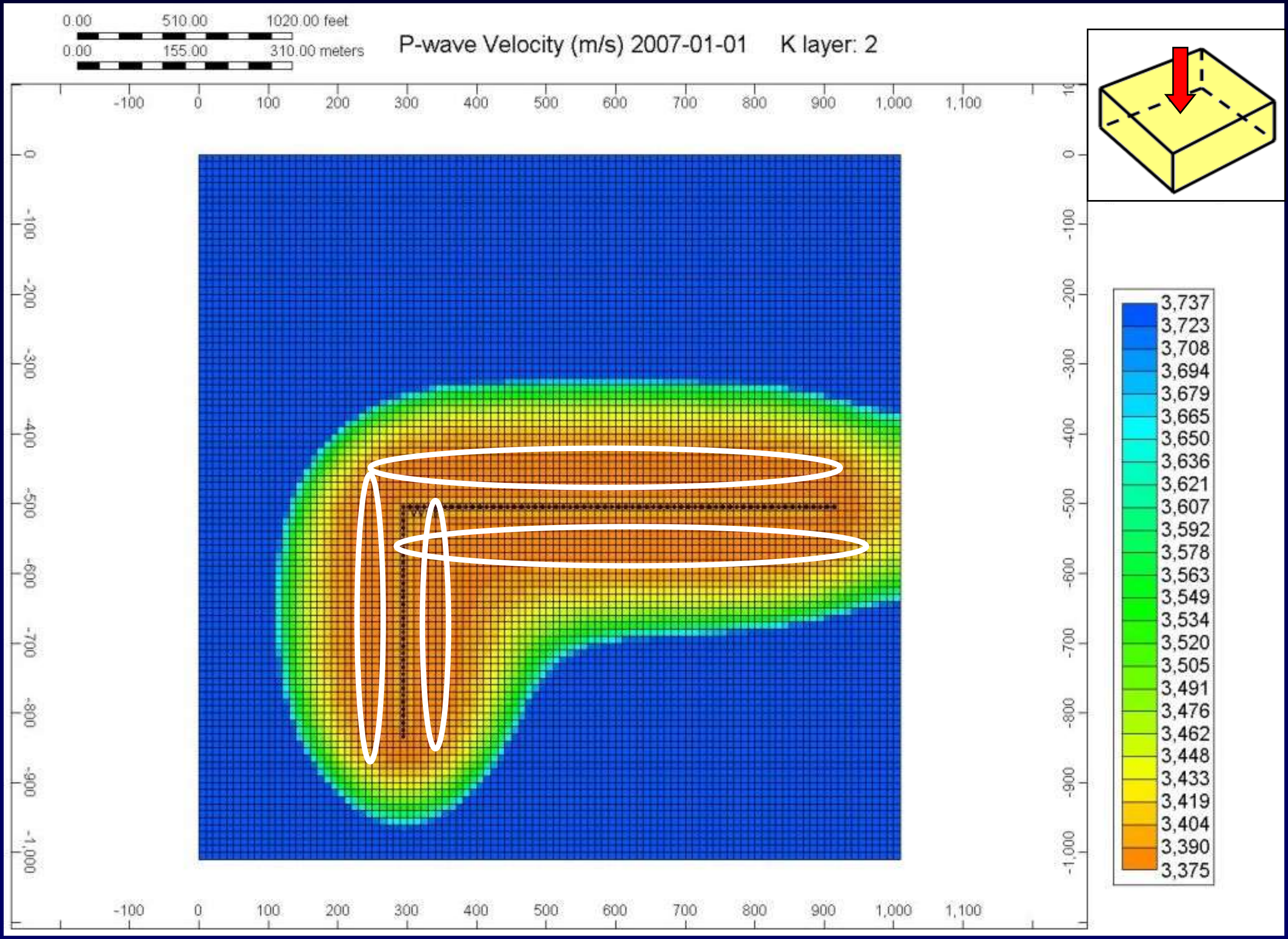
RESERVOIR SIMULATION



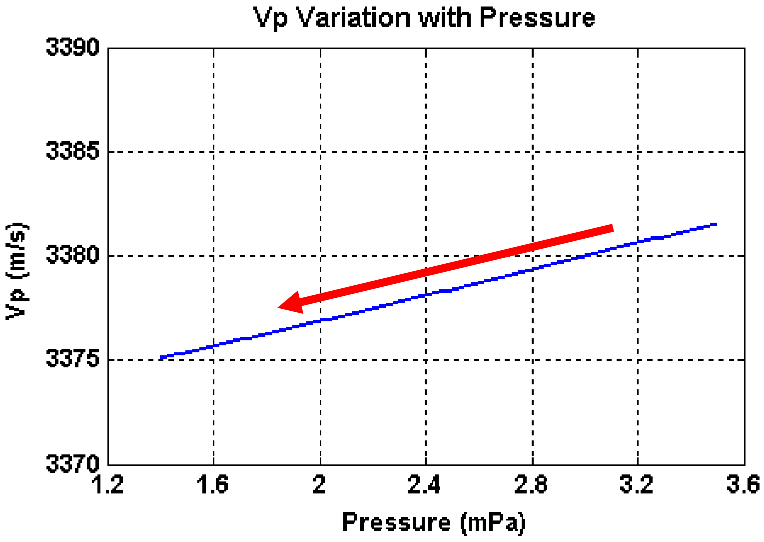
RESERVOIR SIMULATION

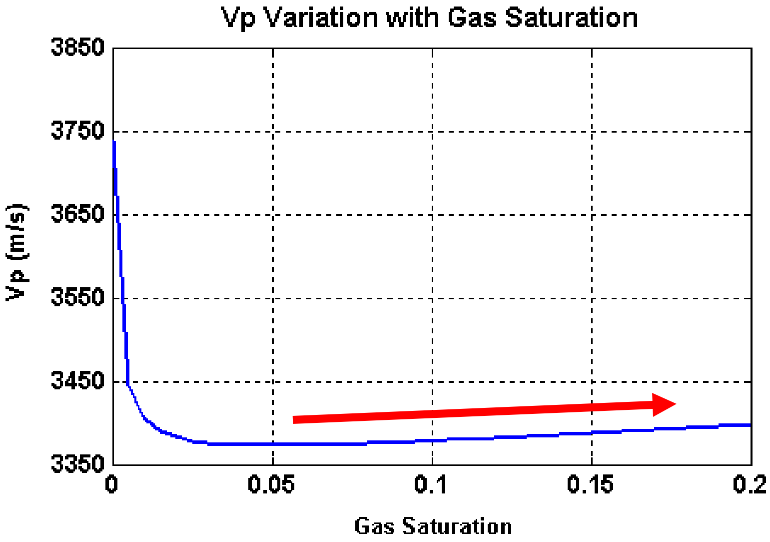


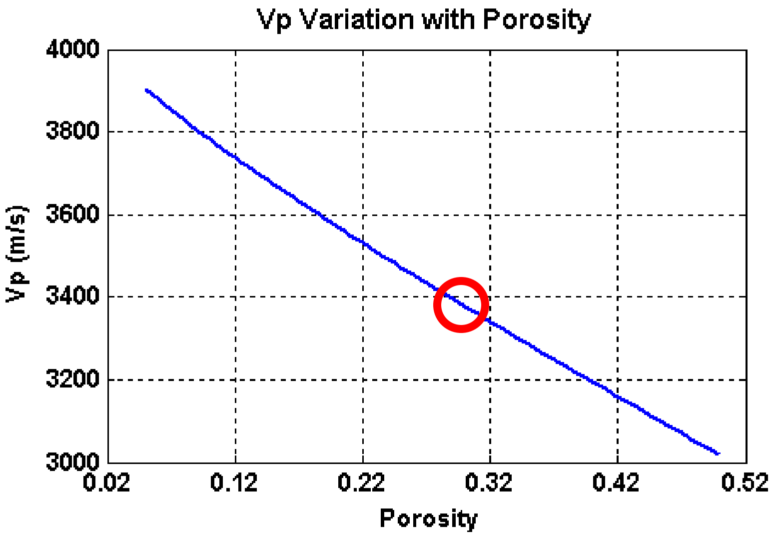
