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CHORUS

Consortium for Heavy Oil Research by University Scientists

Q and the quest for heavy oil viscosity

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Biot + Squirt flow model

$$Q = \frac{\text{Re}(\sqrt{Y})}{2\text{Im}(\sqrt{Y})}$$

$$Y = \frac{\rho_m(1-\phi) + \rho_f \phi}{M + F_{sq} \frac{a^2}{\phi}}$$

$$F_{sq} = F \left[1 - \frac{2|_1(\xi)}{\xi|_0(\xi)} \right]$$

$$\xi = \sqrt{i} \sqrt{\frac{R^2 \mu \phi \omega}{kF}}$$

$$F = \frac{\phi}{\frac{\phi}{K_f} + \frac{1-\phi}{K_m} - \frac{K_d}{K_m^2}}$$

$$\alpha = 1 - \frac{K_d}{K_m}$$

The squirt-flow mechanism: Macroscopic description

Jack Dvorkin*, R

We introduce a rate the two most in interaction in rock squirt-flow mechan (BISQ) model relat tion to the sit ation and of the so saturation, fluid vis characteristic squir a fundamental roo frequency, fluid vis determined experim tic response of ma squirt-flow compo that the viscoelastic expressed throug with $\omega^{1/2}$, where ω is acoustic squir-fre quency. The Biot m adequate explanatio tion and demonstrat many significant

This paper is a sequ Nur, 1993) where we d unifies the Biot and the interaction. These are bined Biot-squirt (BIS important both metho First, the Biot and d have been traditiona intimately interconnect consistent poroelasticit nisms simultaneously

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4) the model explains a number of experimentally observed trends such as increasing compressional velocity and shift in dispersion to lower frequencies with increasing pore-fluid viscosity; and

5) there is a distinct relation between attenuation and permeability structures in well at small permeability values, due to a mixture of permeability poroelasticity and viscous drag for high permeability.

The BISQ model is an improved attempt at quantitatively modeling seismic behavior of the squirt-flow mechanism in acoustically anisotropic rock and fluid properties, and frequency. Additional research effort is needed to accurately model squirt flow in unconsolidated, highly porous gas, and to generalize using global permeability and porosity to permeability and porosity for most of the hydrocarbon reservoirs.

We believe that a better presentation of the BISQ model is needed.

The pore fluids in the reservoirs are assumed to be a mixture of water and hydrocarbons. The pore fluids are assumed to be a mixture of water and hydrocarbons. The pore fluids are assumed to be a mixture of water and hydrocarbons.

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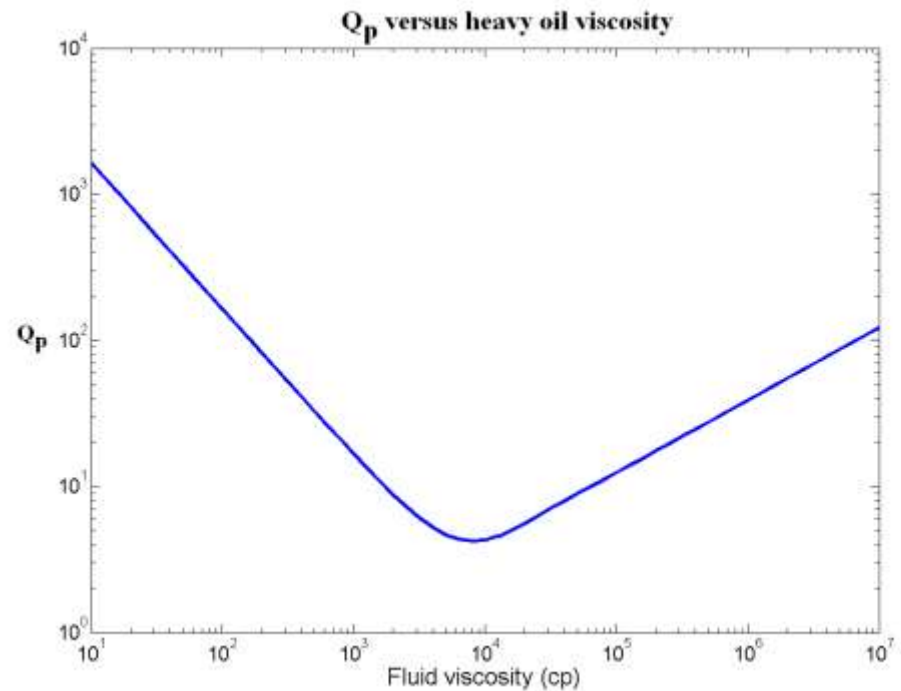
remote sensing methods. We have shown that at a given frequency, both velocity and attenuation may change strongly with the changing pore fluid viscosity. Therefore, by employing the BISQ formulas, we can, in principle, use these seismic signatures to monitor changes in fluid viscosity (and thus temperature). Such monitoring will be appropriate, for example, in a heavy oil reservoir subject to thermal enhanced oil recovery treatment (Nur, 1989; Dvorkin and Nur, 1993).

(Dvorkin et al, 1994)

Biot + Squirt flow model

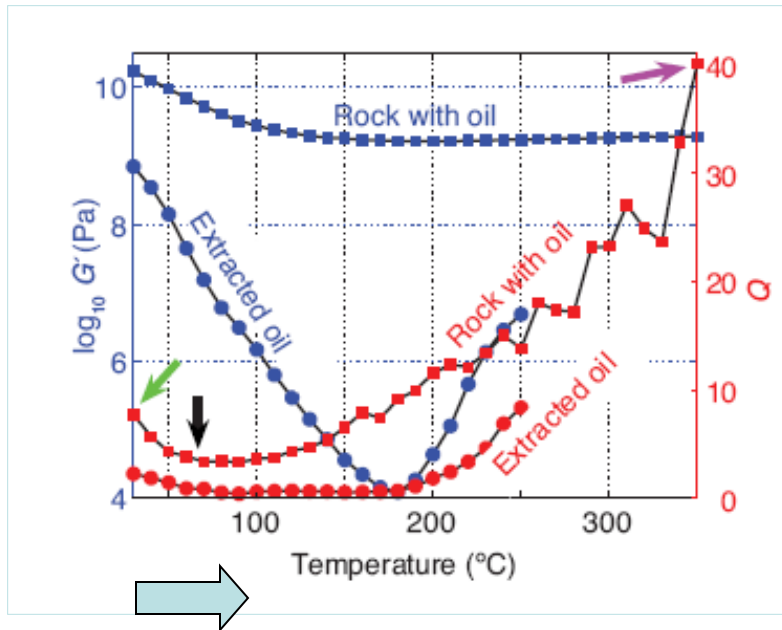
Reservoir and fluid properties	
Fluid Density	1000 kg/m ³
Fluid bulk modulus	1 GPa
Fluid viscosity	Variable
Frequency	300 Hz
R	1 mm
Oil saturation	1
Matrix Bulk modulus	35 GPa
Matrix Density	2650 kg/m ³
Porosity	0.30
Dry frame bulk modulus	1.7 GPa
Dry frame shear modulus	1.35 GPa
Permeability	1 D

