CREWES

Technical Presentation
November 19, 2009

Fluid Flow Numerical Modelling and Its Seismic Response in Time-lapse

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Outline

- Research Significance
- Data Description and Work Flow
- Numerical Modelling and Seismic Response
- Conclusions and Future Work
- Acknowledgements
- Questions

Research Significance
-Industry Prospective-

- Alliance: geologists, geophysicists and engineers.
- Common goal: reservoir localization, production and characterization under economical means.
- Primary production recovery becomes uneconomical: artificial measures employed.
- Success in enhanced recovery: reservoir familiarity.
- Numerical modelling needed.

- Our study will be an improved tool to reservoir characterization.

Research Significance
-Academic Prospective-

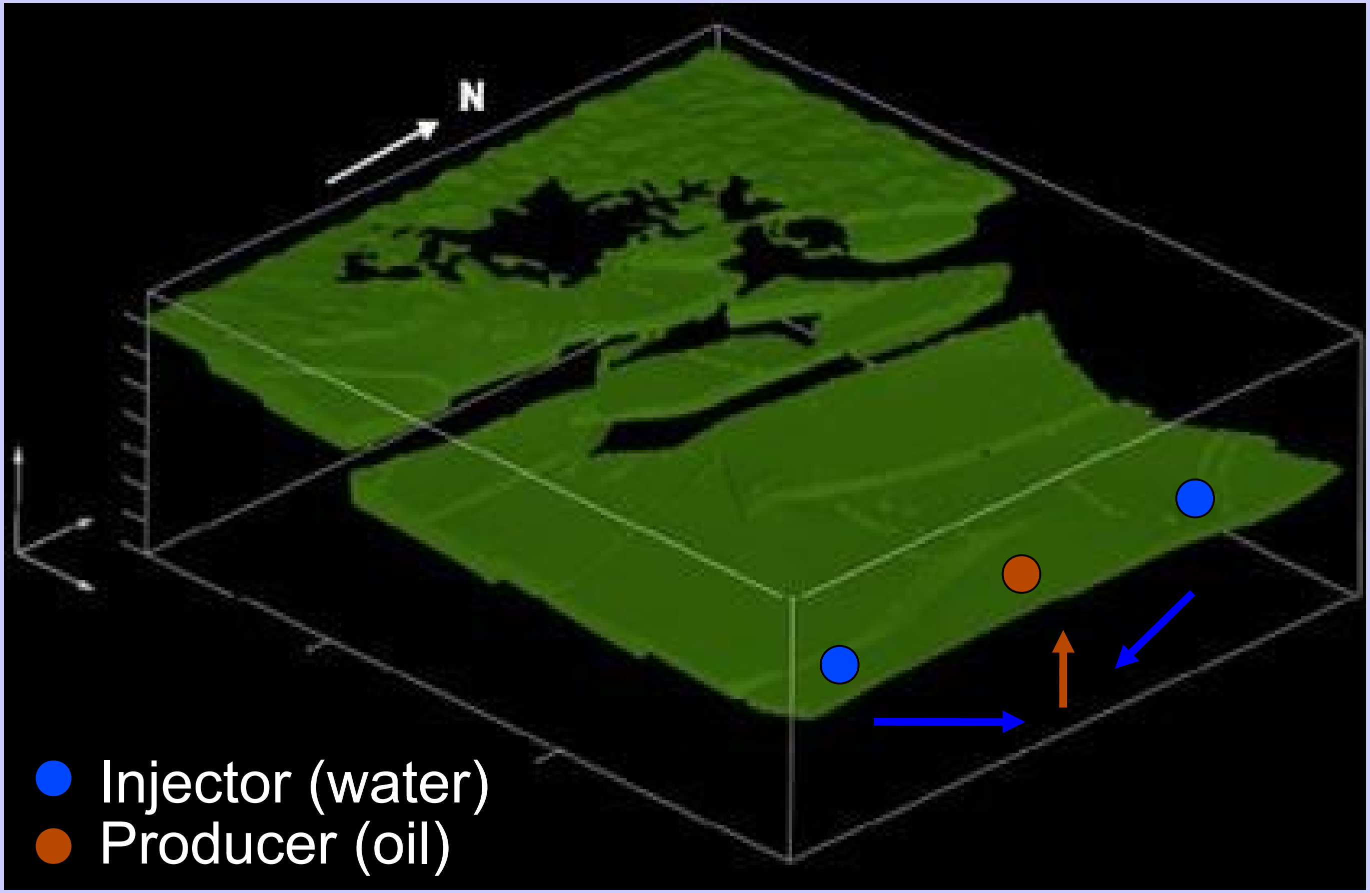
- Chance to employ multidisciplinary research: geophysics, geology, mathematics, engineering and physics.
- Evaluating practical and theoretical approaches.
- Taking significance of seismology further.

Data and Reservoir Description

- 10th SPE Comparative Solution Project
- 3D vertical cross-sectional geometry, no dips/faults
- Sandstone reservoir, 100% oil saturated.
- Homogeneous and isotropic reservoir.
- Boundaries: impermeable.
- Viscosity, porosity, permeability uniform.

Numerical Model

- Model:
  Two-phase flow
  (water and oil)
- Phases are
  immiscible and
  incompressible
- Water and oil
  saturations are
  irreducible
- Study duration:
  28 days



Modified from Reddy, 2009

Work Flow

- Step I: Reservoir Simulator

Input		Output
Geometry Permeability, μ Porosity, ϕ Fluid Properties	$\Rightarrow$	Pressure, p Saturation, s

- Step II: Rock Physics

Input		Output
Saturation, s Pressure, p Porosity, ϕ Dry Rock Properties	$\Rightarrow$	P-wave velocity, α S-wave velocity, β Density saturation, ρ_{sat}

- Step III: Seismic Modelling

Input		Output
P-wave velocity, α S-wave velocity, β Density saturation, ρ_{sat}	$\Rightarrow$	Amplitude, A Phase, φ

Reservoir Simulator

- Pressure:

  amount of fluid flowing through unit area per unit time

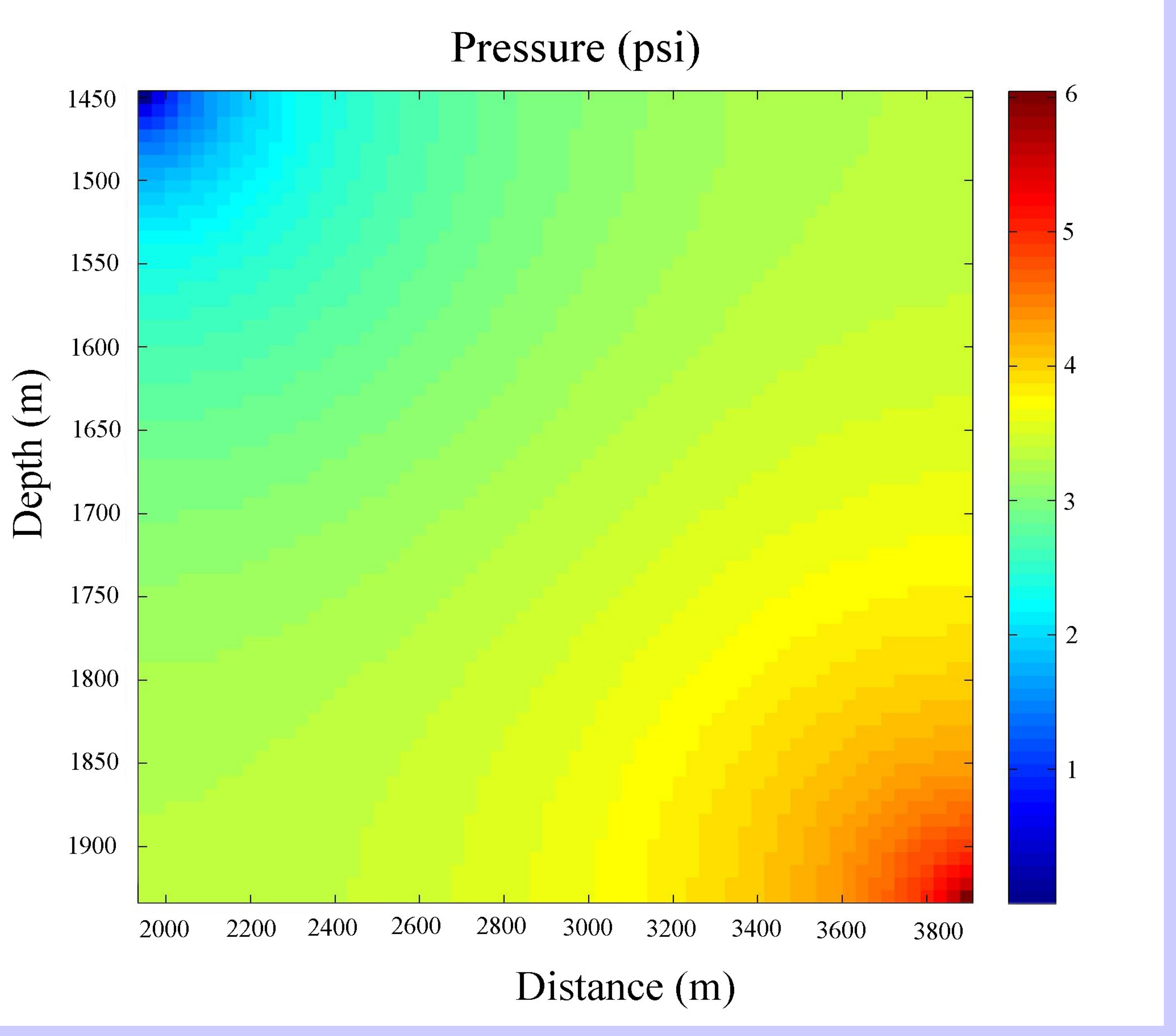
$$\nabla \cdot V_{f,p} = \frac{q_p}{\rho_p} \qquad (1)$$

