Predicting oil sands viscosity from well logs using an industry provided dataset

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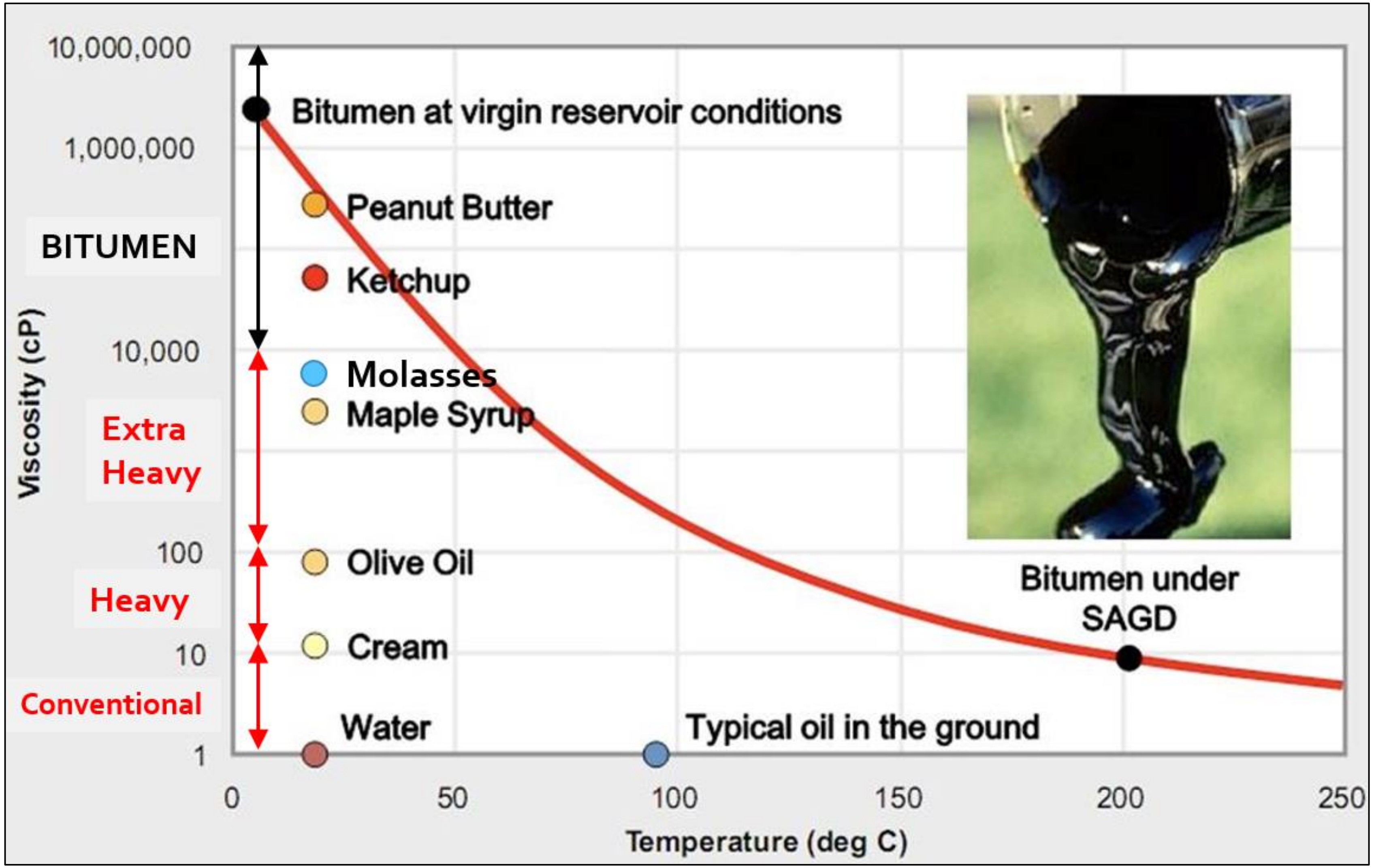
Presentation Outline