Theoretical values



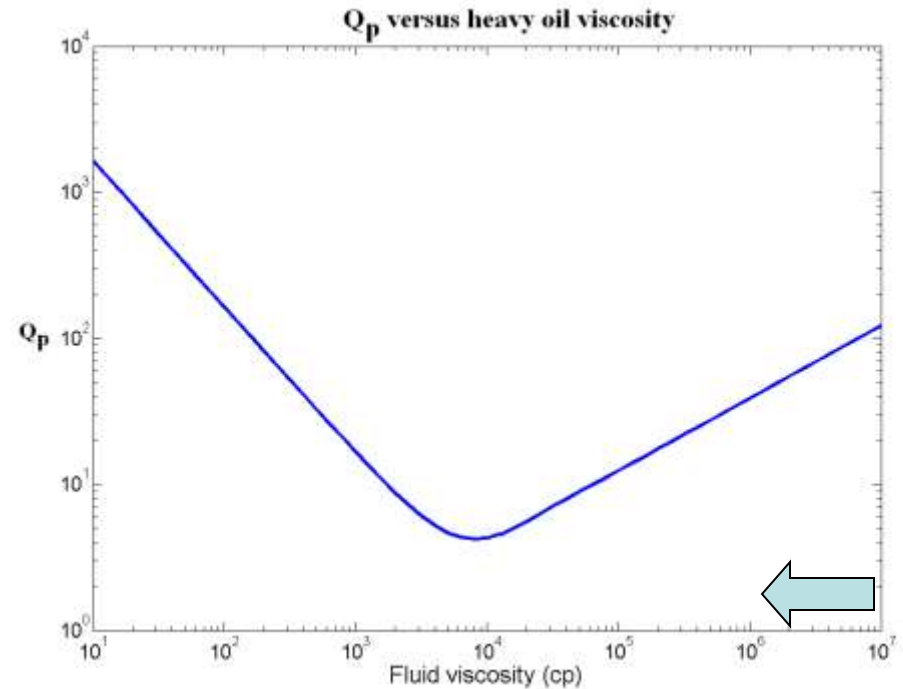
Biot + Squirt flow model

Measured in lab



(Behura et al, 2007)

Theoretical values



- Both show that quality factor decrease to a minimum then increases with viscosity (temperature).

Biot + Squirt flow model

$$Q = \frac{\operatorname{Re}(\sqrt{Y})}{2\operatorname{Im}(\sqrt{Y})}$$

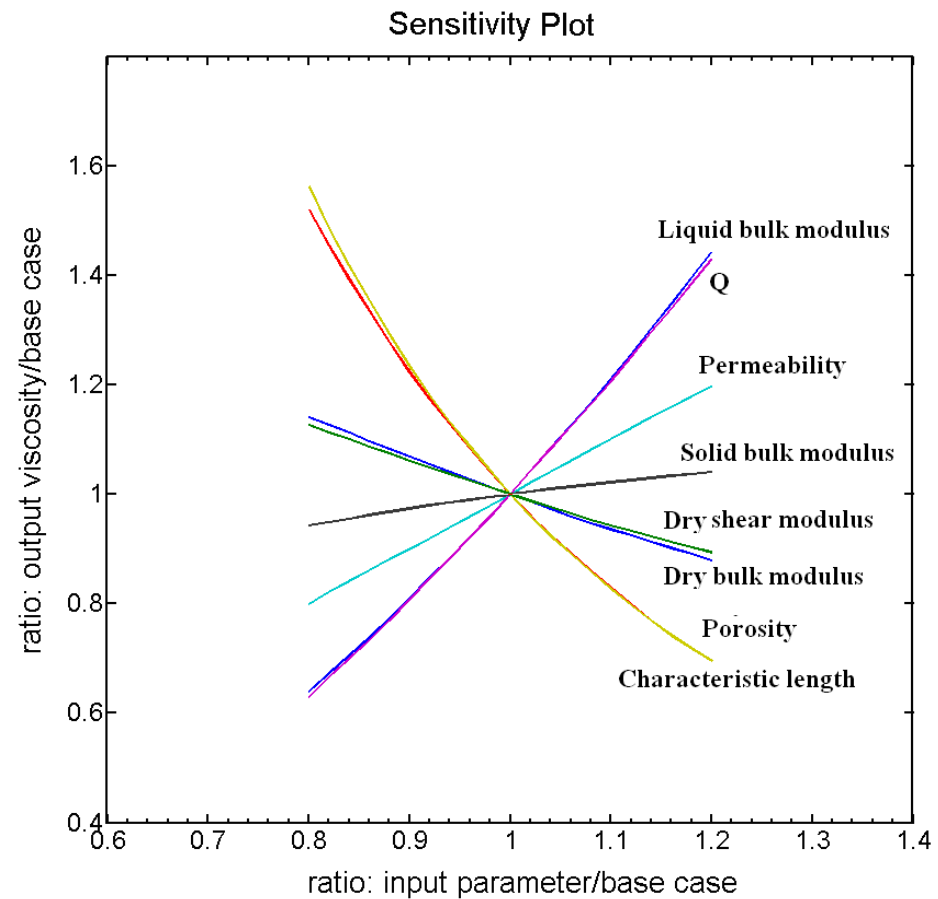
$$Y = \frac{\rho_m(1-\phi) + \rho_f\phi}{M + F_{sq} \frac{\alpha^2}{\phi}}$$

