Q and the quest for heavy oil viscosity

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Biot + Squirt flow model

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

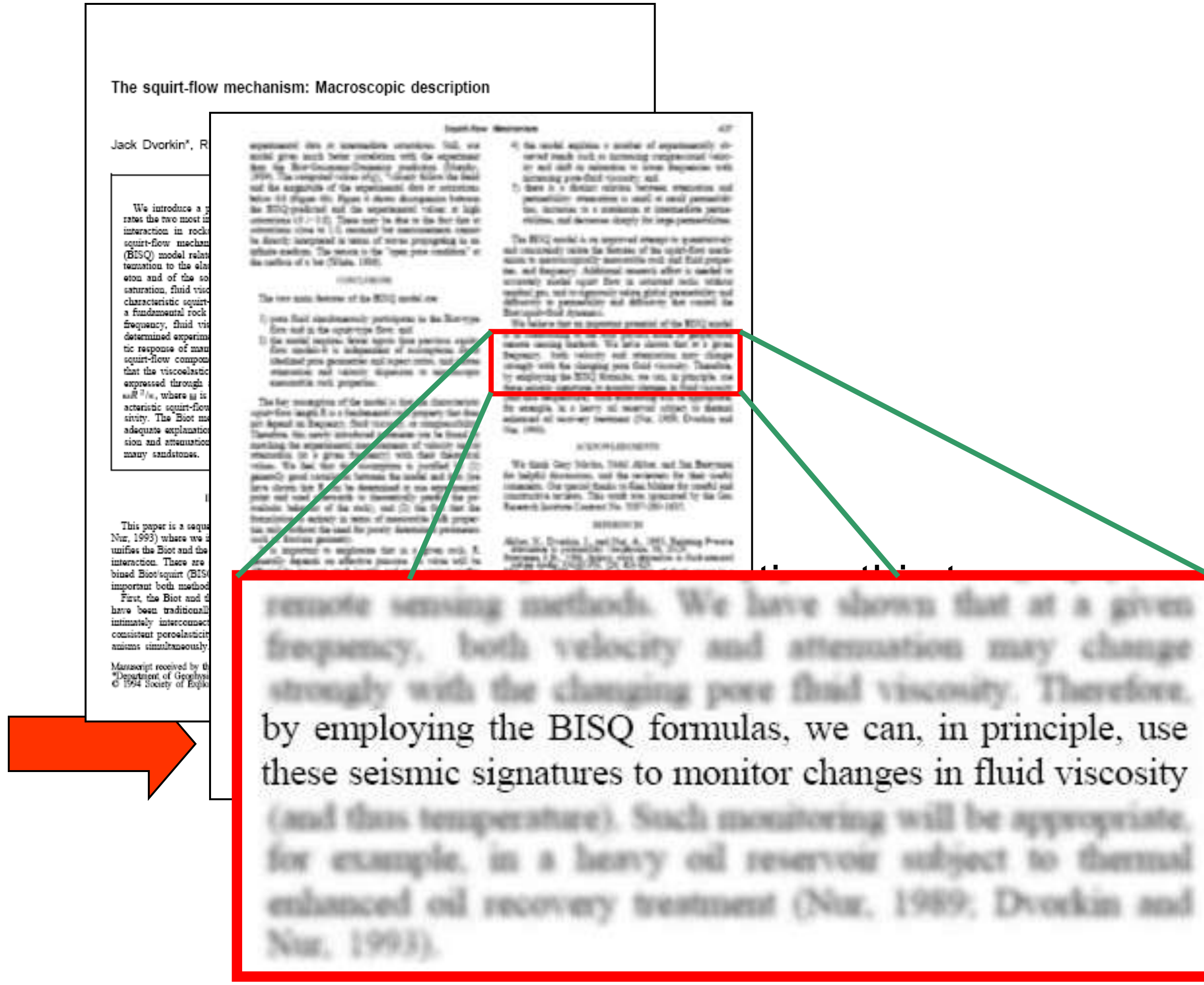
$$Y = \frac{\rho_m(1-\varphi)+\rho_f\varphi}{M+F_{sq}\frac{\alpha^2}{\varphi}}$$

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

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

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

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

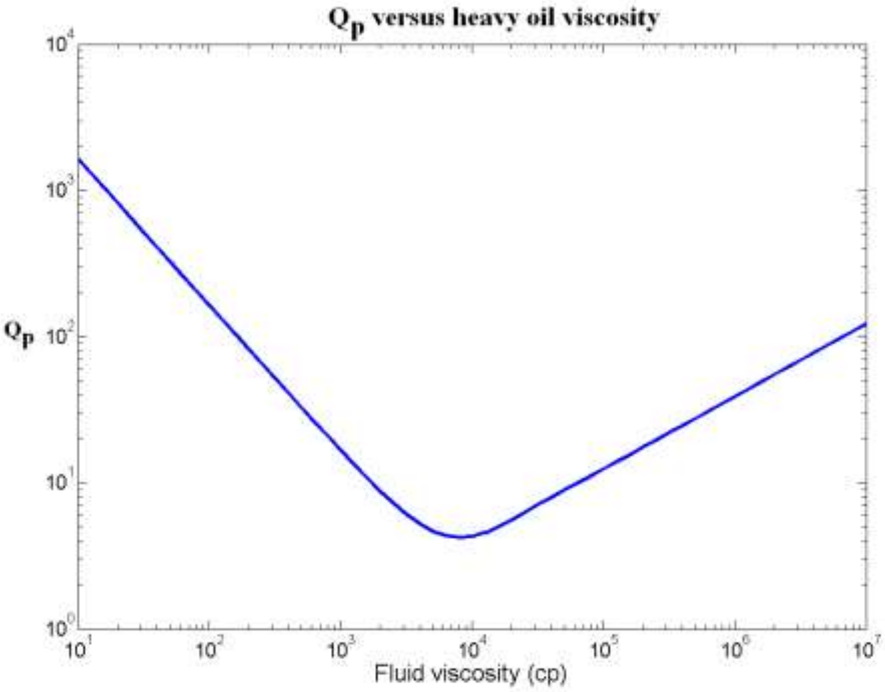


(Dvorkin et al, 1994)