1. Brief introduction to viscosity
2. Theory of multi-attribute analysis
3. Athabasca North viscosity predictions
4. Athabasca South viscosity predictions
5. Conclusions
6. Future work

Introduction – Viscosity

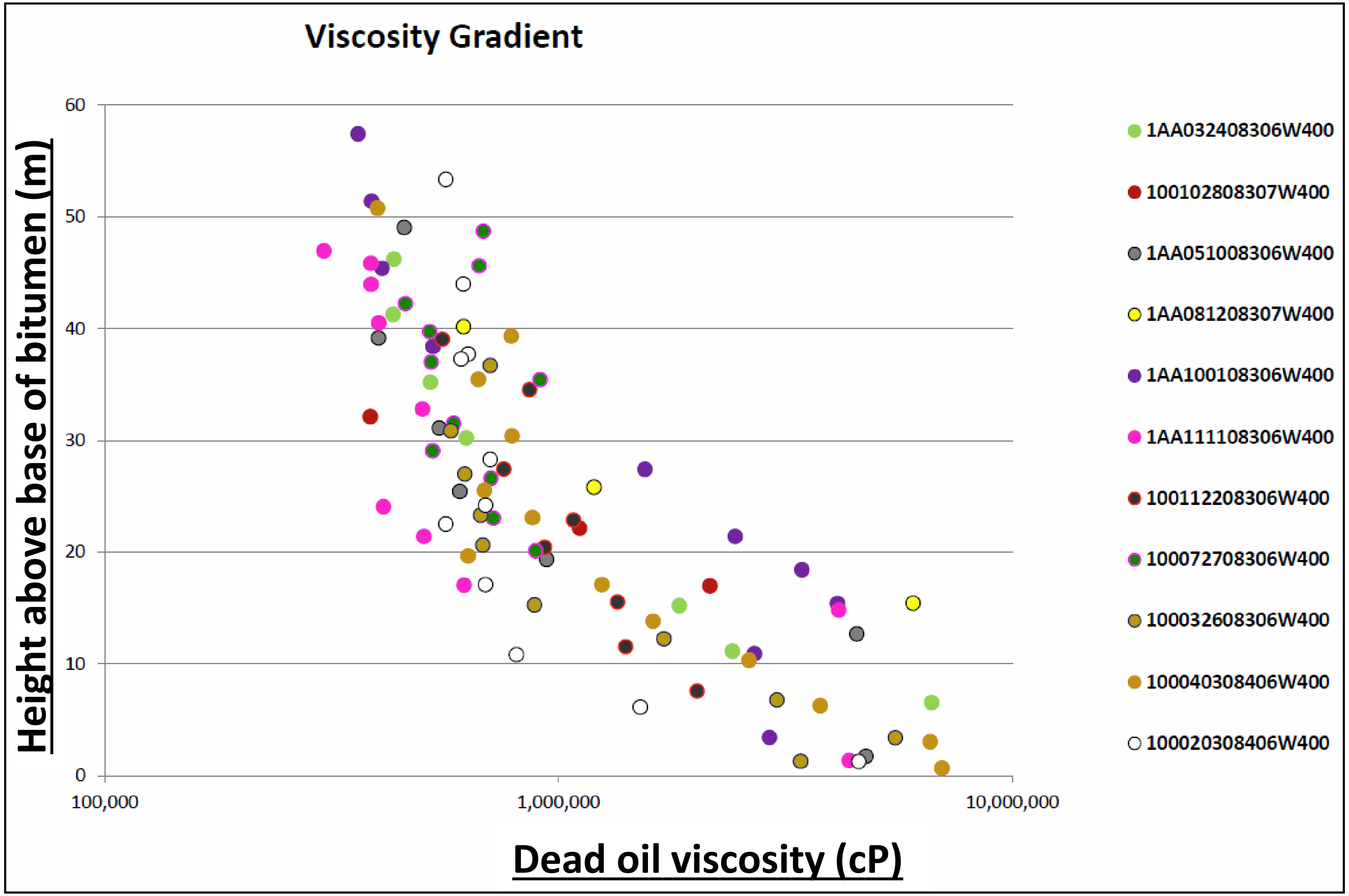
Oil grades based on their viscosities

- Increasing reservoir temperature decreases the viscosity



ConocoPhillips Oil Sands website

McMurray formation viscosity measurements



- Viscosity tends to increase with reservoir depth

- Located about 10km south of the study area

ConocoPhillips AER Report (2015)