$$F_{sq} = F \left[1 - \frac{2J_1(\xi)}{\xi J_0(\xi)} \right]$$

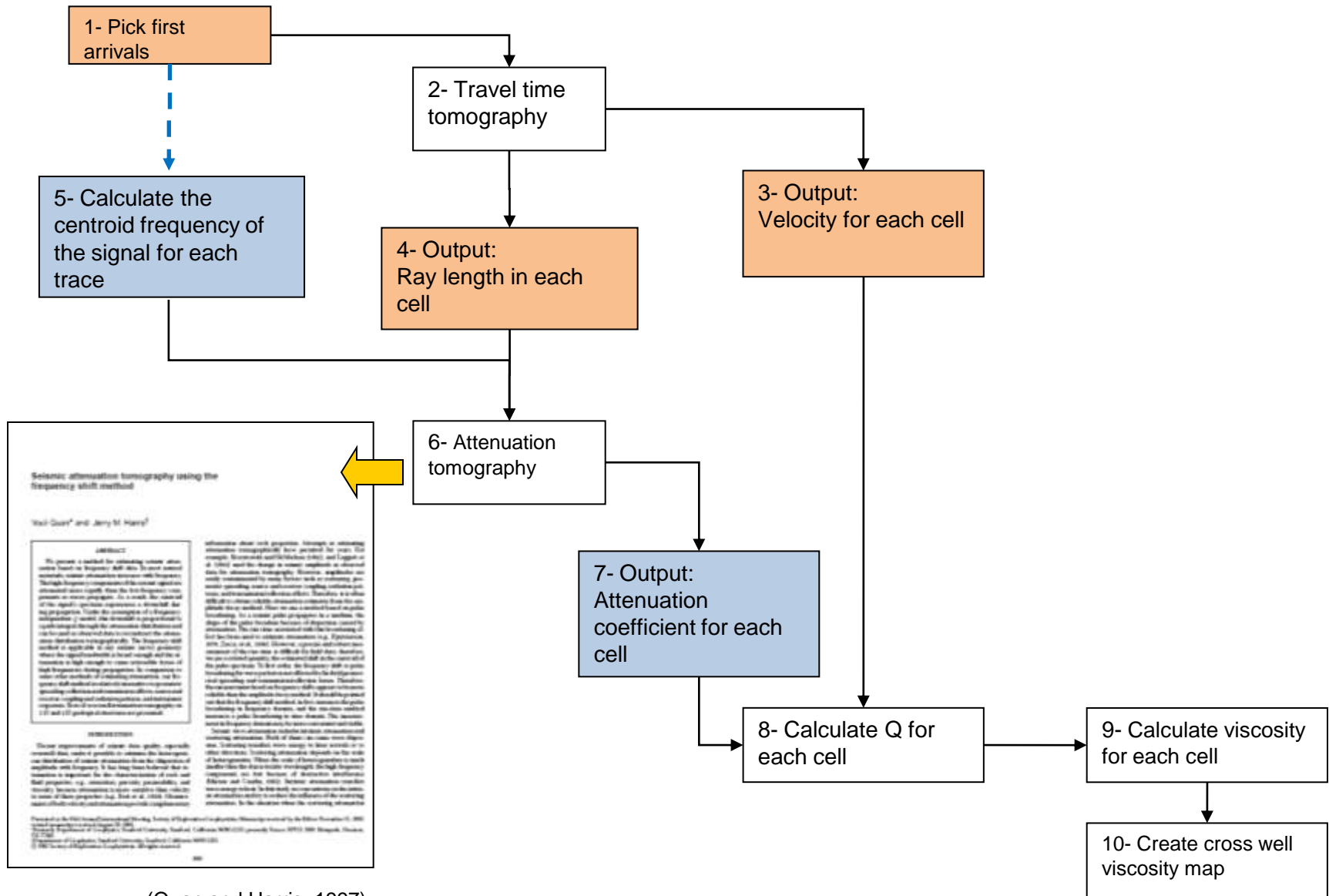
$$\xi = \sqrt{i} \sqrt{\frac{R^2 \mu \phi \omega}{kF}}$$