Biot + Squirt flow model

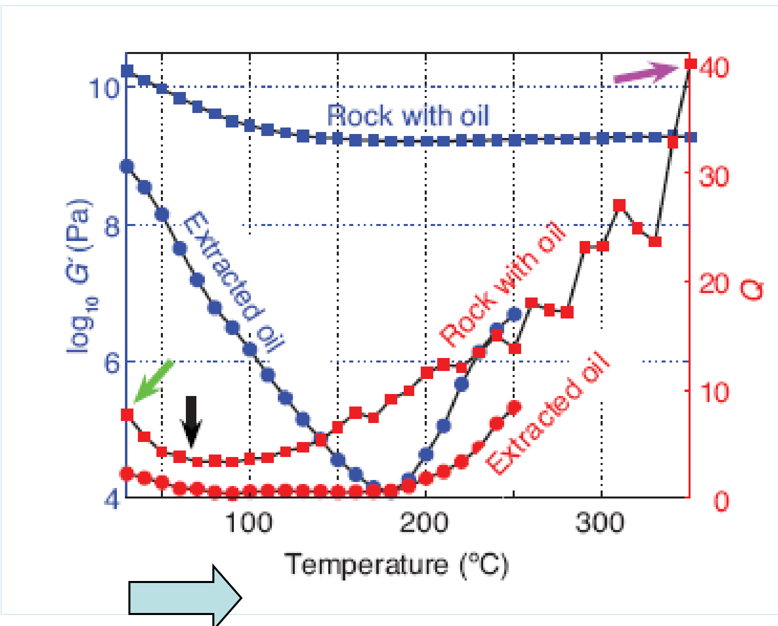
Reservoir and fluid properties	
Fluid Density	1000 kg/m^3
Fluid bulk modulus	1 GPa
Fluid viscosity	Variable
Frequency	300 Hz
R	1 mm
Oil saturation	1
Matrix Bulk modulus	35 GPa
Matrix Density	2650 kg/m^3
Porosity	0.30
Dry frame bulk modulus	1.7 GPa
Dry frame shear modulus	1.35 GPa
Permeability	1 D

Theoretical values



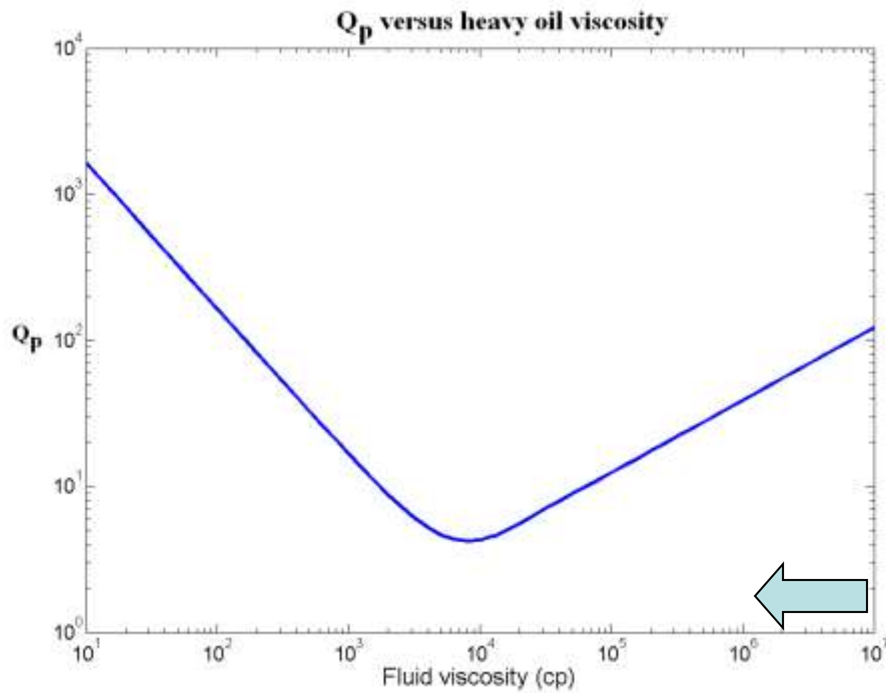
Biot + Squirt flow model

Measured in lab



(Behura et al, 2007)