- Water Saturation:

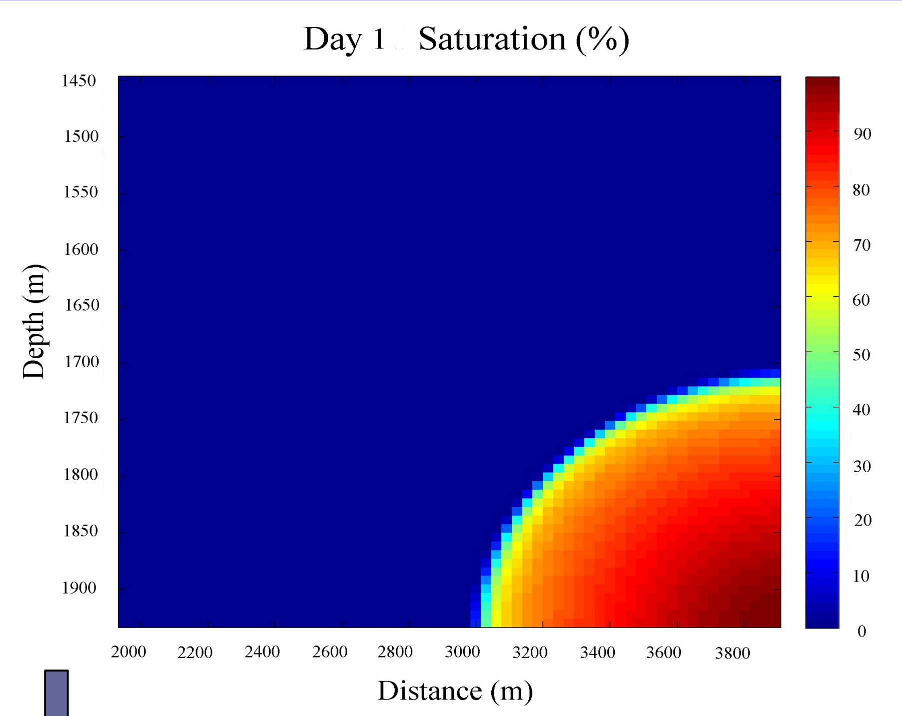
  oil displacement by water

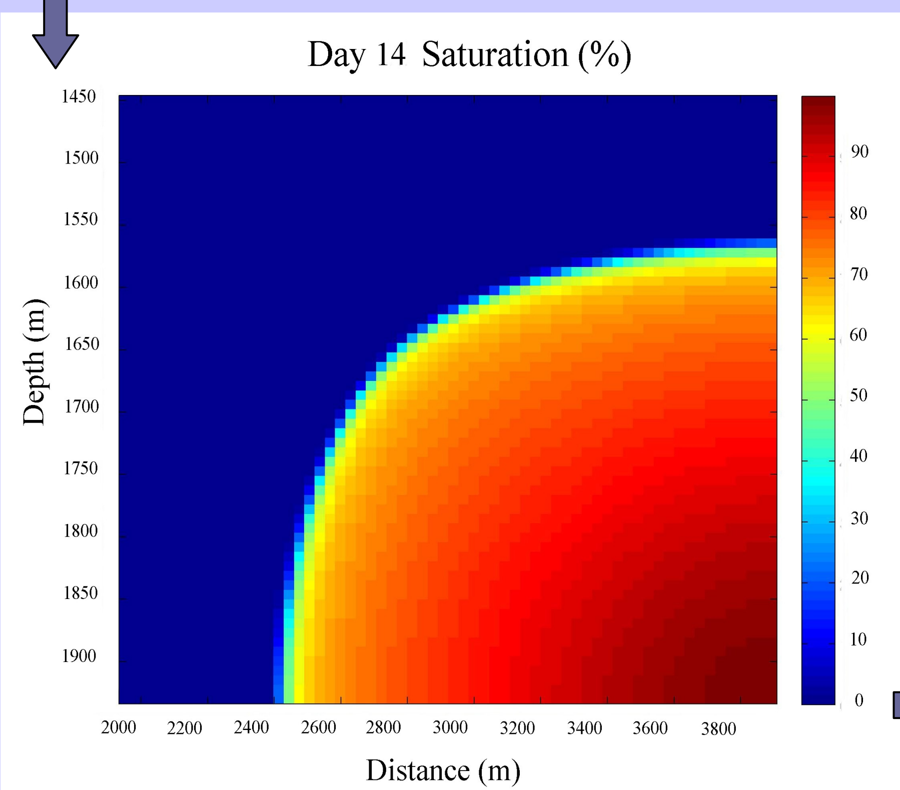
$$\phi \frac{\partial s}{\partial t} + \nabla \cdot (f(s) V_{f,w}) = \frac{q_w}{\rho_w} \qquad (2)$$

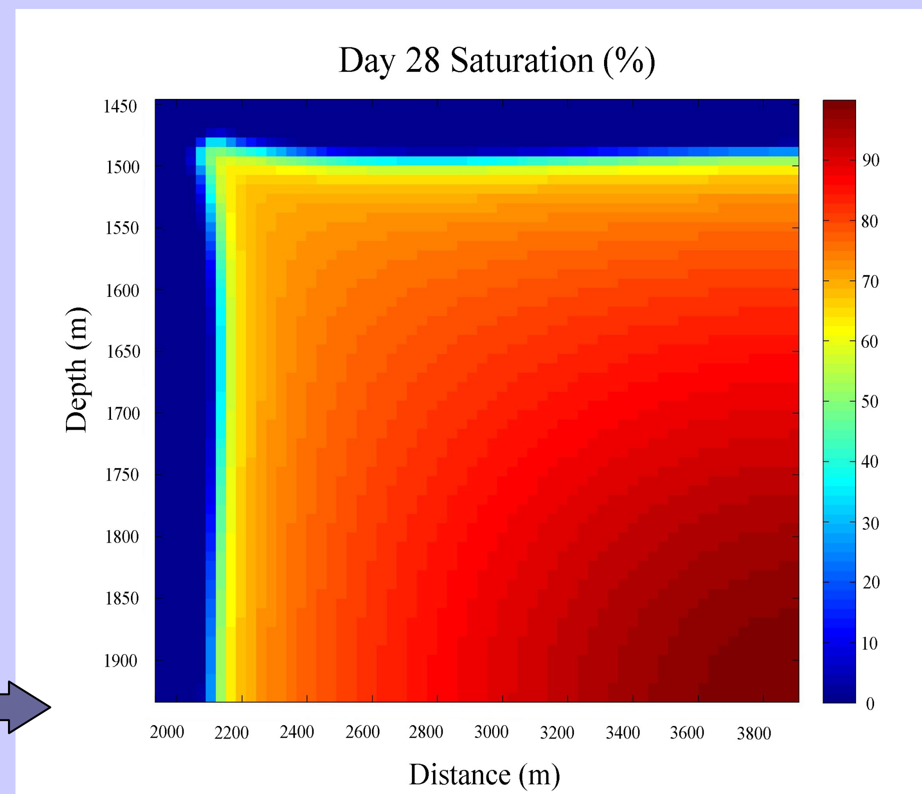
Pressure Model



Water Saturation Models







Work Flow

- Step I: Reservoir Simulator

Input		Output
Geometry Permeability, μ Porosity, ϕ Fluid Properties	→	Pressure, p Saturation, s