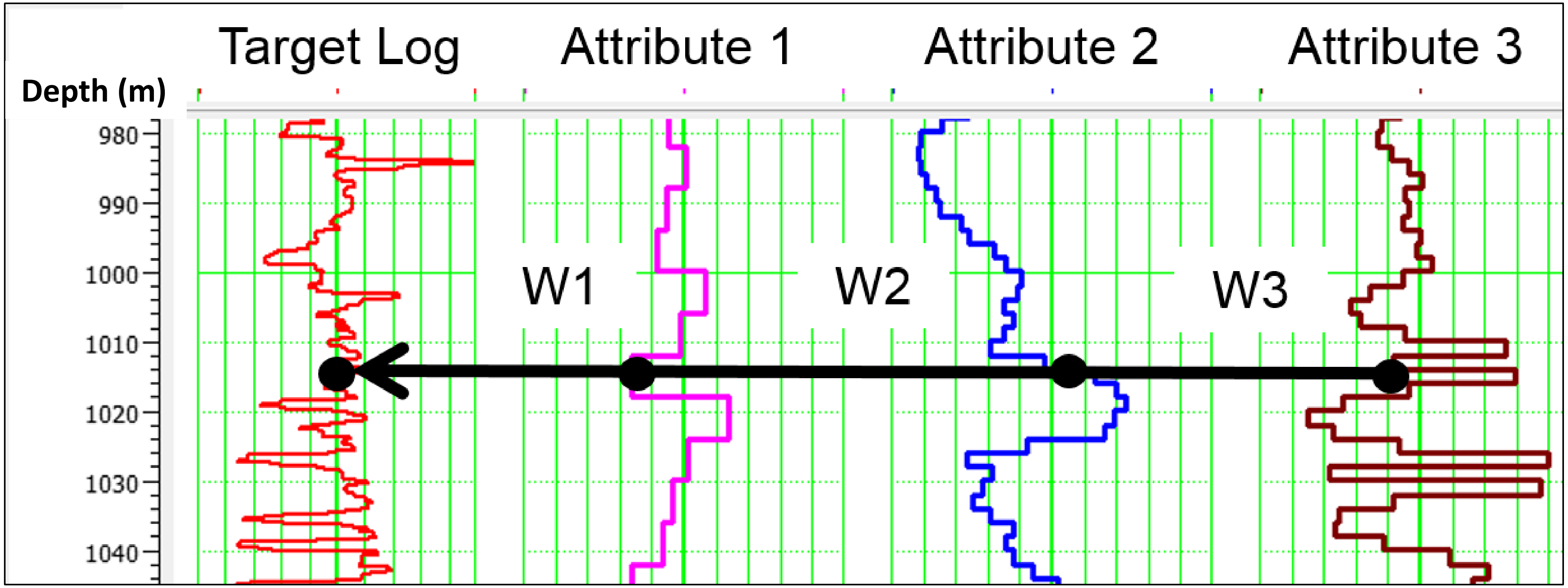
Why do we care about viscosity?

- *"Viscosity is the key controlling heavy-oil production and, as we shall see, it also has a strong influence on seismic properties."* (Han & Liu & Batzle, 2008)
- It is used as a main criterion in determining the optimum recovery method.

Theory of multi-attribute-analysis

Multi-attribute analysis

- At each time sample, the target log is modeled as a linear combination of several attributes.