$$F = \frac{\phi}{\frac{\phi}{K_f} + \frac{1-\phi}{K_m} - \frac{K_d}{K_m^2}}$$

$$\alpha = 1 - \frac{K_d}{K_m}$$

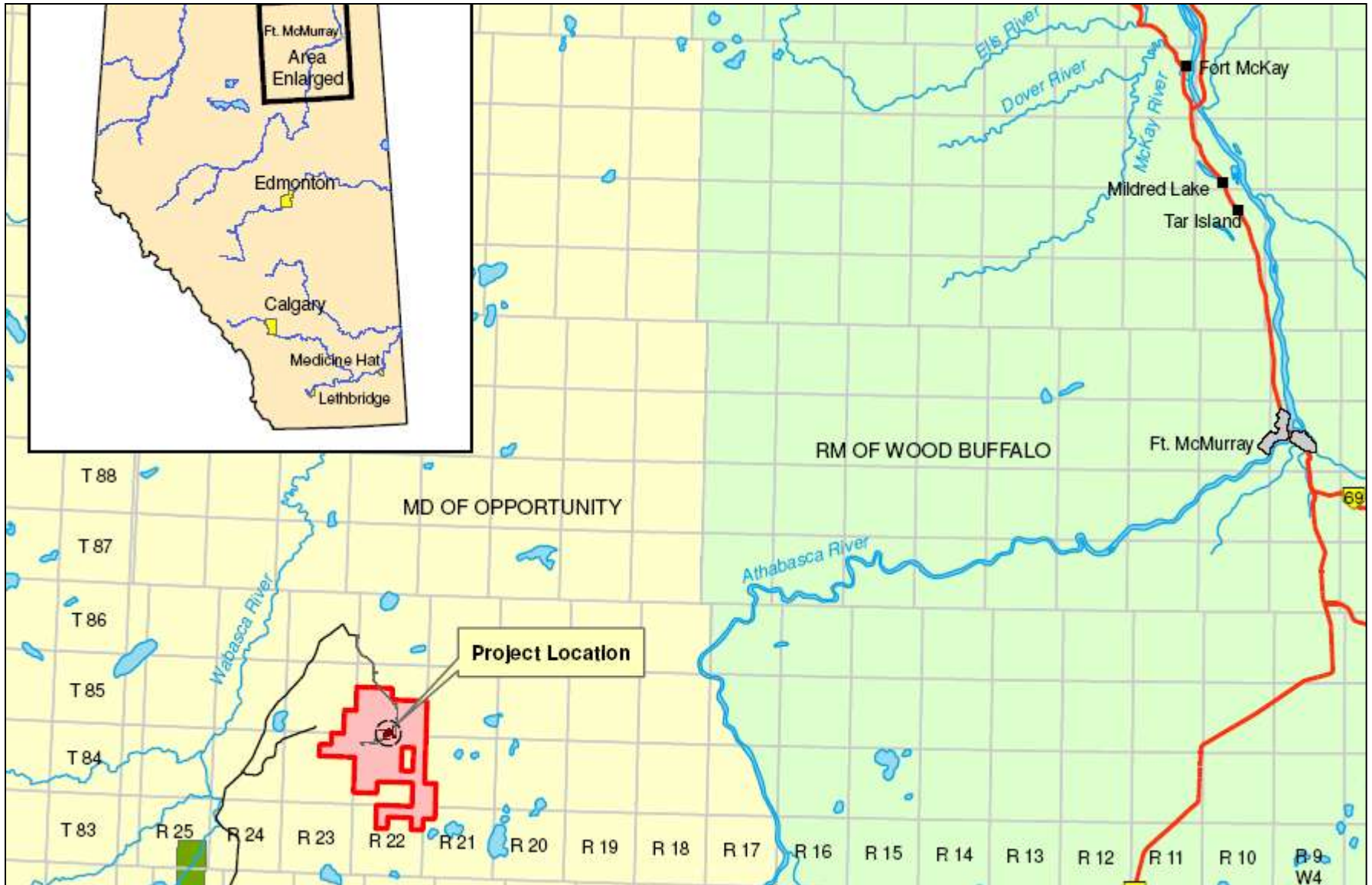


Methodology



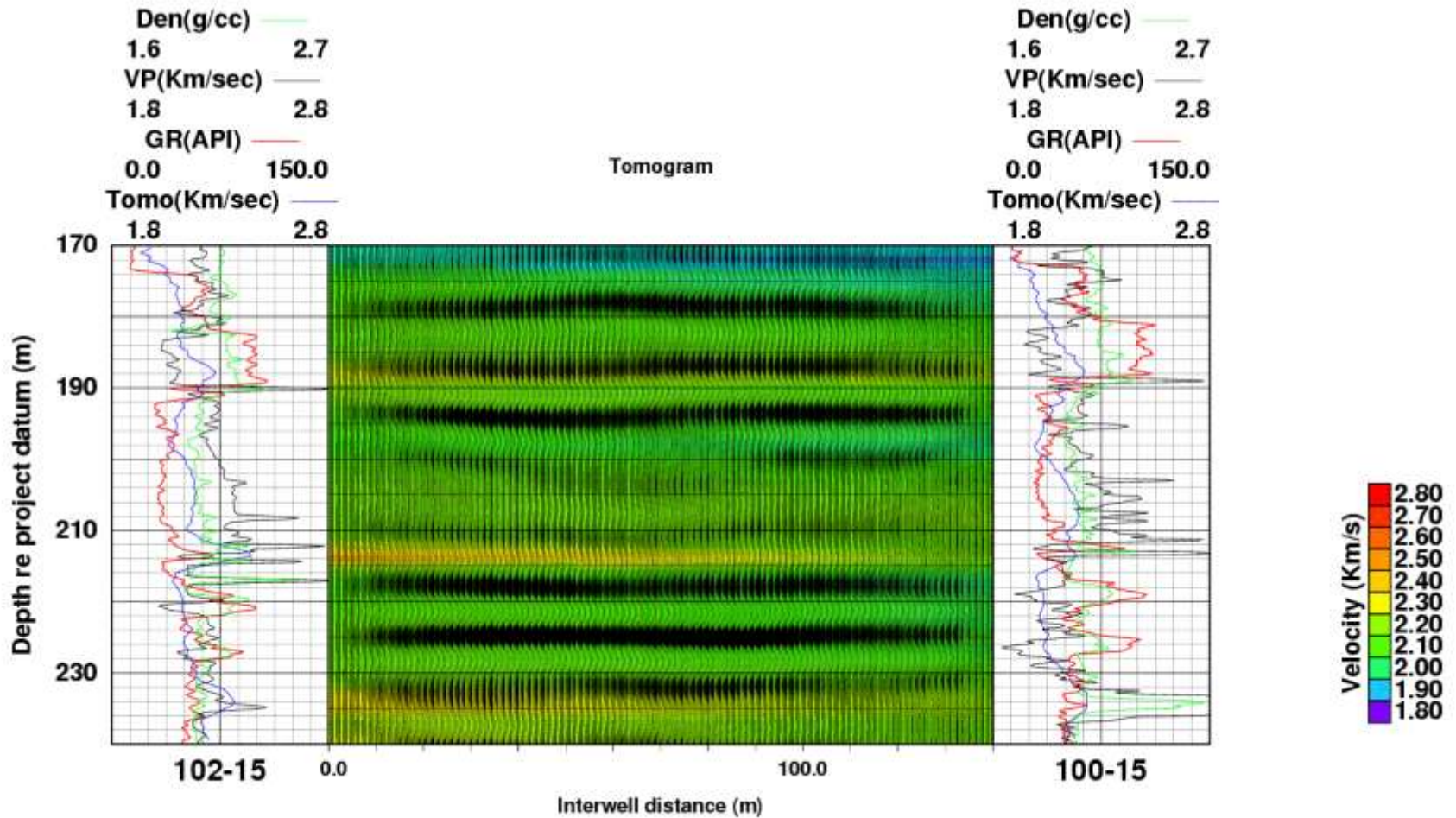
(Quan and Harris, 1997)