Theoretical values



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

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Biot + Squirt flow model

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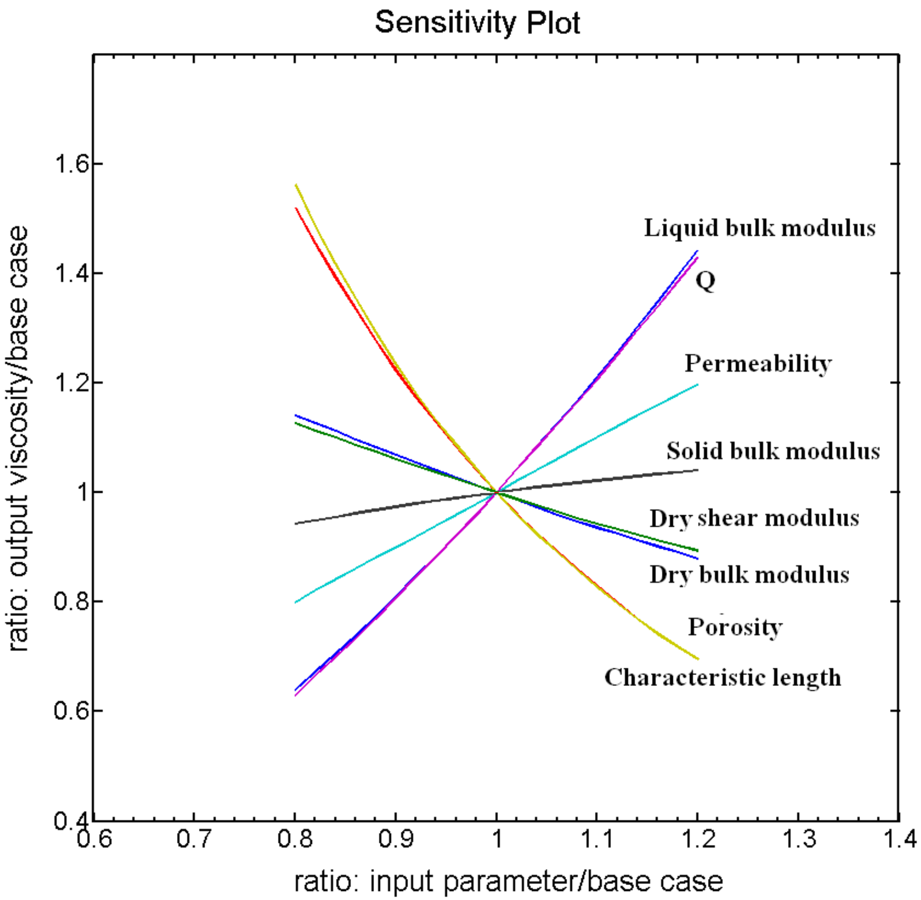
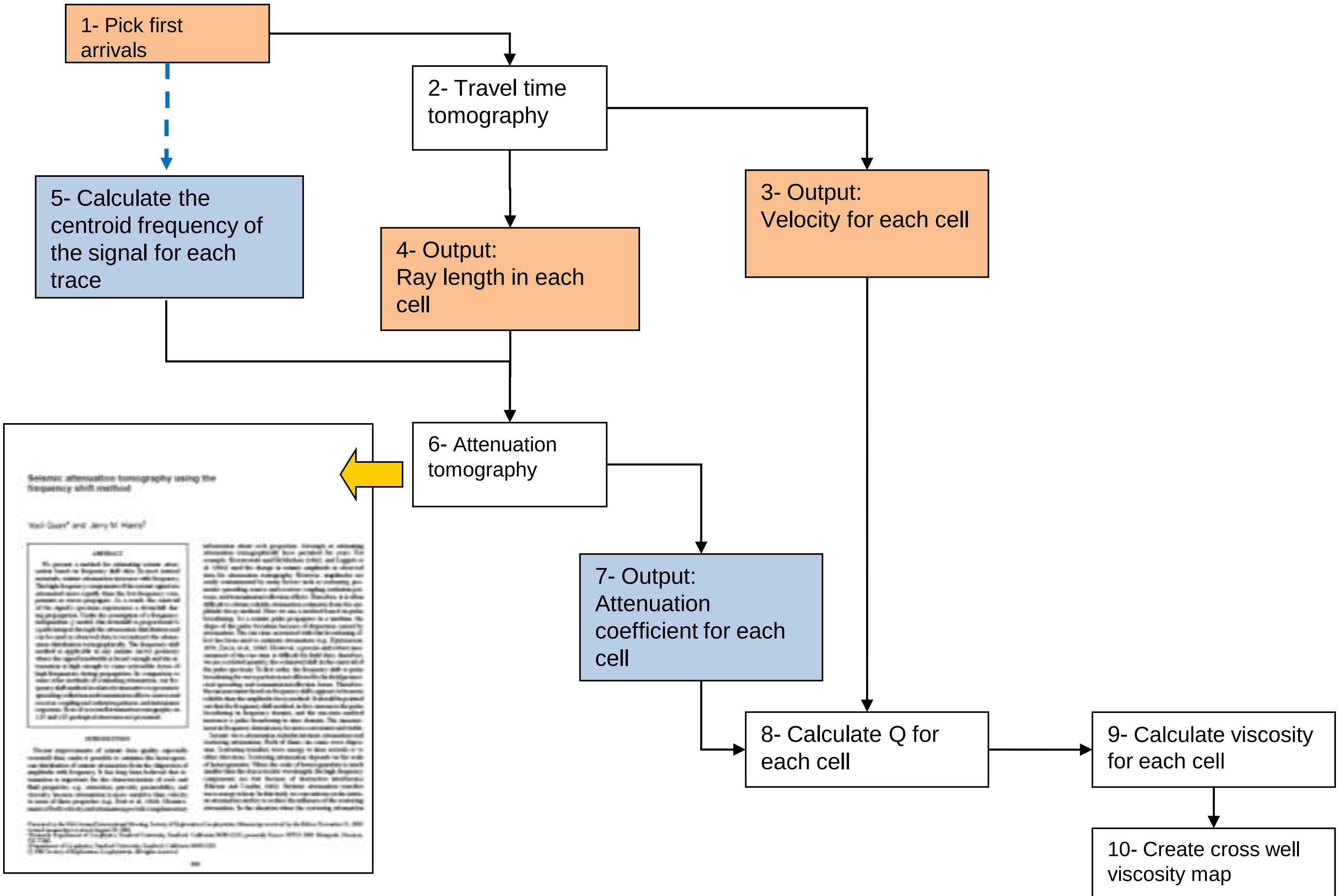
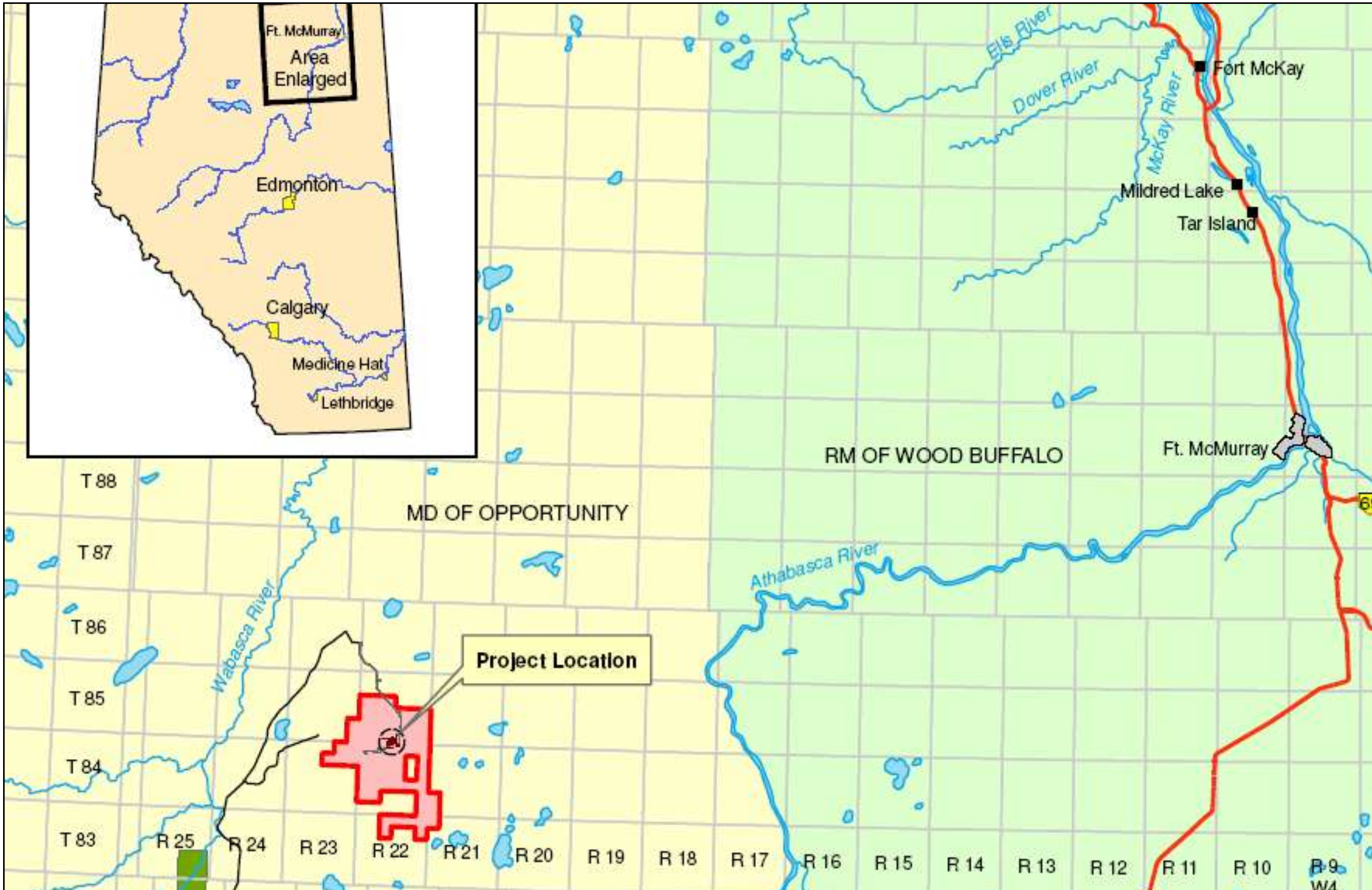