Hampson-Russell Emerge™ course notes

Example: Predicting Viscosity using 3 attributes

$$V(z) = w_0 + w_1 D(z) + w_2 G(z) + w_3 R(z)$$

where: *V(z)* = Viscosity (cP)
D(z) = Bulk density (kg/m³)
G(z) = Gamma ray (API units)
R(z) = Resistivity (Ohm*m)

D, G, and R were chosen arbitrarily here

In matrix form:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = \begin{bmatrix} 1 & D_1 & G_1 & R_1 \\ 1 & D_2 & G_2 & R_2 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & D_N & G_N & R_N \end{bmatrix} \begin{bmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

Or more compactly as: $\boldsymbol{V} = A\boldsymbol{W}$

The regression coefficients can be solved for using least-squares: $\boldsymbol{W} = [A^T A]^{-1} A^T \boldsymbol{V}$

What are the best attributes to use?

Goal is to minimize the **prediction error:**

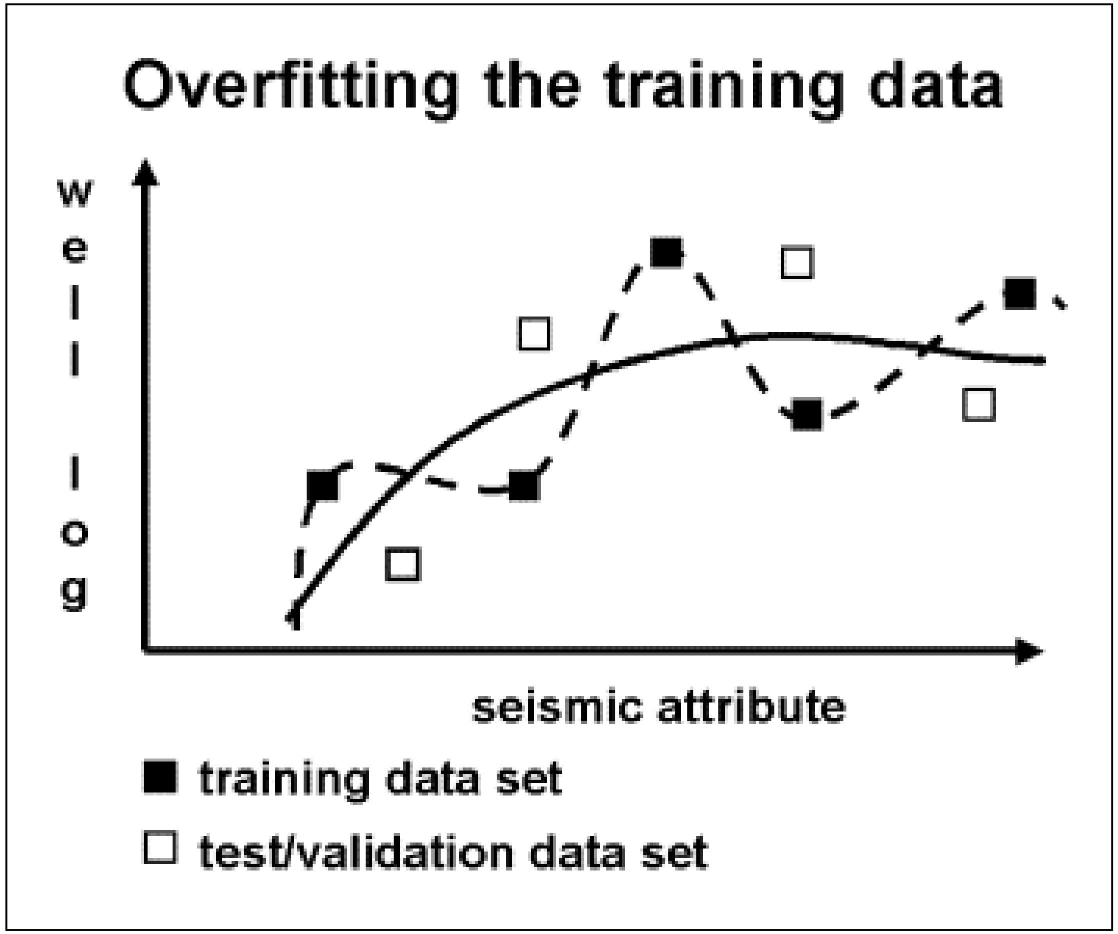
$$PE = \sqrt{\frac{\sum_{i=1}^{N}(V_{True,i} - V_{Predicted,i})^2}{N}}$$