Cross well location

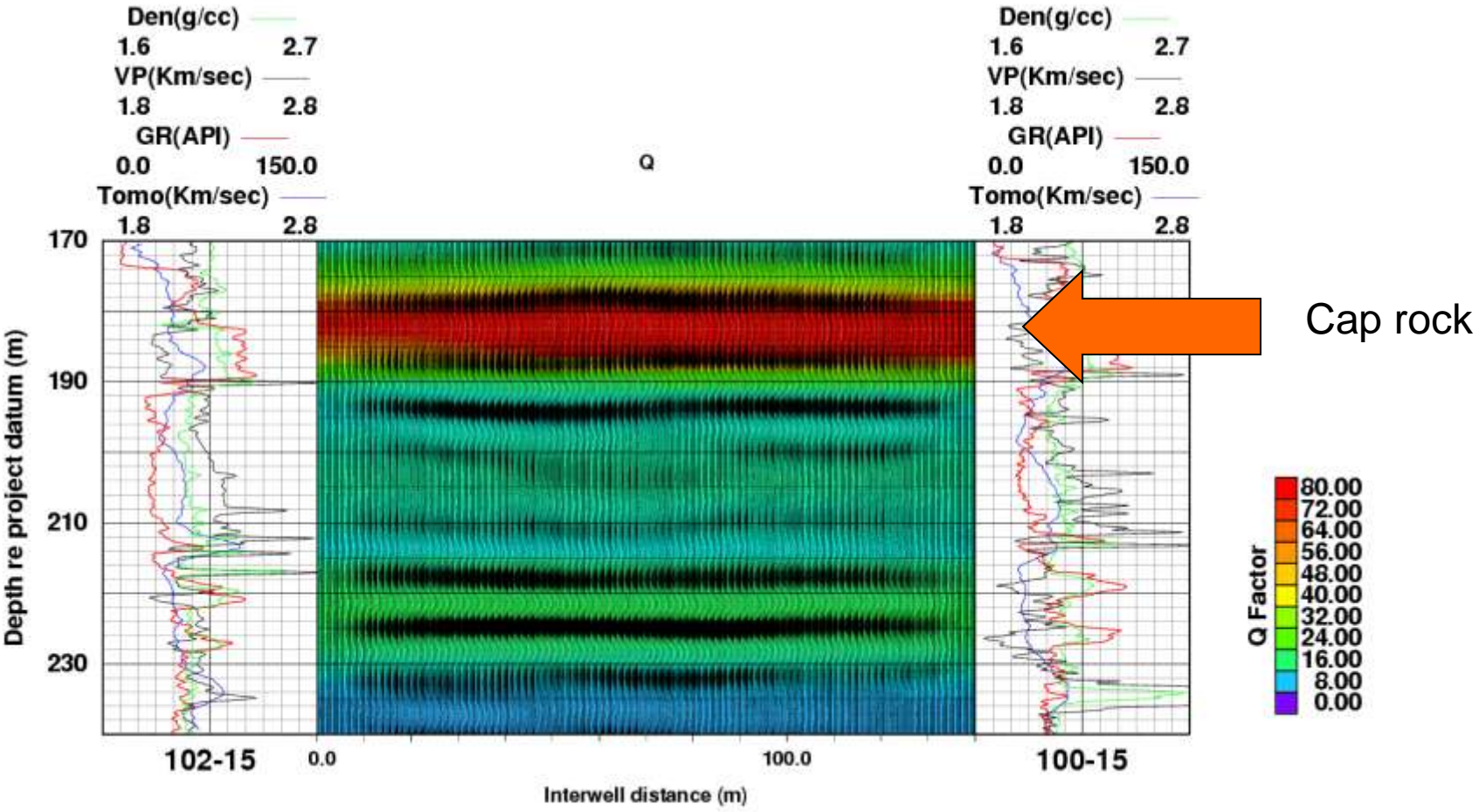


(modified from ERCB)