SIMULATOR TO SEISMIC



SIMULATOR TO SEISMIC

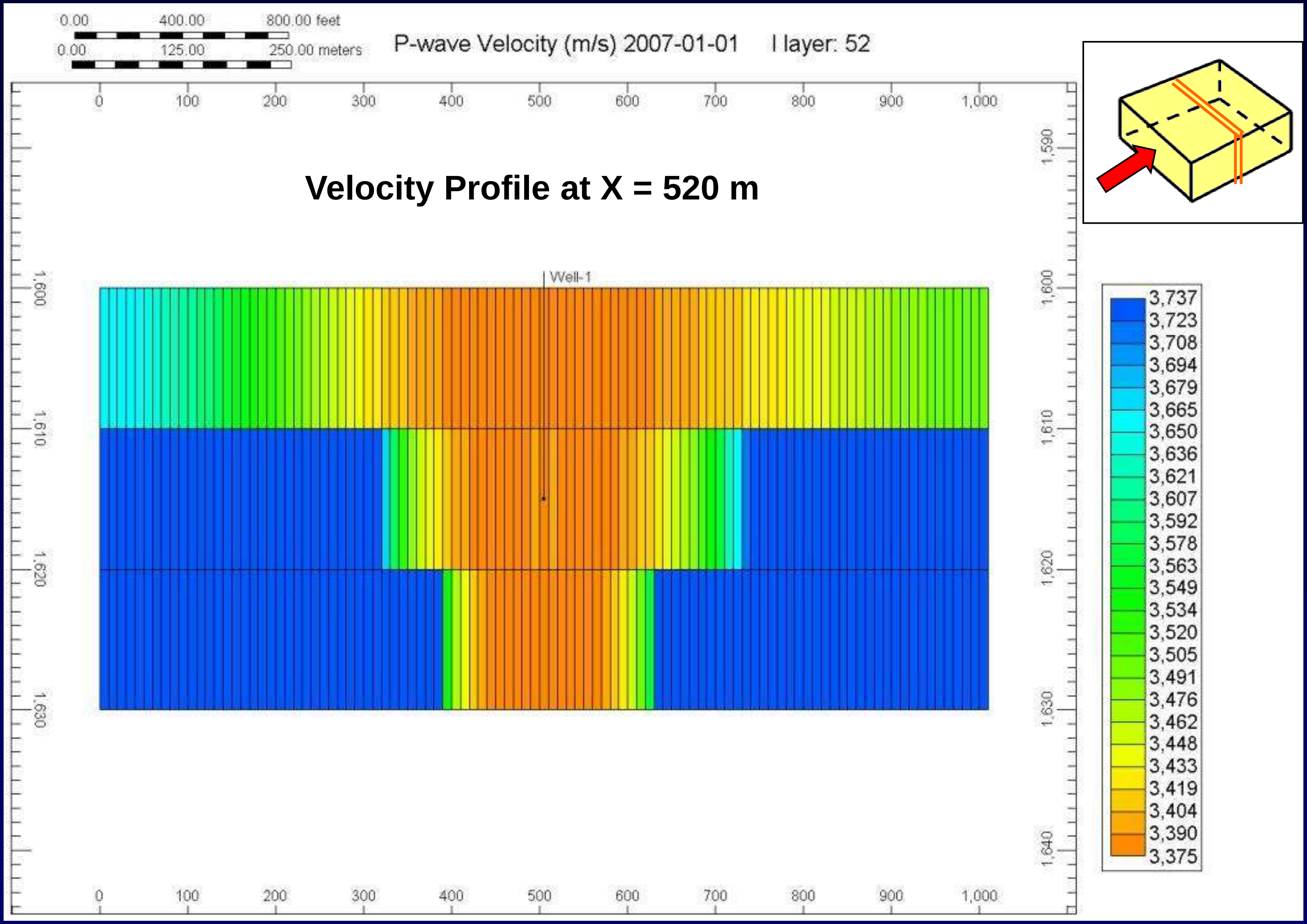






Reservoir Properties, Reference Values	
Porosity	0.3
Pressure (mPa)	2.3
Temperature (°C)	35
Water Saturation	0.2
Oil Saturation	0.7
Gas Saturation	0.1
Water Salinity (ppm)	350 000
Oil Gravity (API)	10
Gas Specific Gravity	0.56
Matrix Bulk Modulus (mPa)	40 000
Matrix Shear Modulus (mPa)	30 000
Dry Bulk Modulus (mPa)	3 250
Matrix Density (g/cc)	2.71