Step-wise regression:

1. Find the ***single*** best attribute, call it A1
2. Find the best ***pair*** of attributes *including* A1
3. Find the best ***triplet*** of attributes *including* A1 and A2
4. Carry on as long as desired

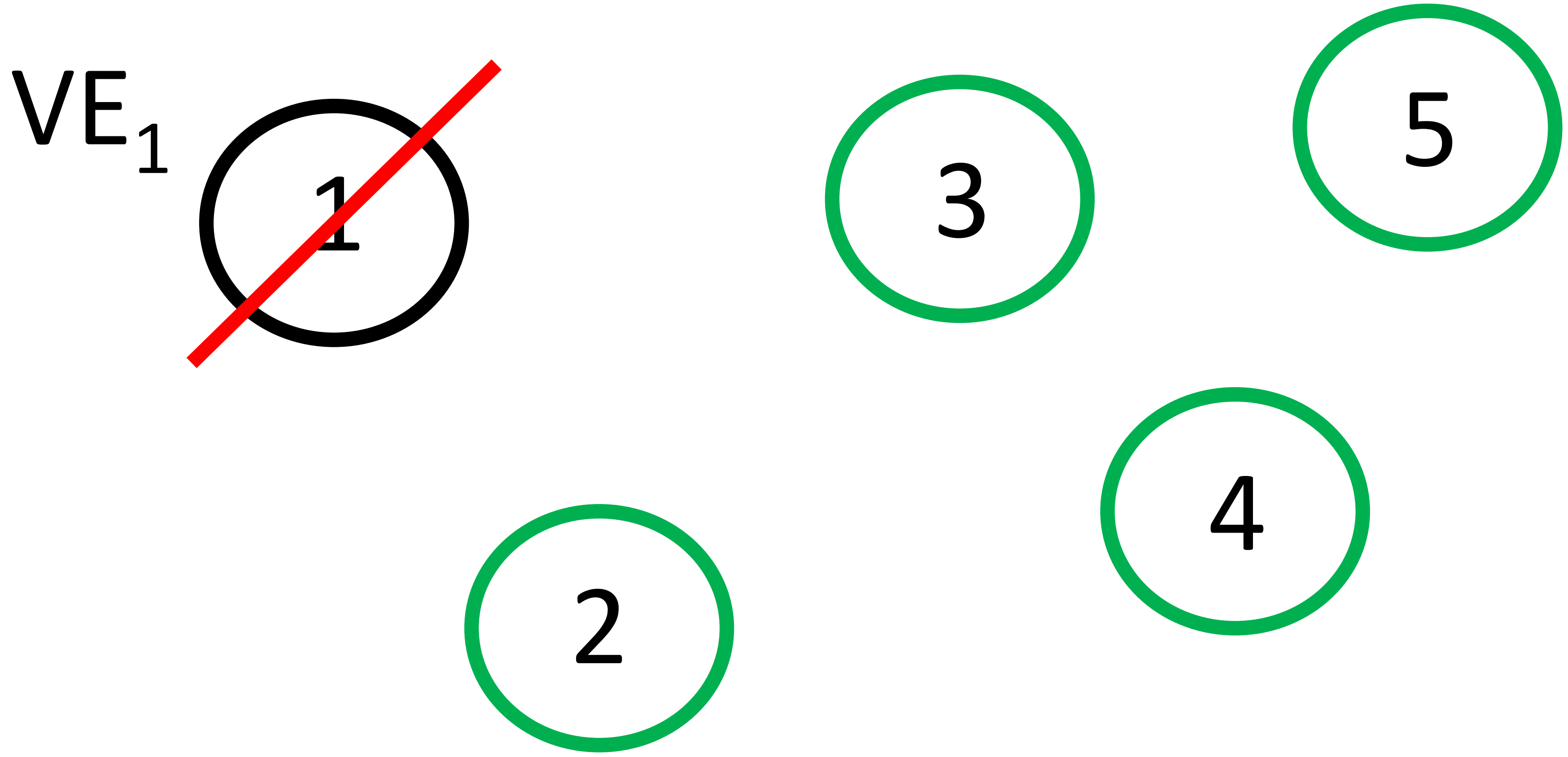
When do we stop adding attributes? (why would we want to?)