Velocity

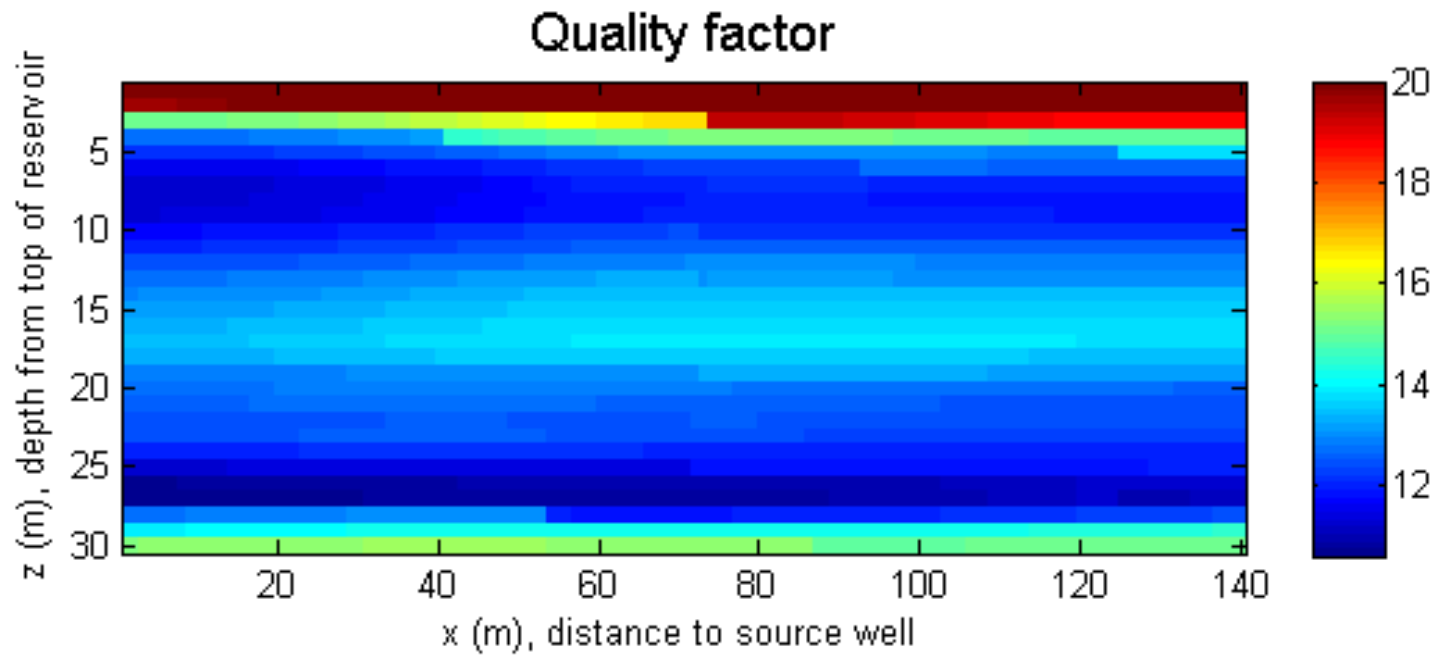


Quality factor

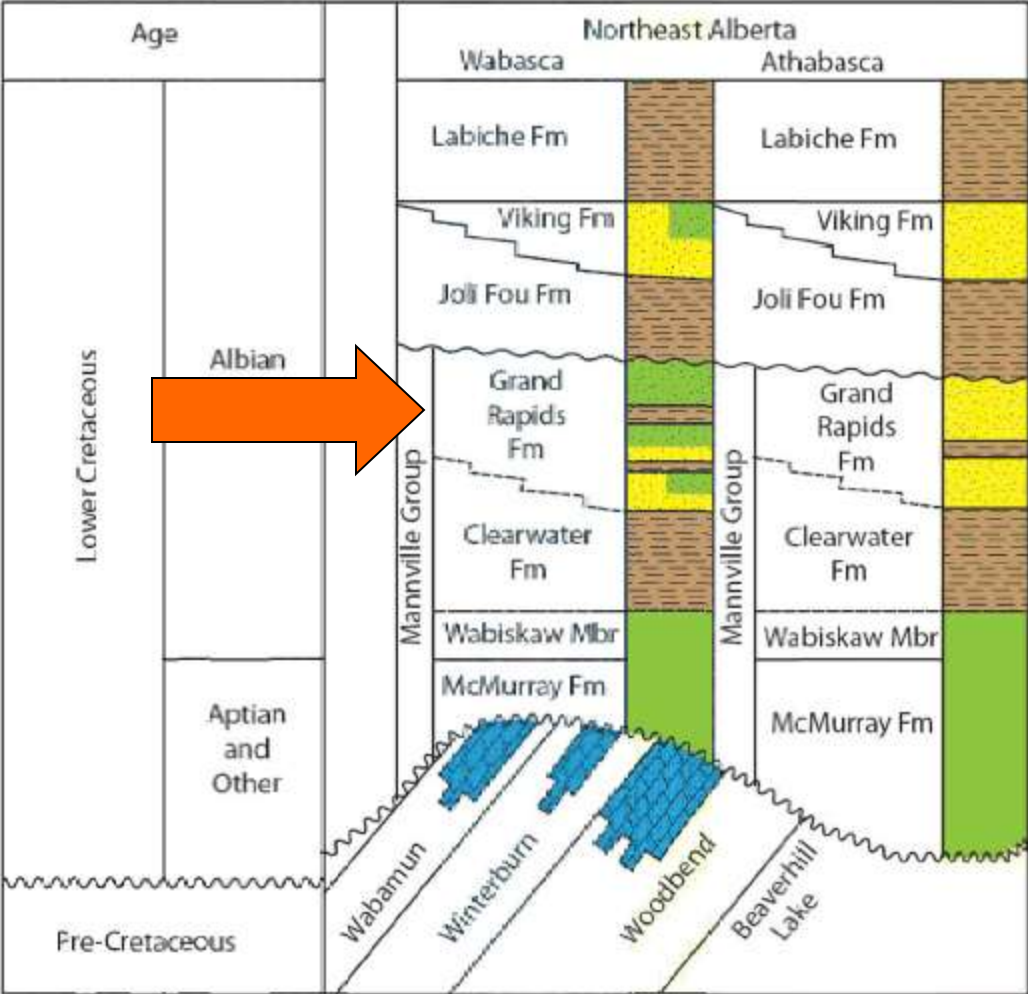


Quality factor

- Zone of interest



Stratigraphy



Assumptions

$$Q = \frac{\operatorname{Re}(\sqrt{Y})}{2\operatorname{Im}(\sqrt{Y})}$$

$$Y = \frac{\rho_m(1-\phi) + \rho_f\phi}{M + F_{sq} \frac{\alpha^2}{\phi}}$$

$$F_{sq} = F \left[1 - \frac{2J_1(\xi)}{\xi J_0(\xi)} \right]$$

$$\xi = \sqrt{i} \sqrt{\frac{R^2 \mu \phi \omega}{kF}}$$

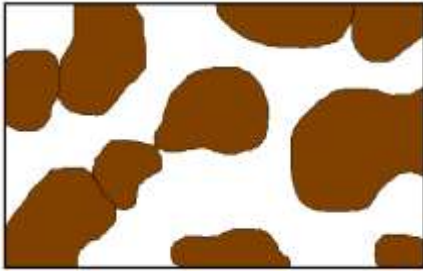
$$F = \frac{\phi}{\frac{\phi}{K_f} + \frac{1-\phi}{K_m} - \frac{K_d}{K_m^2}}$$

$$\alpha = 1 - \frac{K_d}{K_m}$$

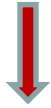
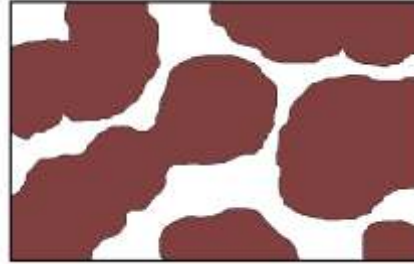
- Valid when rock is saturated with **single** phase:
 - What should be done about the **water**?
- Other reservoir parameters should be known:
 - Porosity, permeability, bulk moduli, etc.

Water

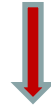
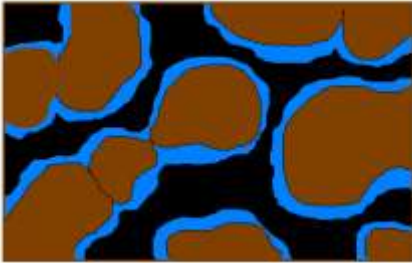
Dry porous media



wet porous media



Saturated porous media



Saturated porous media



Assumption:

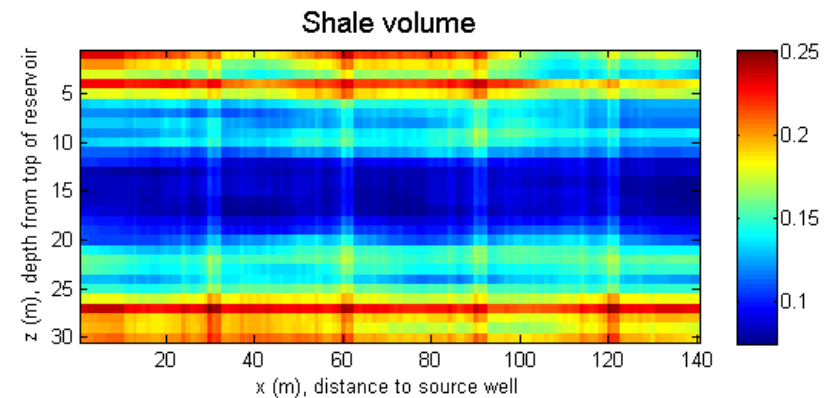
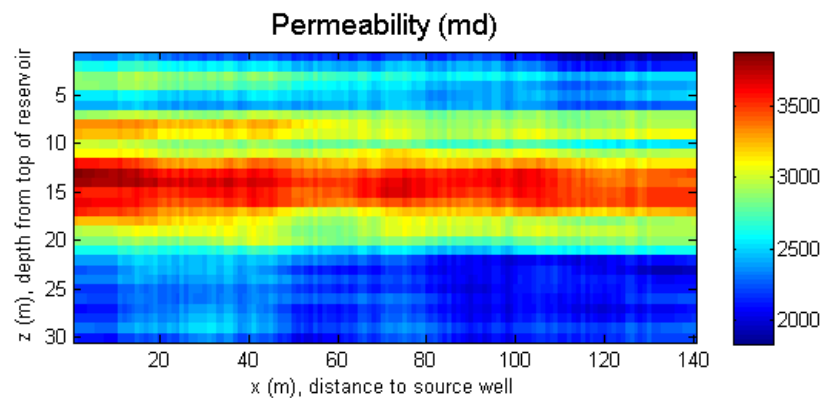
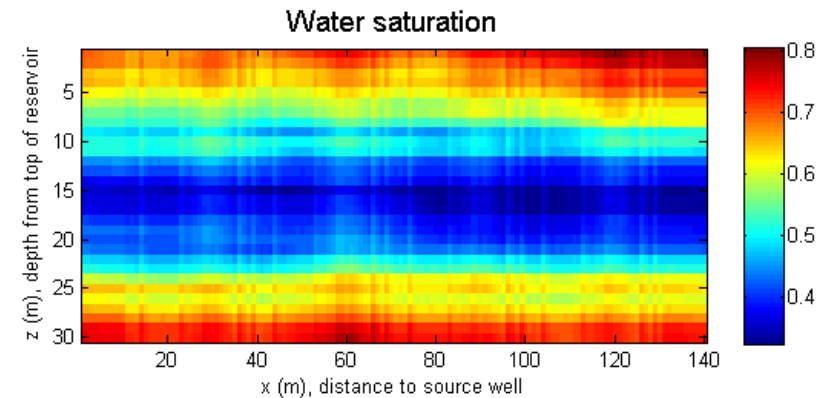
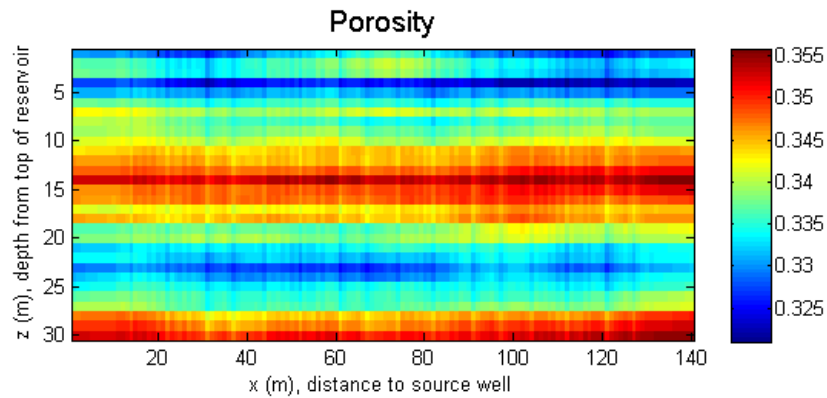
- Water acts as an elastic material, therefore its viscosity is ignored.

Parameters to be modified:

- Bulk modulus: dry \rightarrow wet (using Gassmann or Hashin-Shtrikmann relations)
- Grain density \rightarrow weighted average of grain and water densities
- Porosity: \rightarrow porosity * oil saturation
- Permeability \rightarrow oil relative permeability

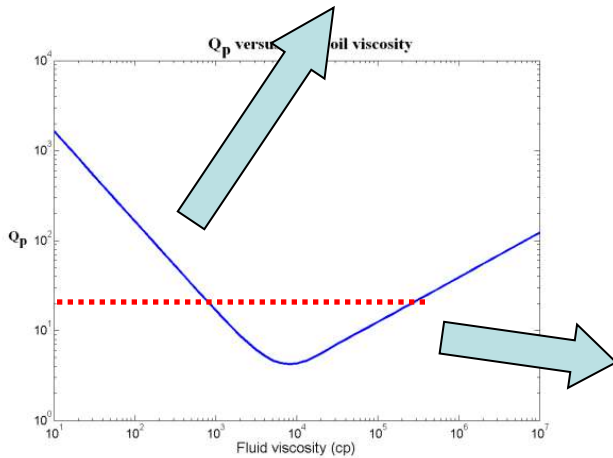
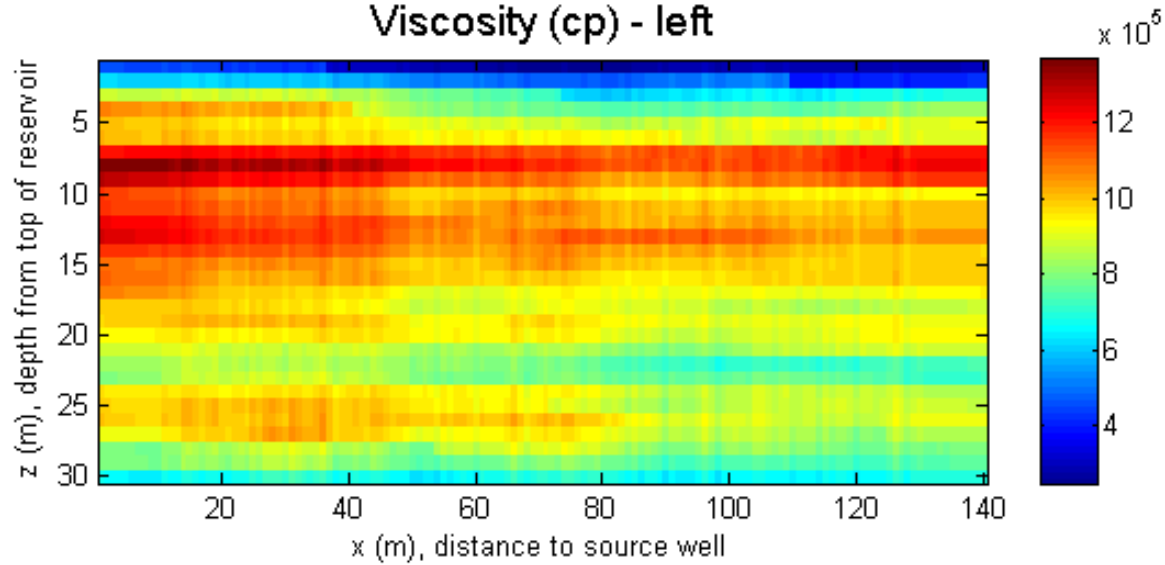
Geological model