Methodology



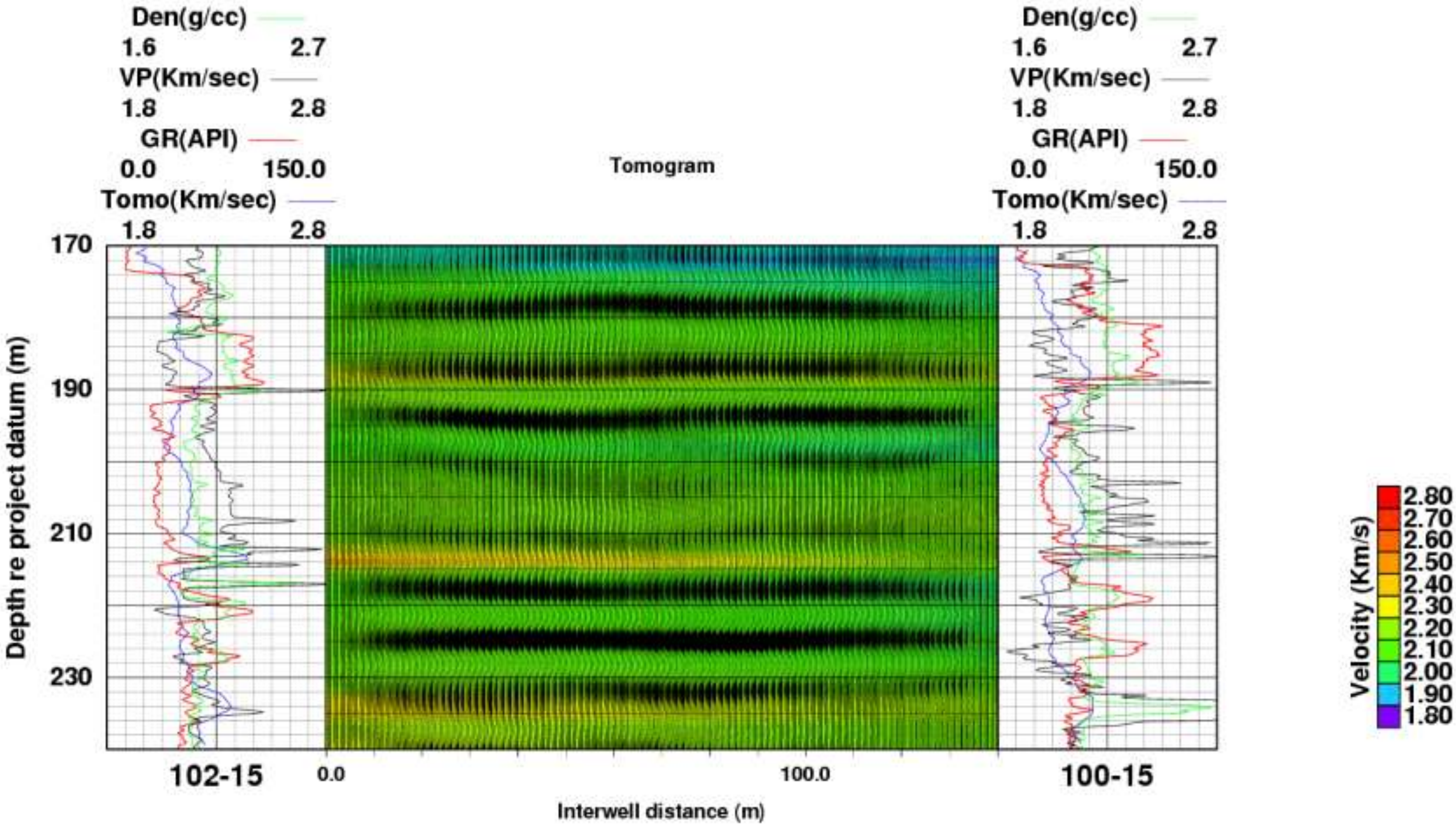
(Quan and Harris, 1997)