- Adding attributes is similar to fitting a curve through a set of points, using a polynomial of increasing order
- A higher order polynomial can "***over-fit***" the data
- Emerge™ uses **Cross Validation** to determine when to stop adding attributes

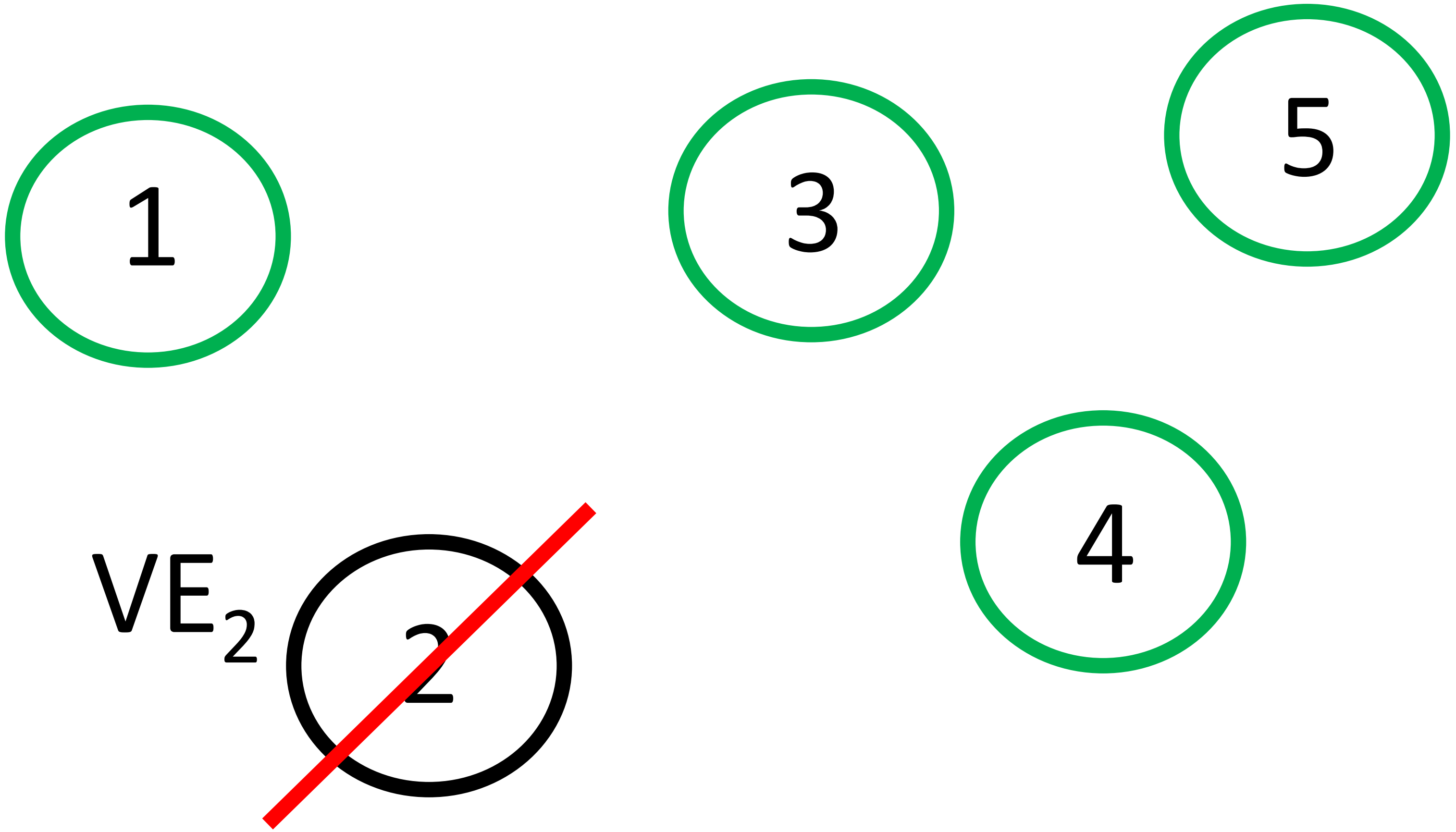


Hampson-Russell Emerge™ course notes

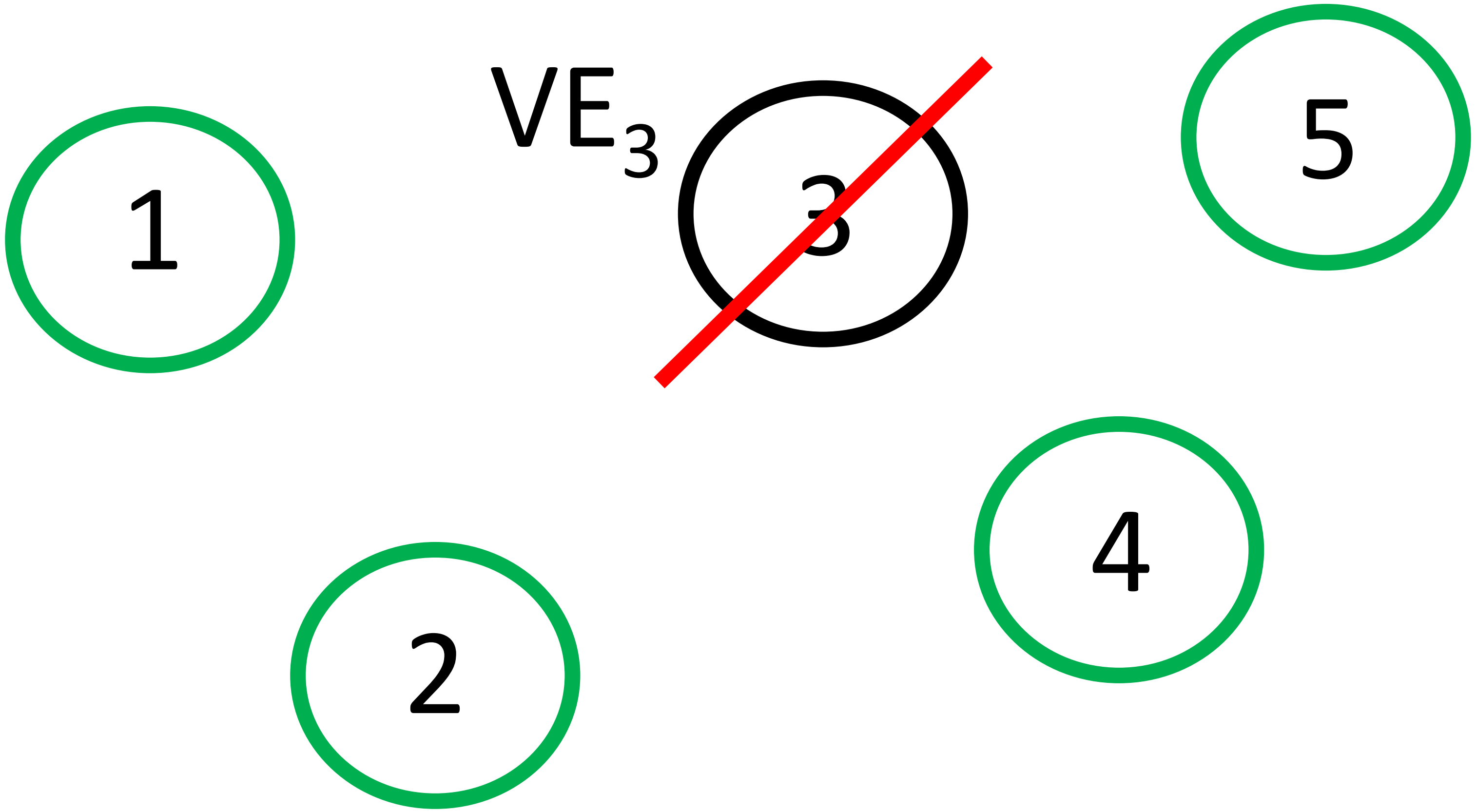
Cross Validation (5 Well example)