- From core and well log data.
- Using statistical modeling techniques

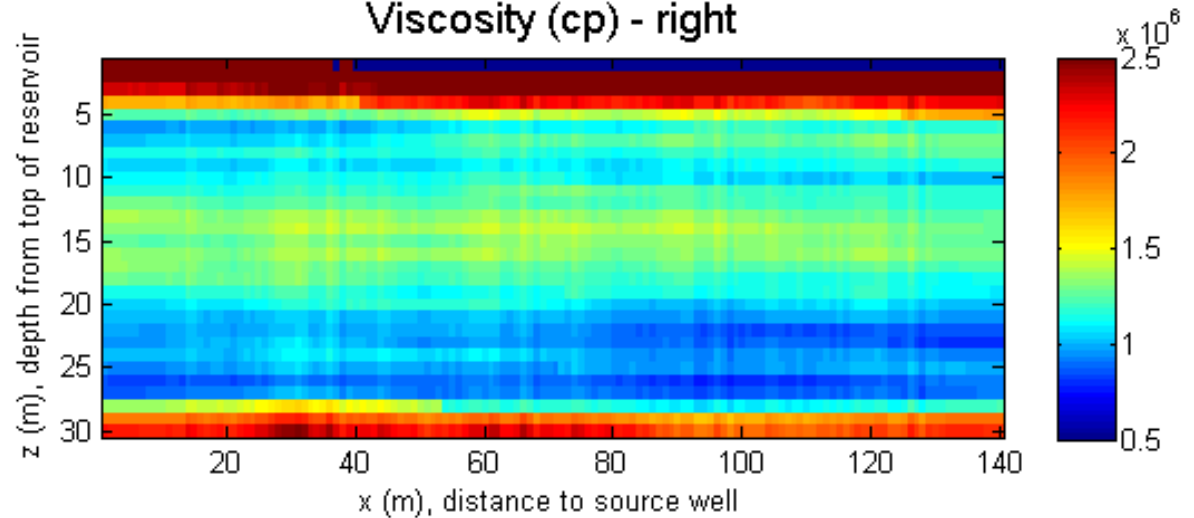


Viscosity: ambiguity

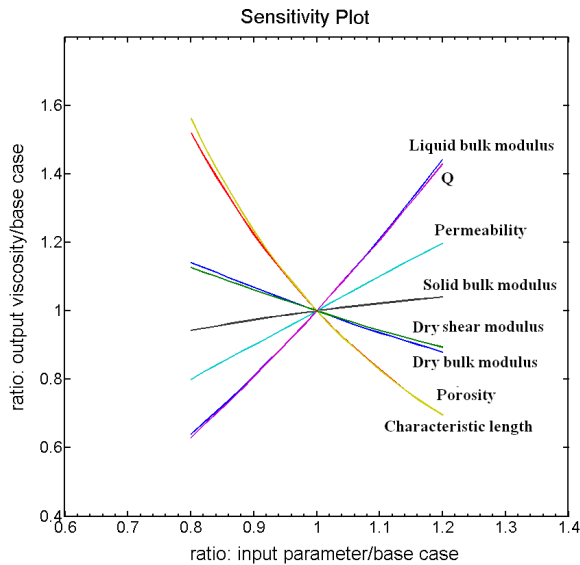
Viscosity (cp) - left



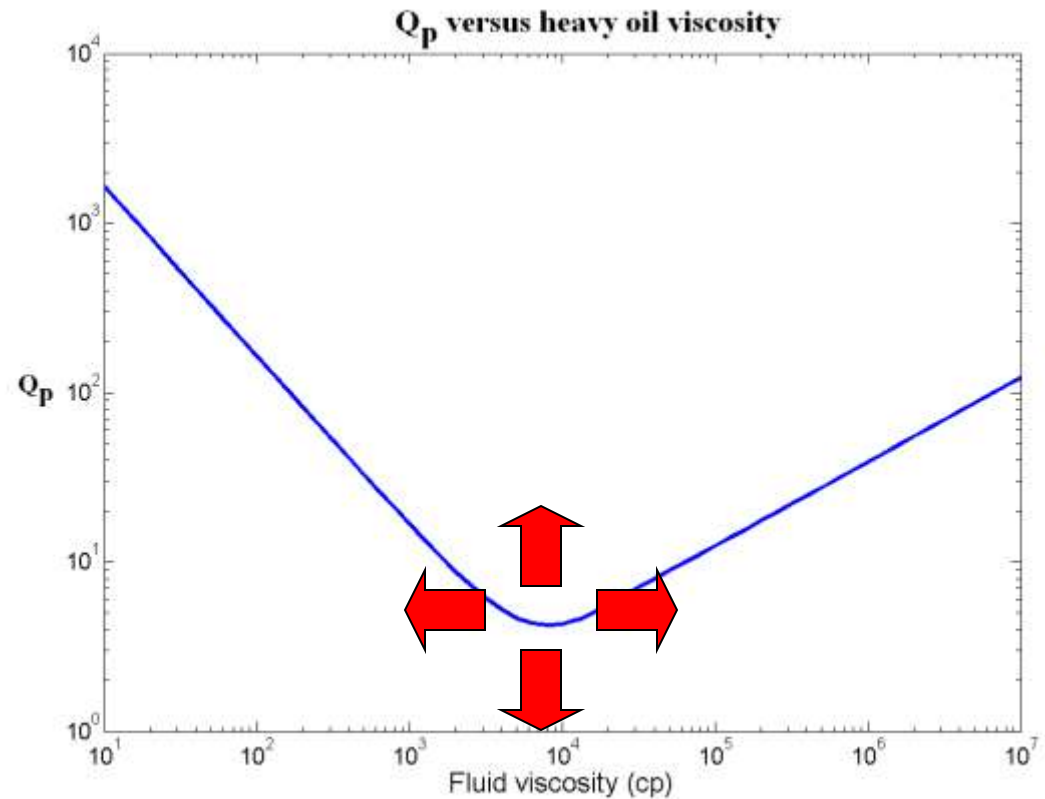
Viscosity (cp) - right



Viscosity: uncertainty



Uncertainties in the input parameters will shift the Q-viscosity curve and create error in the viscosity values.



Conclusions

- Heavy oils are considered viscoelastic materials and their shear properties are important.
- Both theory and measurements show that Q has a decreasing-increasing behavior with viscosity.
- The Q -viscosity behavior, unfortunately, demonstrates that there can be nonuniqueness (ambiguity) in determining viscosity from Q .
- The uncertainties in the input parameters can move the Q -viscosity curve a and create error.
- Viscosity can be estimated from Q , but further research is needed.
- No real viscosity data were available to the authors during this research for validation purposes.
- According to BISQ theory, Q does not change with density.

Acknowledgements

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- Laricina Energy for providing the data and technical assistance
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