Cross well location



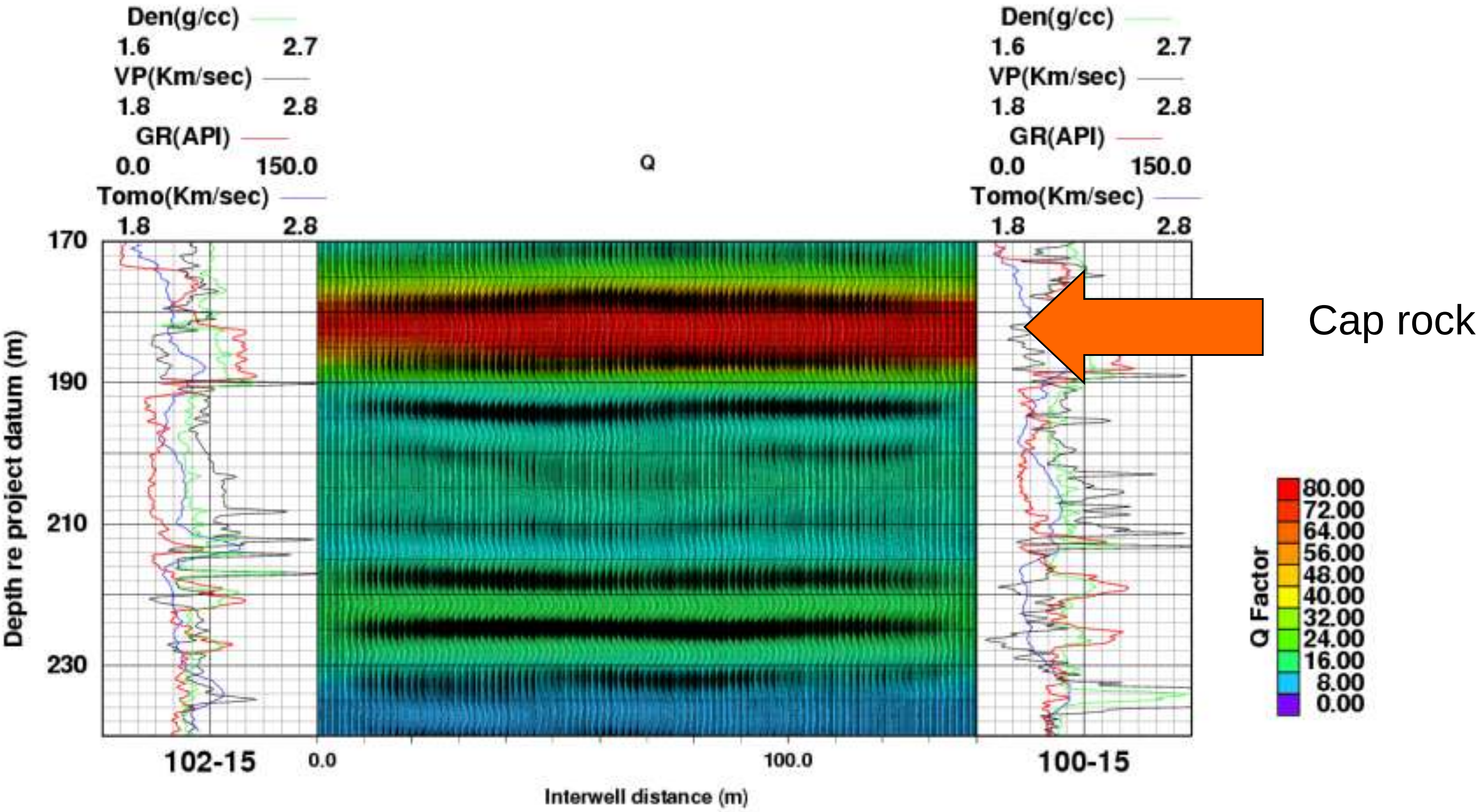
(modified from ERCB)

Velocity



Den(g/cc)
1.6 2.7
VP(Km/sec)
1.8 2.8
GR(API)
0.0 150.0
Tomo(Km/sec)
1.8 2.8
Tomogram
Depth re project datum (m)
170
190
210
230
102-15
0.0
100.0
100-15
Interwell distance (m)
Velocity (Km/s)
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80

Quality factor



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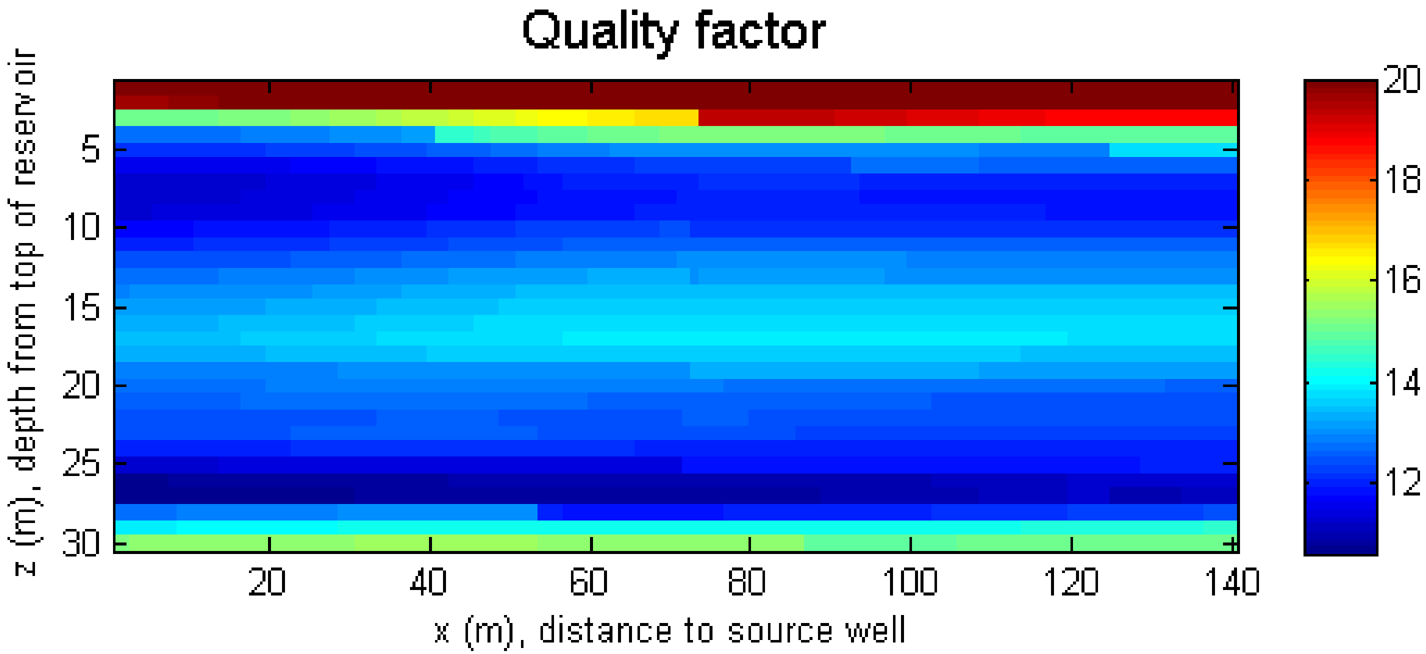
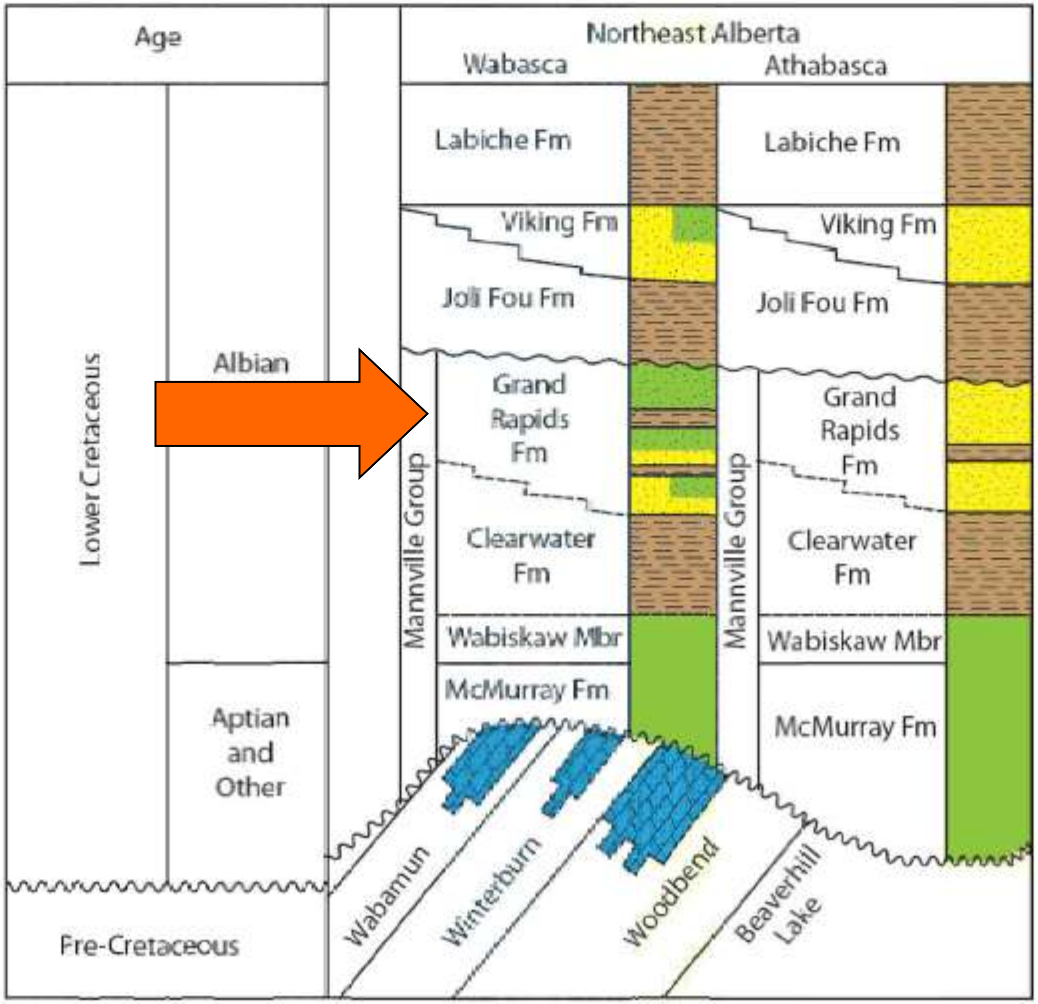
Quality factor