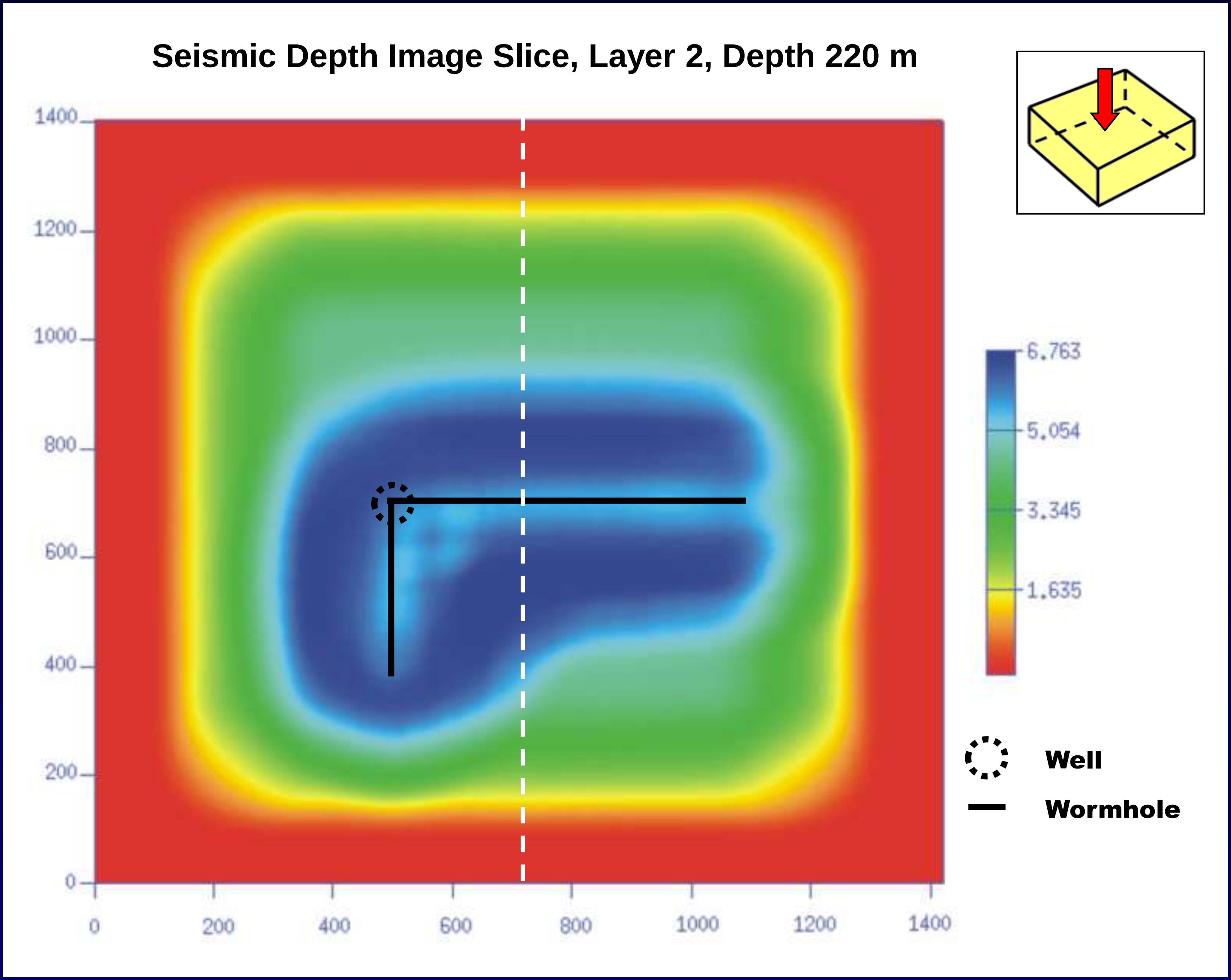
SIMULATOR TO SEISMIC



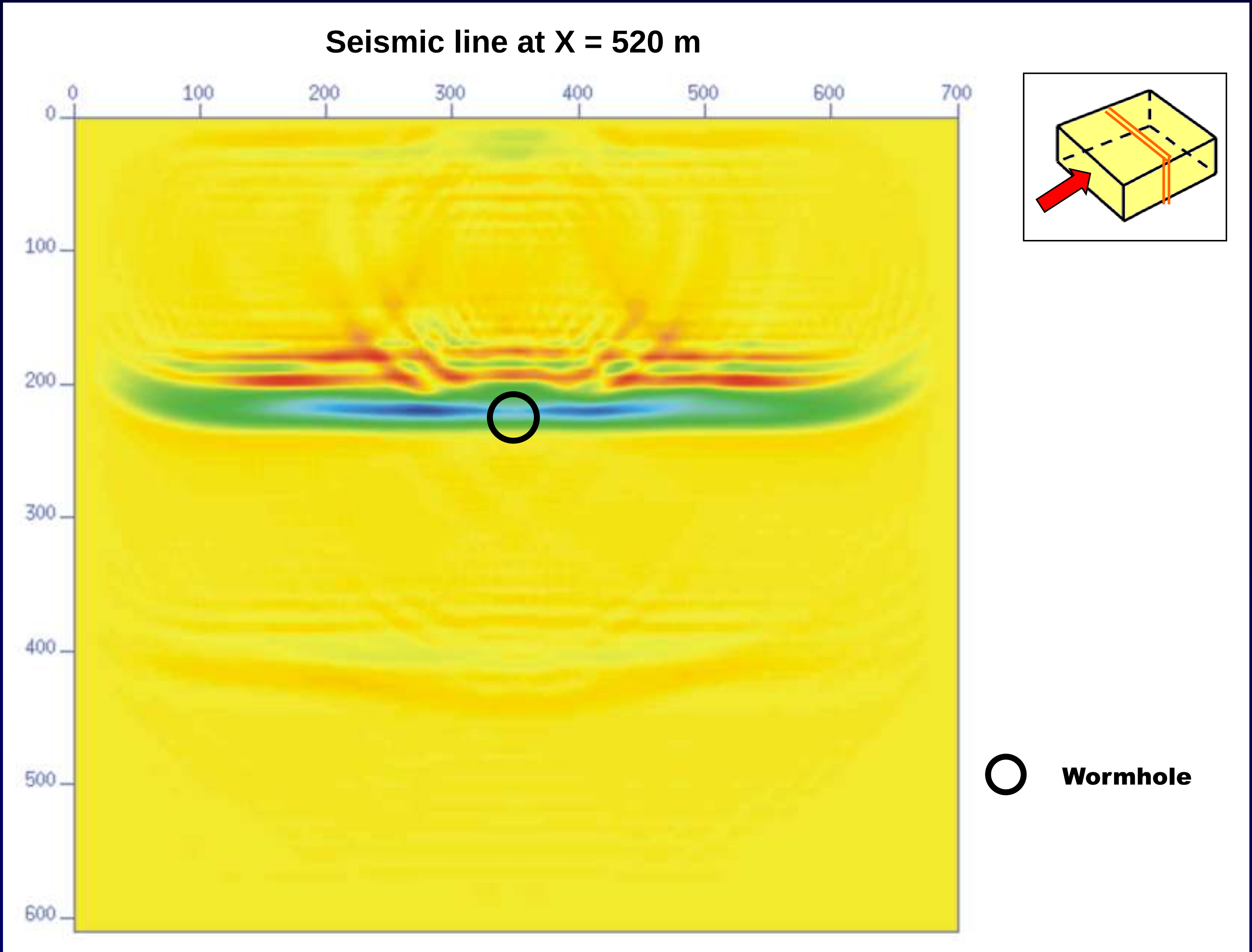
SYNTHETIC SEISMOGRAMS

- Forward Modeling Method:
  - 4^{th} order in space, 2^{nd} order in time finite difference scheme
  - 3D acoustic wave equation
  - The reservoir is surrounded by an overburden and an underburden of constant velocities
- Imaging:
  - 3D reverse-time depth migration

SYNTHETIC SEISMOGRAMS



SYNTHETIC SEISMOGRAMS



CONCLUSIONS

- For foamy oils, harmonic average of fluid bulk moduli can be used.

- P-wave velocity is a function of reservoir pressure, temperature, porosity, fluid saturation and distribution

- Increasing the following parameters:
  - Porosity: Vp decreases.
  - Gas saturation: Vp decreases rapidly and then increases slowly.
  - Pressure: Vp increases.

  With gas saturation being the most important parameter.

- Minimum Vp occurs at some blocks away from the wormhole.

- Seismic image shows the extent of wormholes and free gas zones.

ACKNOWLEDGMENTS

- CHORUS for supporting my research at the University of Calgary
- CHORUS sponsors
- AICISE
- Schulich School of Engineering

REFERENCES

- Kristetter, O., Corbett, P., Somerville, J. and MacBeth, C.; 2006, Elasticity/Saturation Relationships Using Flow Simulation From an Outcrop Analogue for 4D Seismic Modeling, *Petroleum Geoscience* **12**, 205.

- Maini, B. B., 2001, Foamy-Oil Flow, SPE 68885, *Distinguished. Author Series*, SPE.