- Step II: Rock Physics

Input		Output
Saturation, s Pressure, p Porosity, ϕ Dry Rock Properties	→	P-wave velocity, α S-wave velocity, β Density saturation, ρ_{sat}

- Step III: Seismic Modelling

Input		Output
P-wave velocity, α S-wave velocity, β Density saturation, ρ_{sat}	→	Amplitude, A Phase, φ

Rock Physics

- Gassmann's relations are employed to calculate density, P-wave and S-wave velocities.
- Assumptions: homogeneous and isotropic reservoir.

$$K_{sat} = K_d + \frac{\left(1 - \frac{K_d}{K_0}\right)^2}{\frac{\phi}{K_f} + \frac{(1-\phi)}{K_0} - \frac{K_d}{K_0^2}} \quad \text{and} \quad \mu_{sat} = \mu_d \qquad (3)$$

Rock Physics

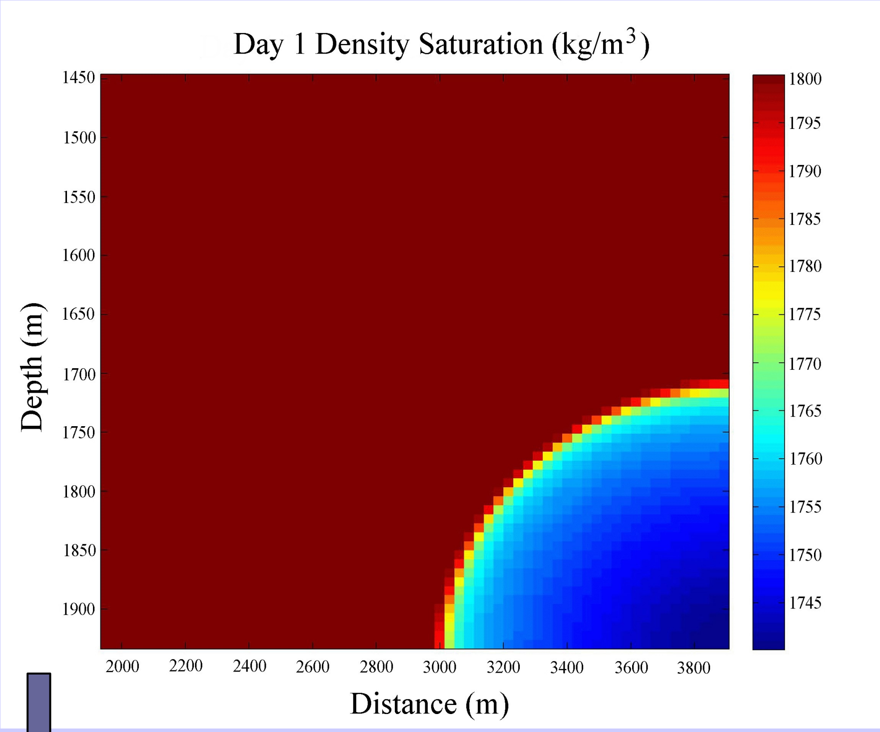
- Density Saturation:

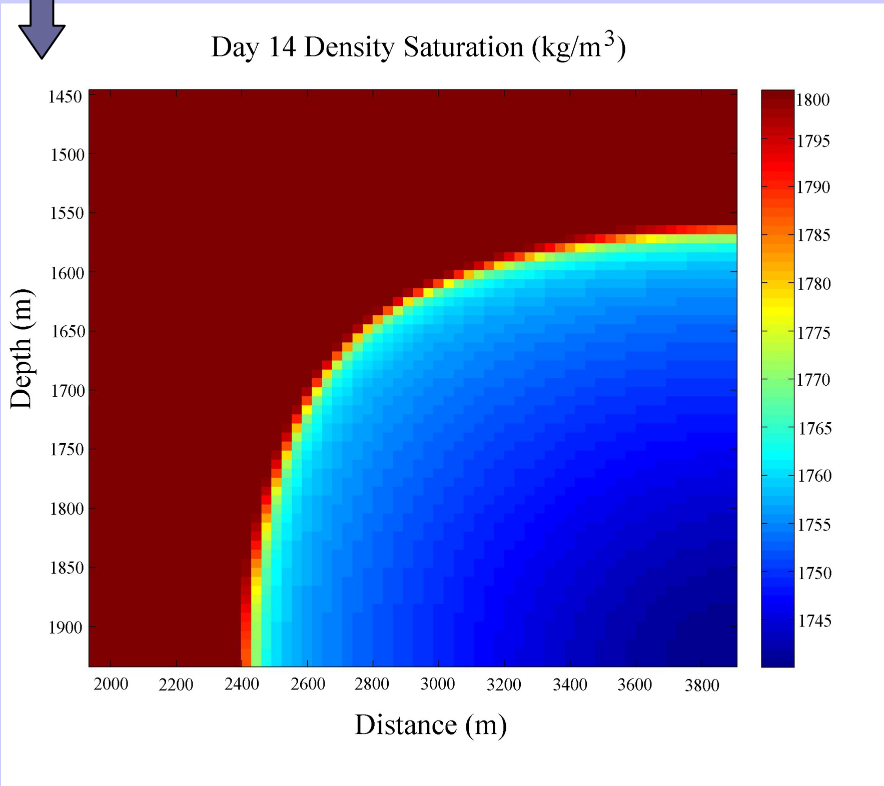
$$\rho_{sat} = (1-\phi)\,\rho_d + \phi\,\rho_f \qquad (4)$$

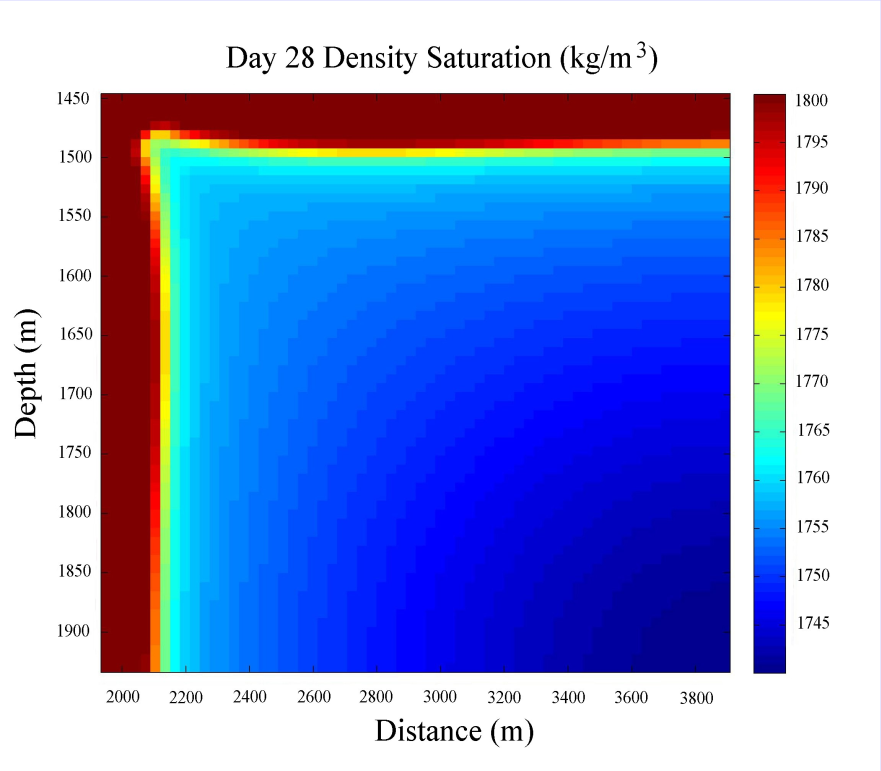
- P-wave velocity:

$$V_p = \sqrt{\frac{K_{sat} + (4/3\mu_{sat})}{\rho_{sat}}} \qquad (5)$$

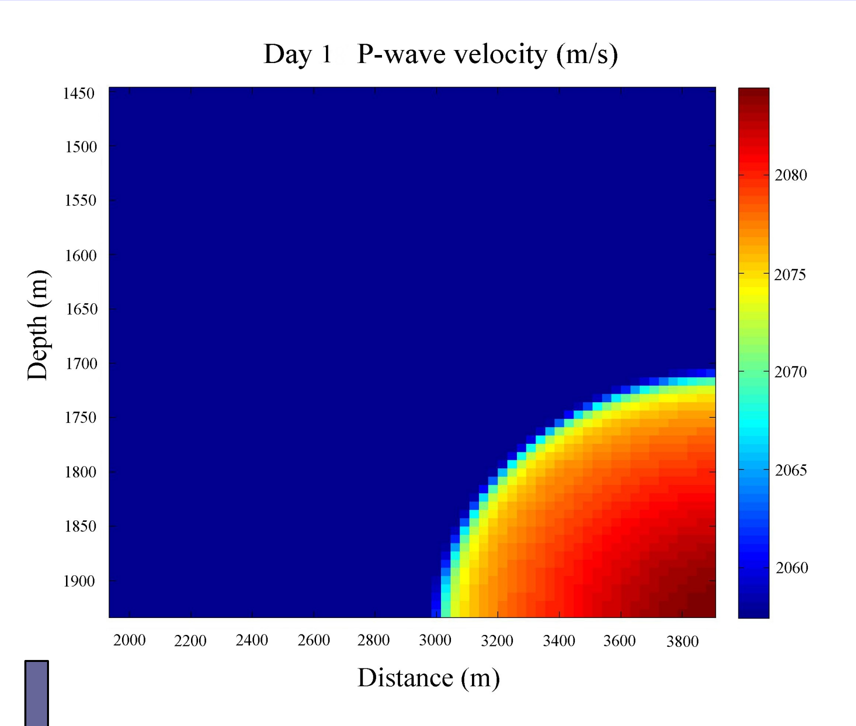
Density Saturation Models

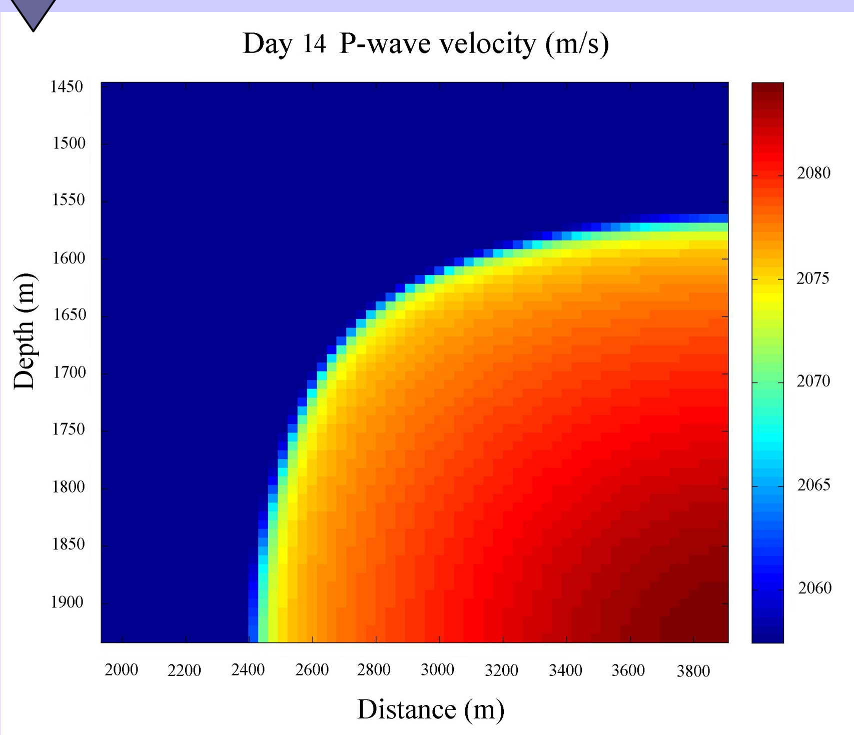


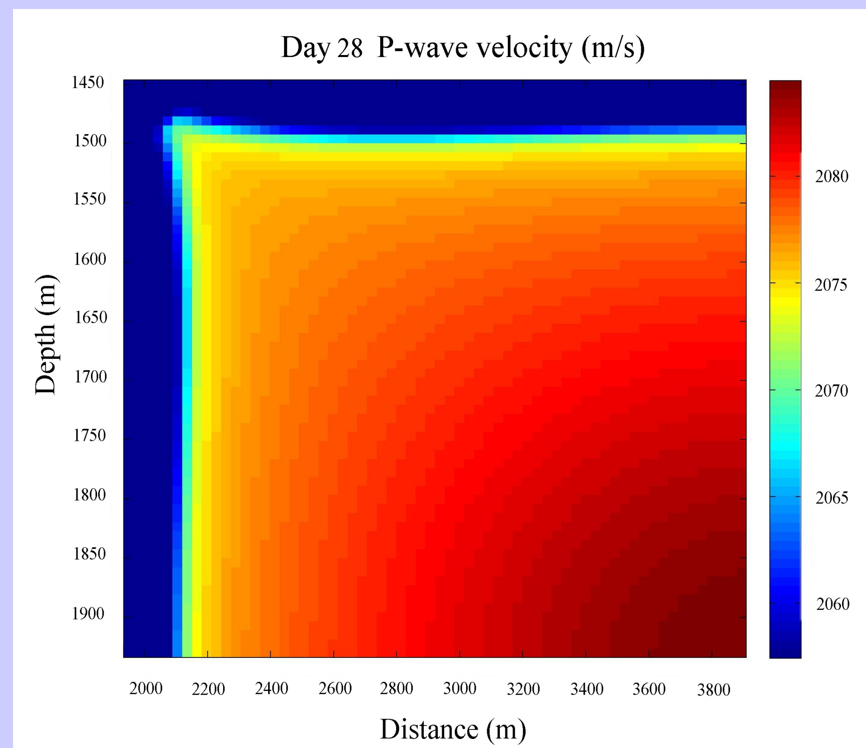




P-wave Velocity Models







Work Flow

- Step I: Reservoir Simulator

Geometry
Permeability, μ
Porosity, ϕ
Fluid Properties

→

Pressure, p
Saturation, s

- Step II: Rock Physics

Saturation, s
Pressure, p
Porosity, ϕ