- Zone of interest



Stratigraphy



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Assumptions

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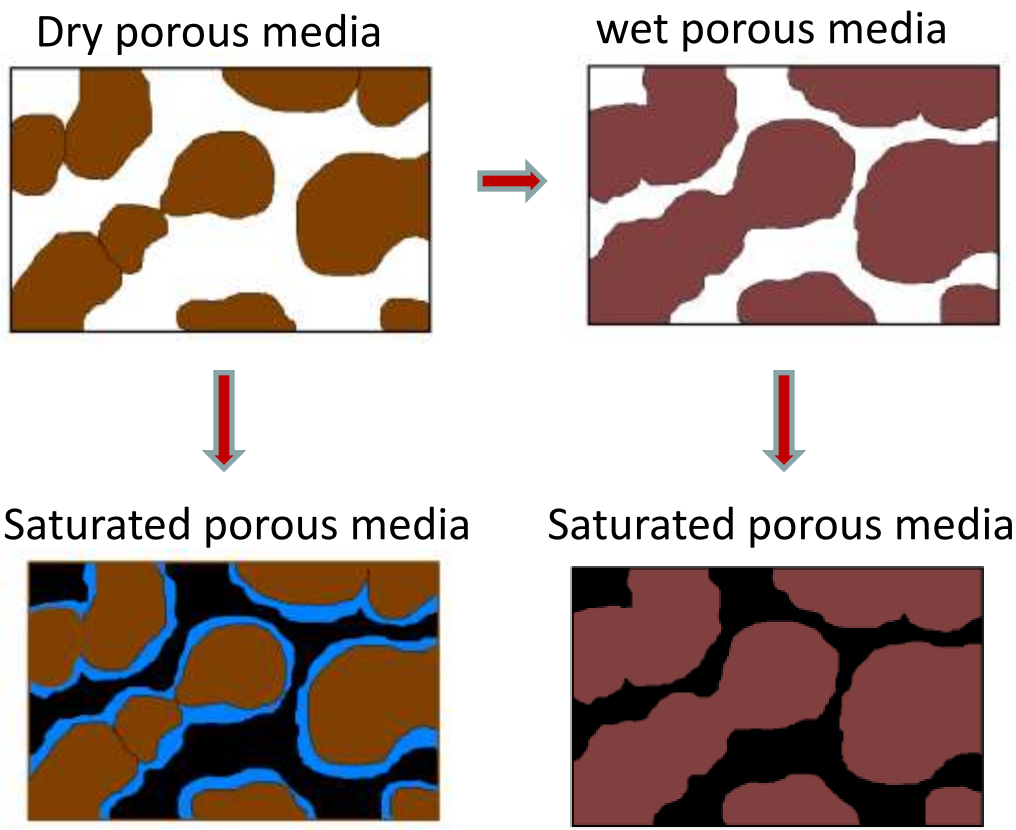
$$\alpha = 1 - \frac{K_d}{K_m}$$

- 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



Assumption:

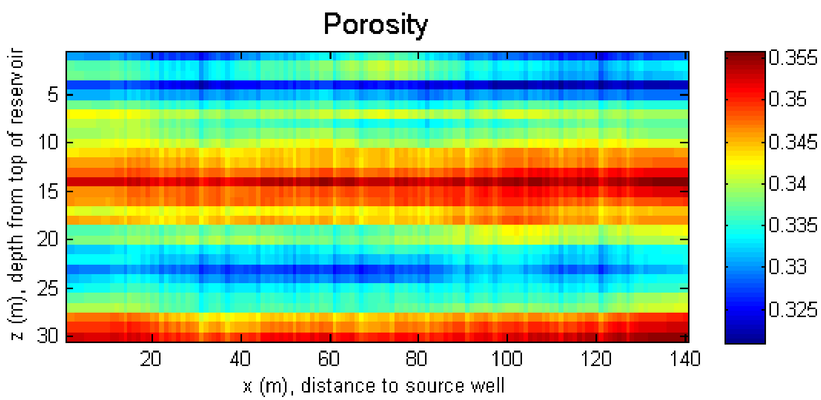
- Water acts as an elastic material, therefore its viscosity is ignored.

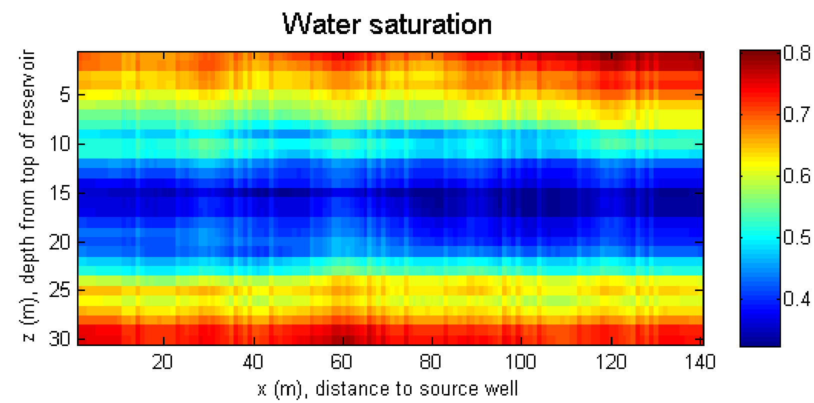
Parameters to be modified:

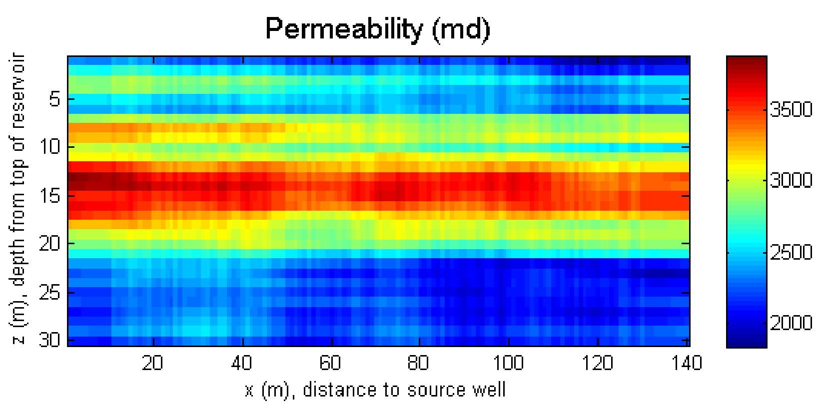
- Bulk modulus: dry → wet (using Gassmann or Hashin-Shtrikmann relations)
- Grain density → weighted average of grain and water densities
- Porosity: → porosity * oil saturation
- Permeability → oil relative permeability