Dry Rock Properties

→

P-wave velocity, α
S-wave velocity, β
Density saturation, ρ_{sat}

- Step III: Seismic Modelling

P-wave velocity, α
S-wave velocity, β
Density saturation, ρ_{sat}

→

Amplitude, A
Phase, φ

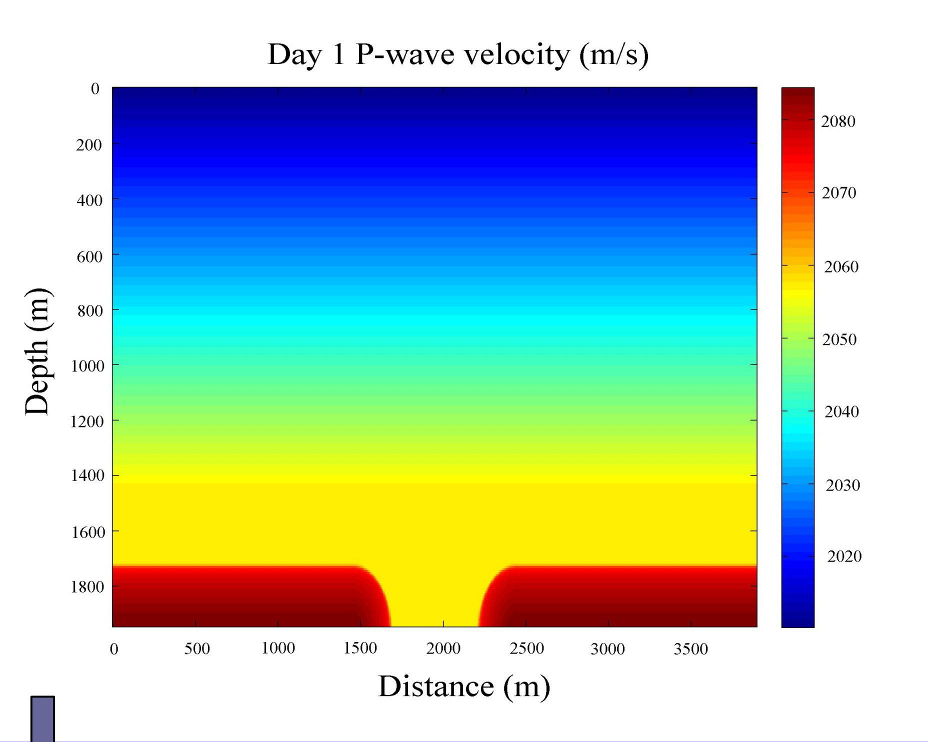
Seismic Response

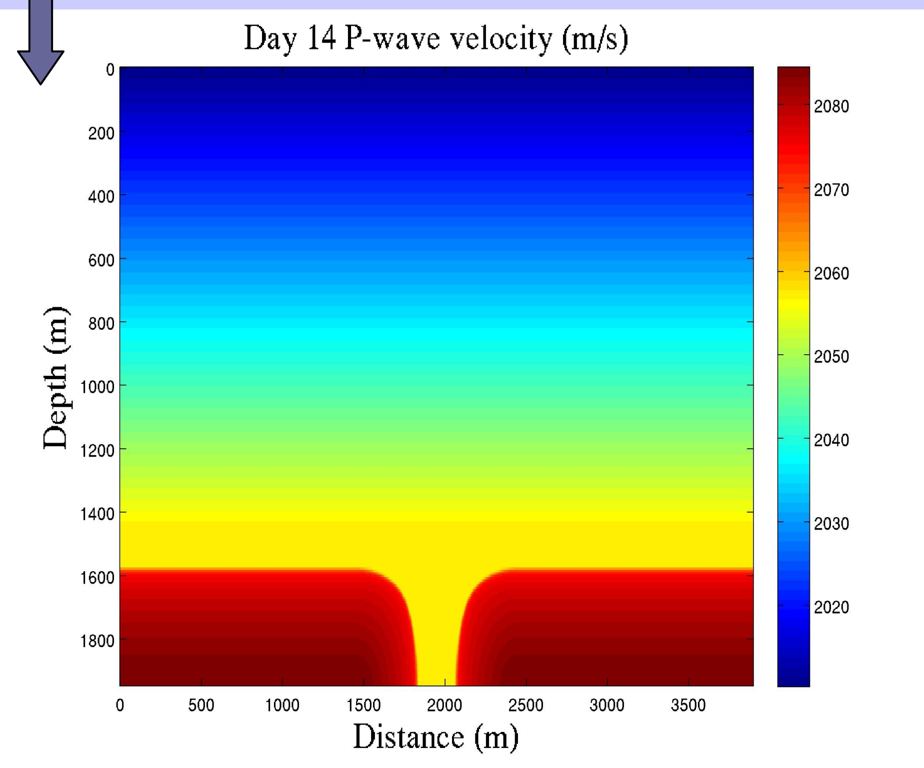
- Acoustic medium models:

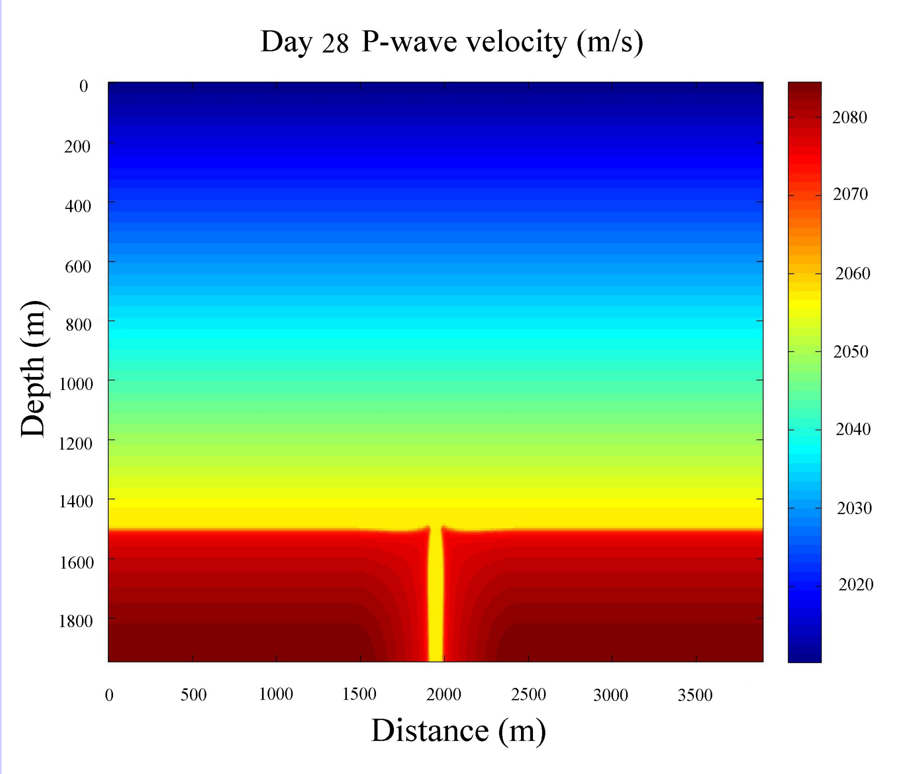
  Exploding Reflector Gatherer: 2D models
- Elastic medium models:

  Shot Gatherer: 3D models

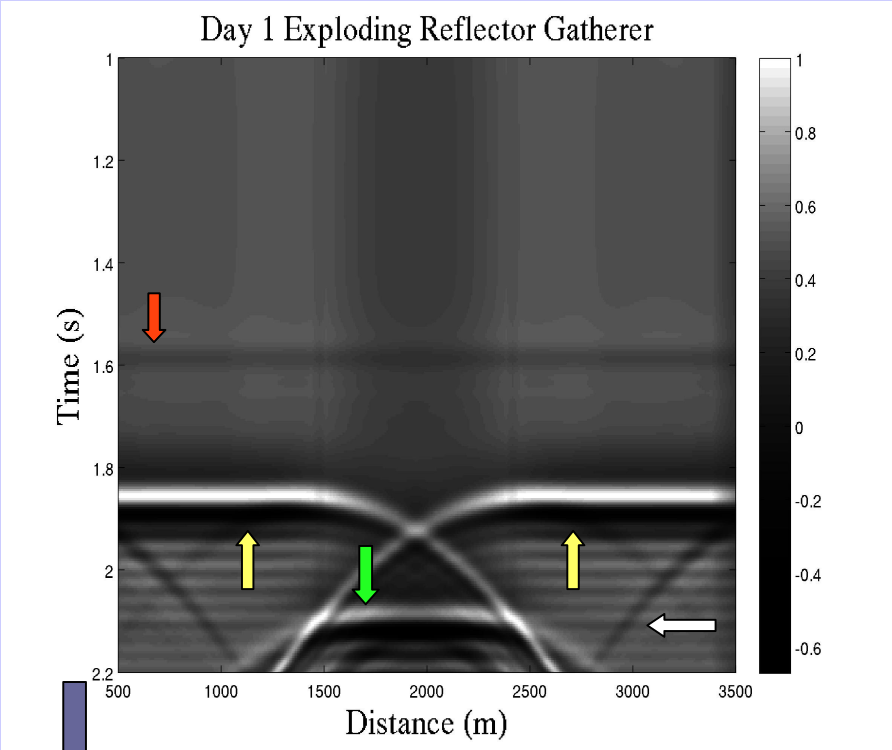
P-wave Velocity Models





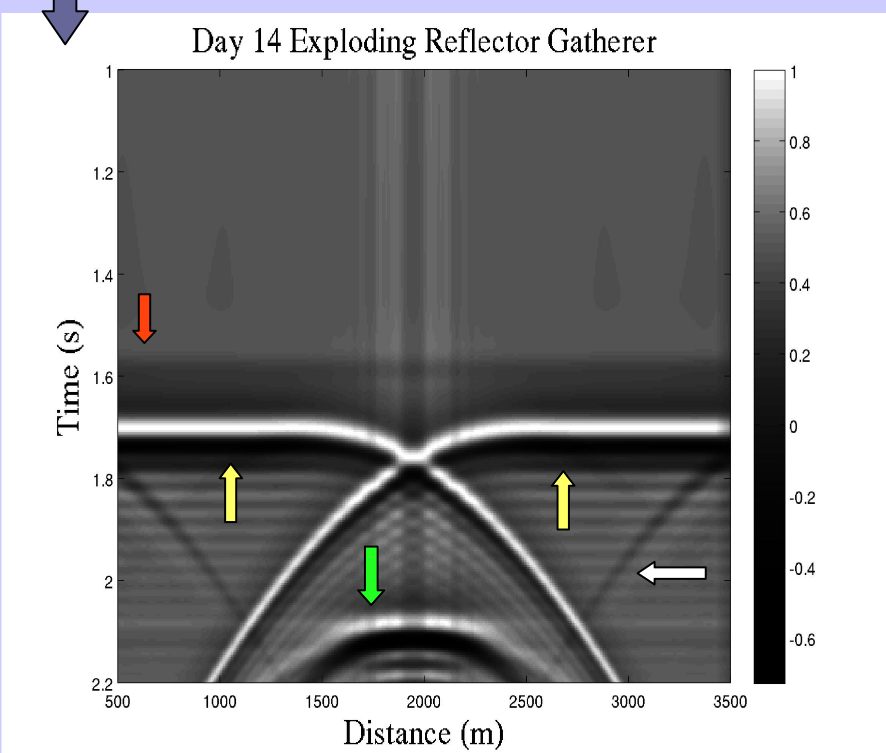


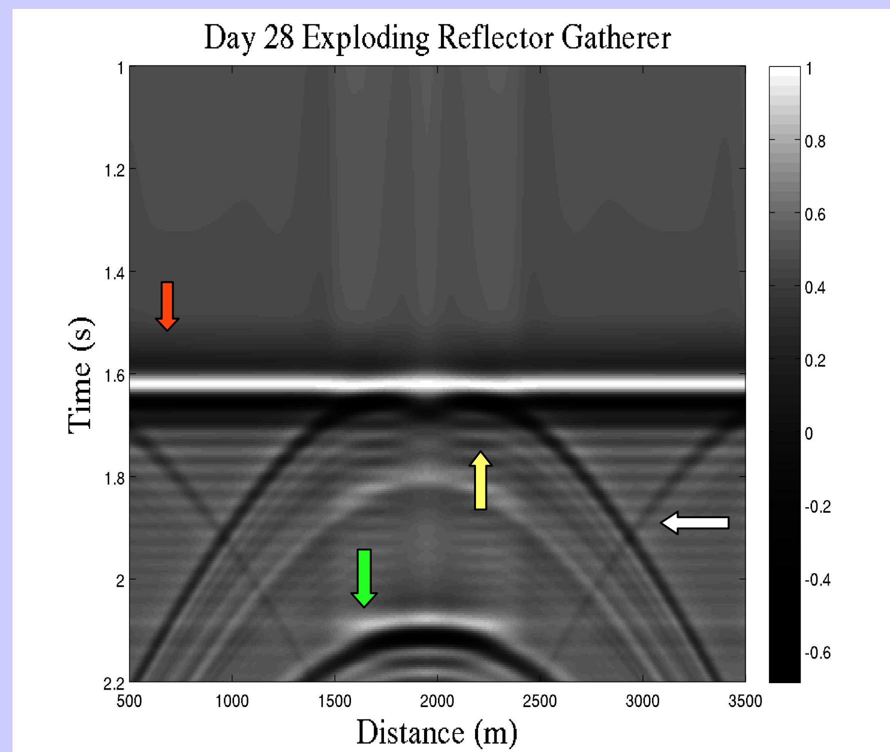
2D Acoustic Seismic Models



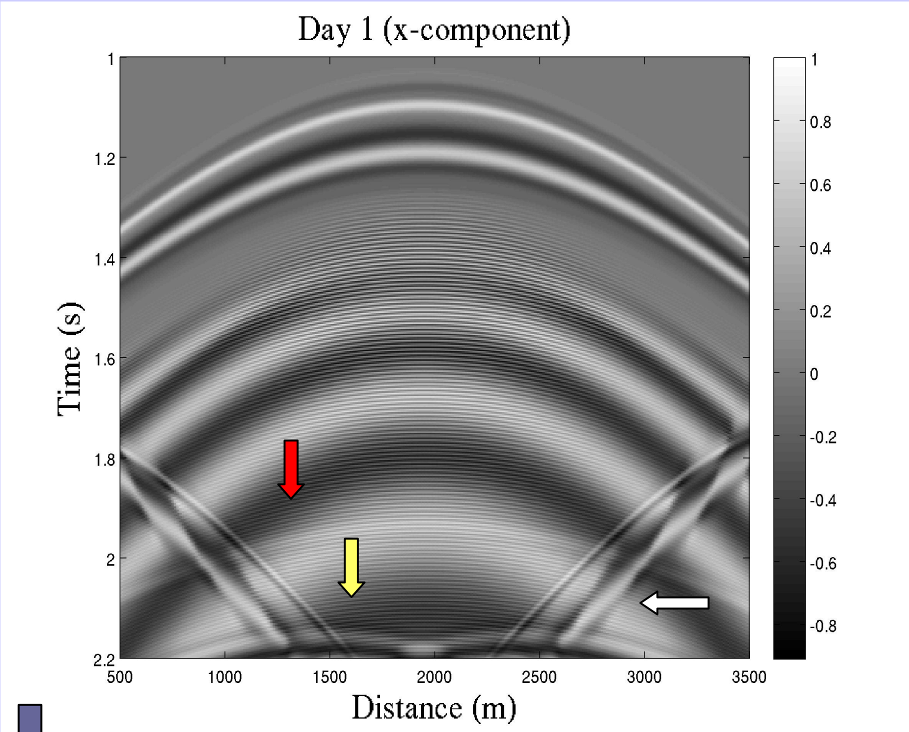
Legend:

- reservoir top
- reservoir bottom
- waterfront
- boundary effect



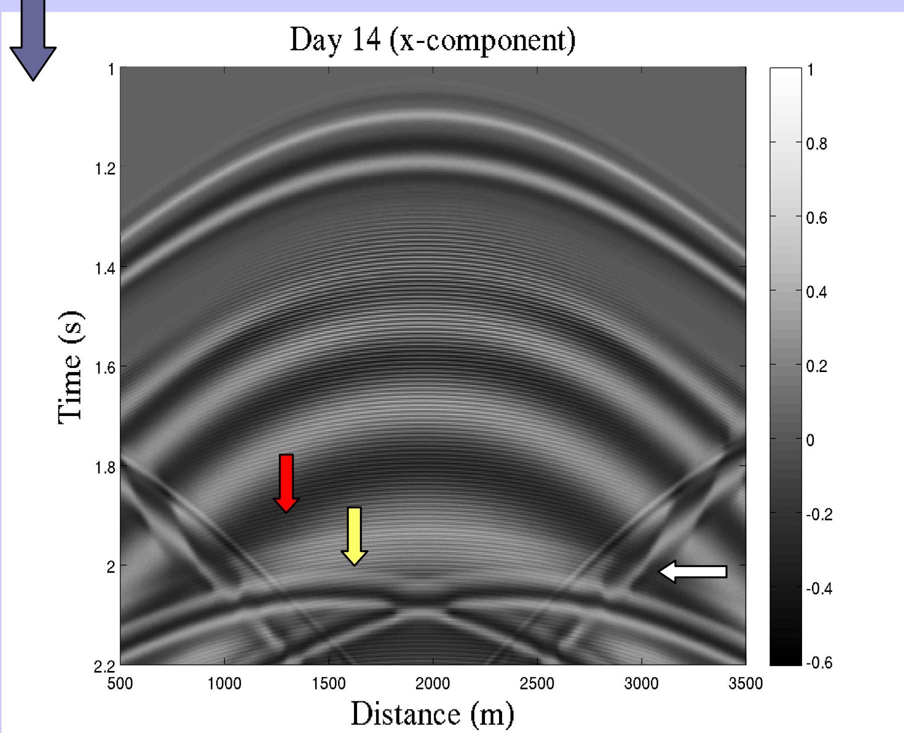


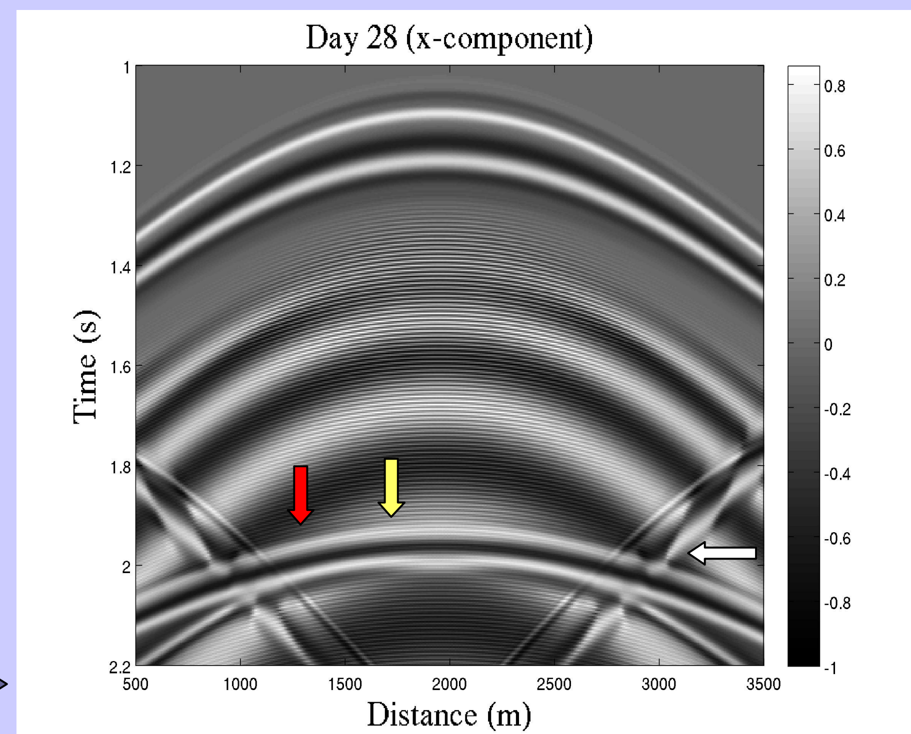
3D Elastic Seismic Models
velocity x-component



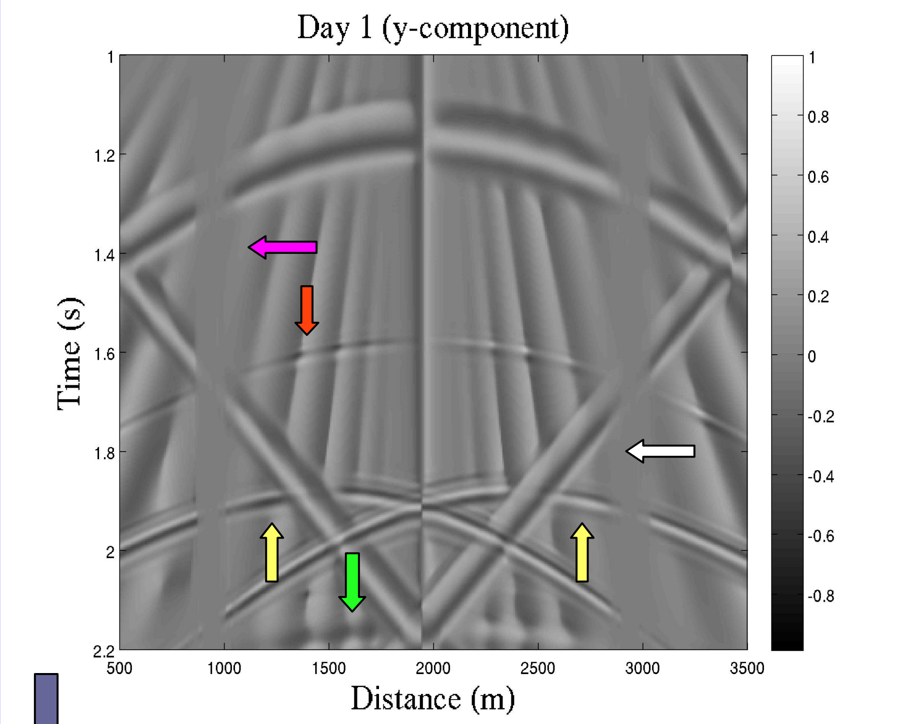
Legend:

- reservoir top
- waterfronts
- boundary effect



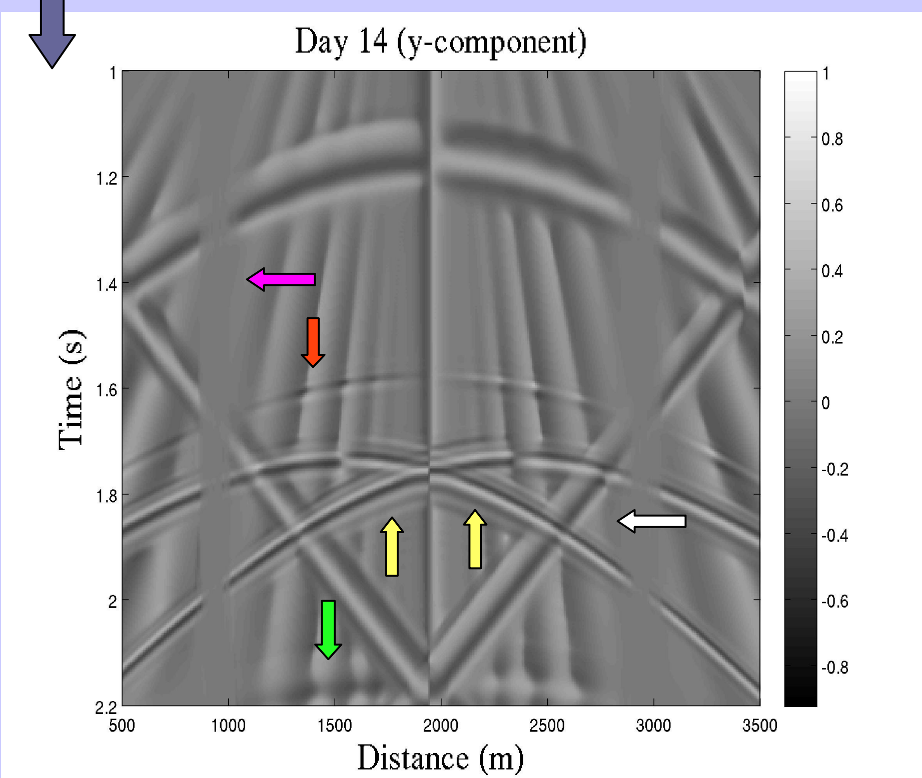


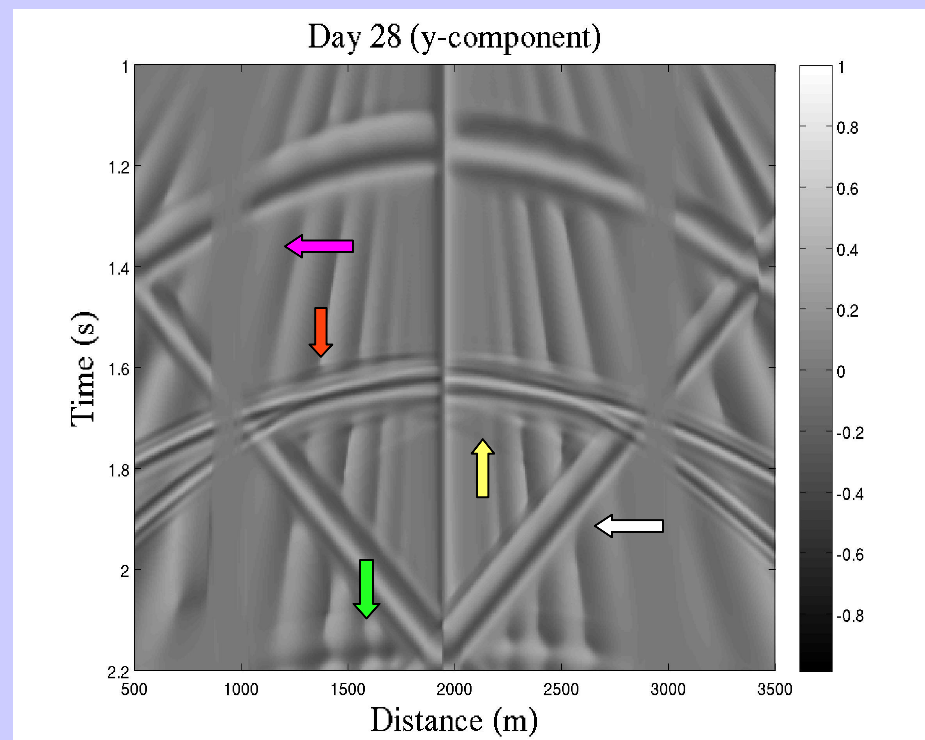
3D Elastic Seismic Models
velocity y-component