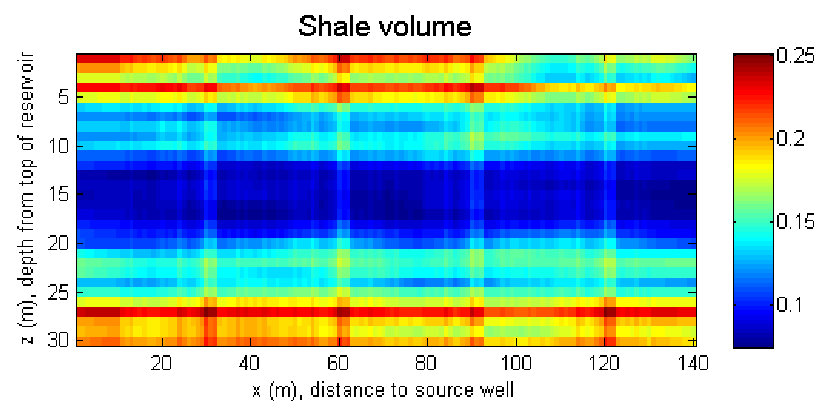
Geological model

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

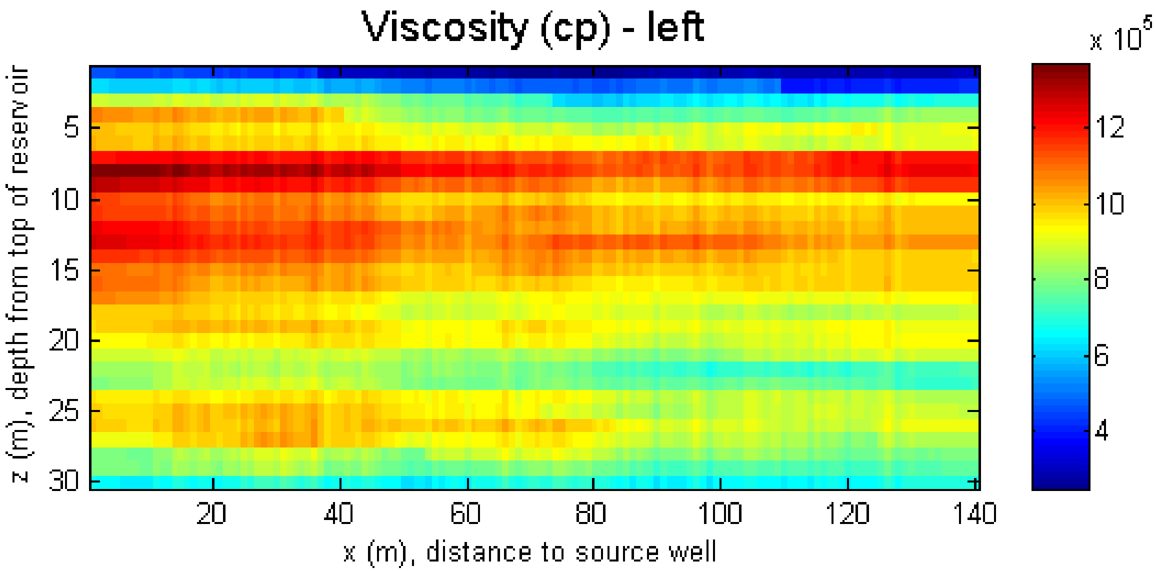


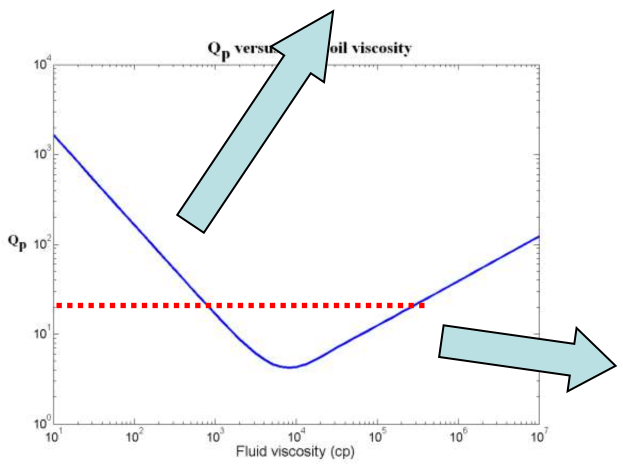


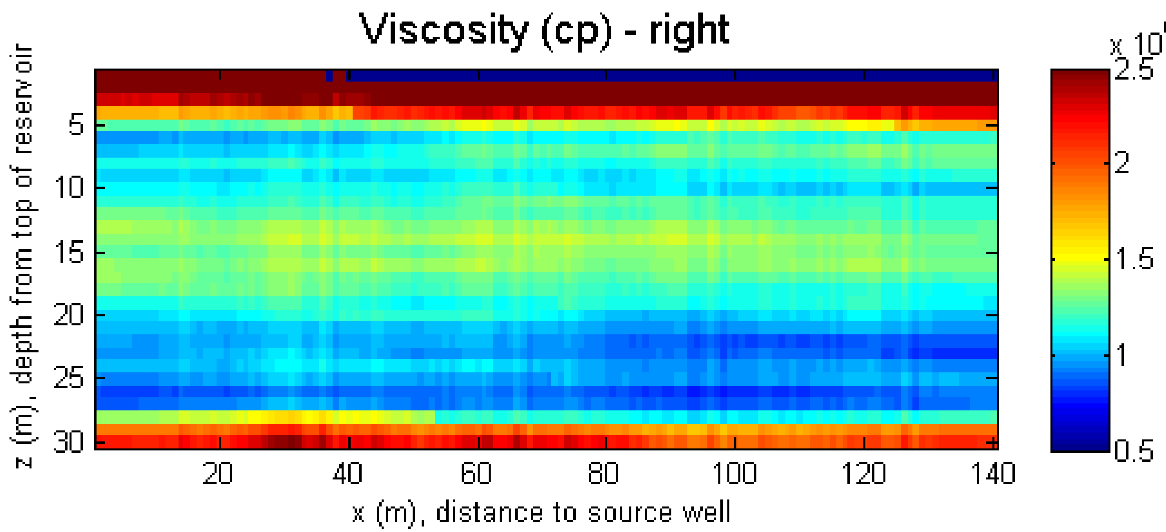




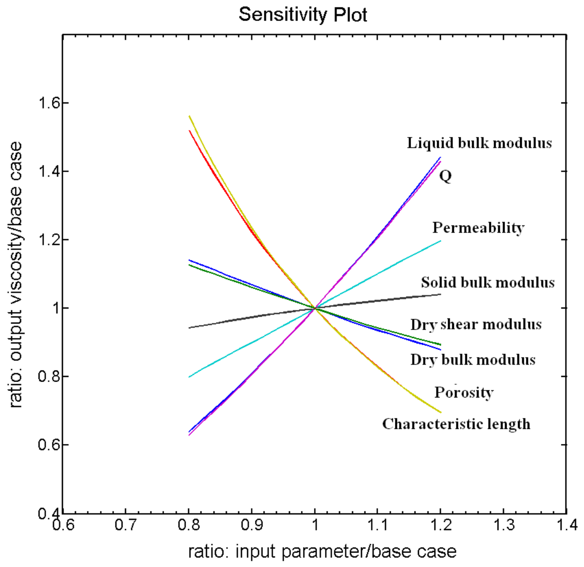
Viscosity: ambiguity

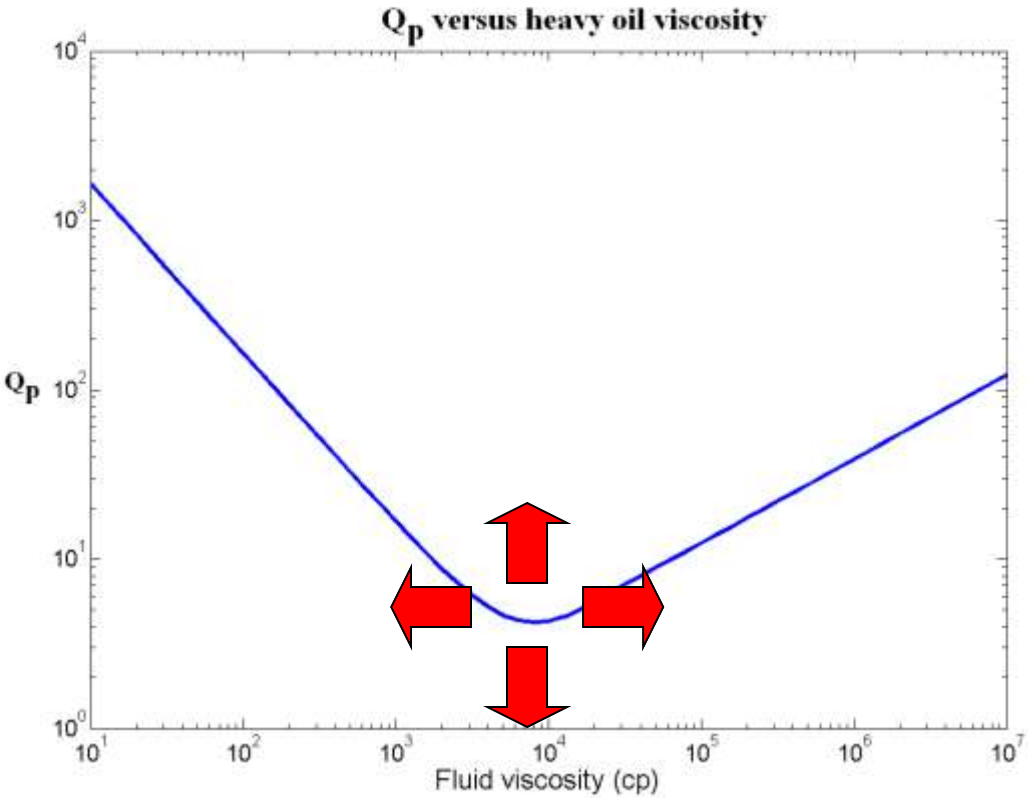






Viscosity: uncertainty





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.

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- Schlumberger's RTC (Calgary) for providing technical and financial support.

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