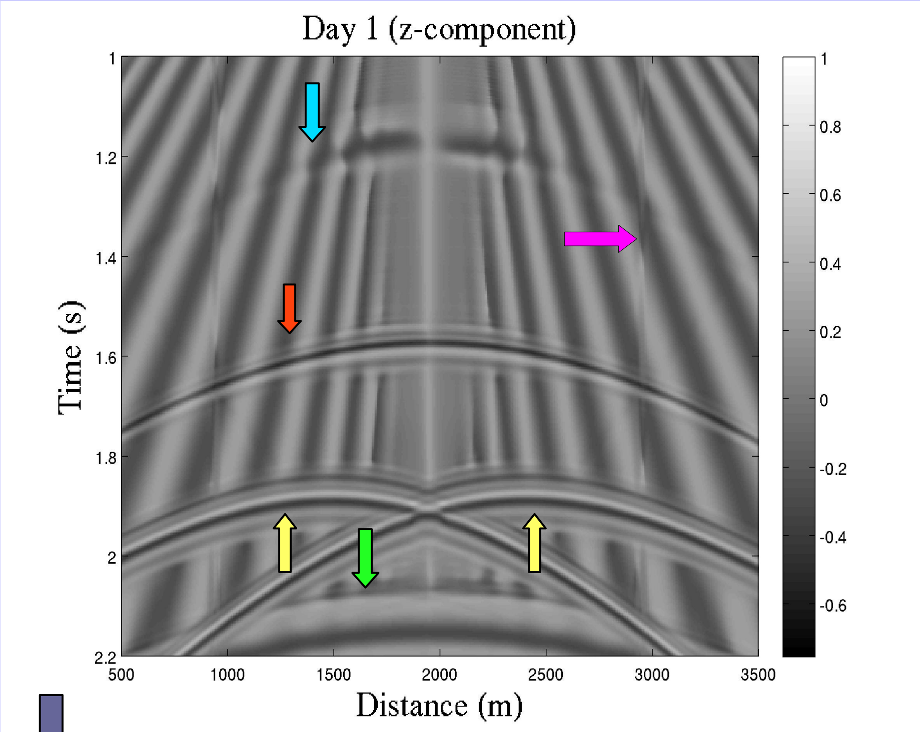
Legend:

- reservoir top
- reservoir bottom
- waterfronts
- boundary effect
- numerical artifacts

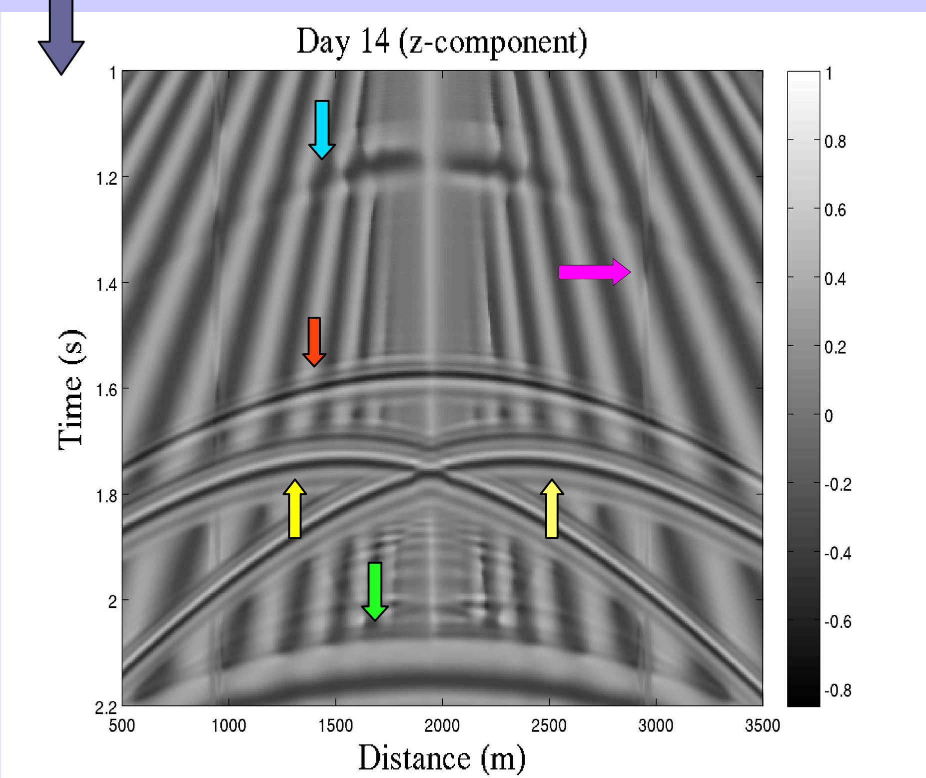


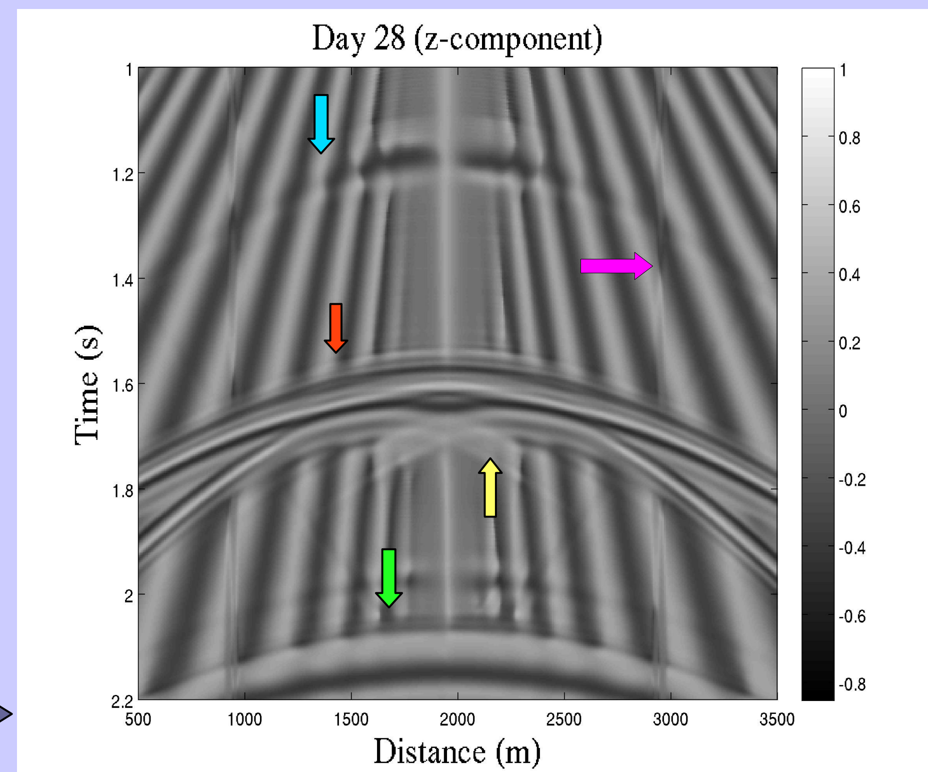


3D Elastic Seismic Models
velocity z-component



Legend:
- reservoir top
- reservoir bottom
- waterfronts
- S-wave projection
- numerical artifacts





Conclusion

Acoustic and elastic models differences:

- more details on elastic models
- computation time

Acoustic and elastic models similarities:

- events
- amplitude change as waterfront reaches reservoir top

- Depending on the study, both models show to be valuable.

Future work

- Employ meandering streams
- Run acousto-elastic algorithms
- Apply work flow to data set in Alberta's Blackfoot Field.

Acknowledgements

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- Thank you to Dr Gary Margrave, Dr Don Lawton, Dr Adam Pidlisecky and Dr Steve Hubbard for valuable lectures.

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  - CREWES Directors, Staff and Students

Questions