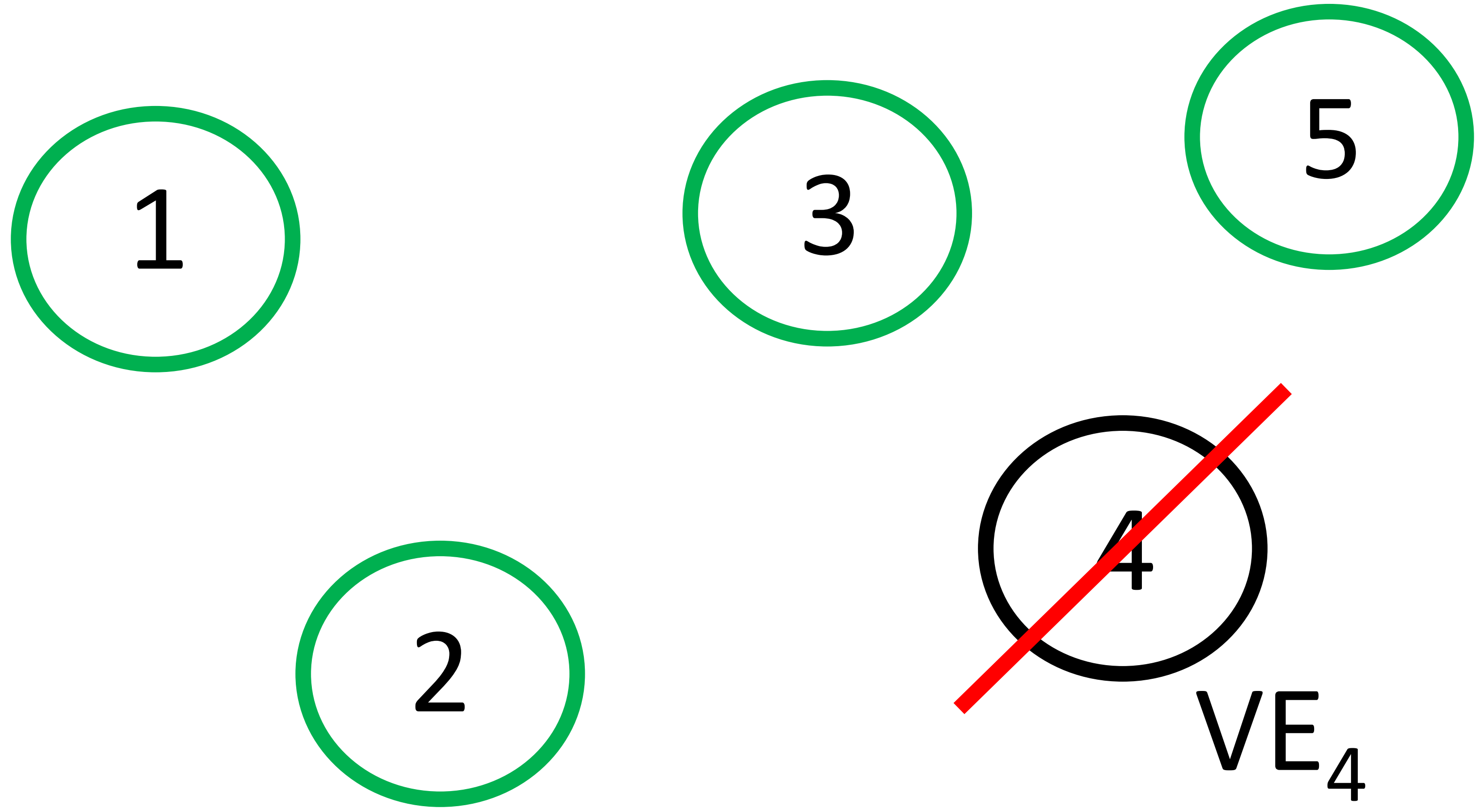
Cross Validation (5 Well example)



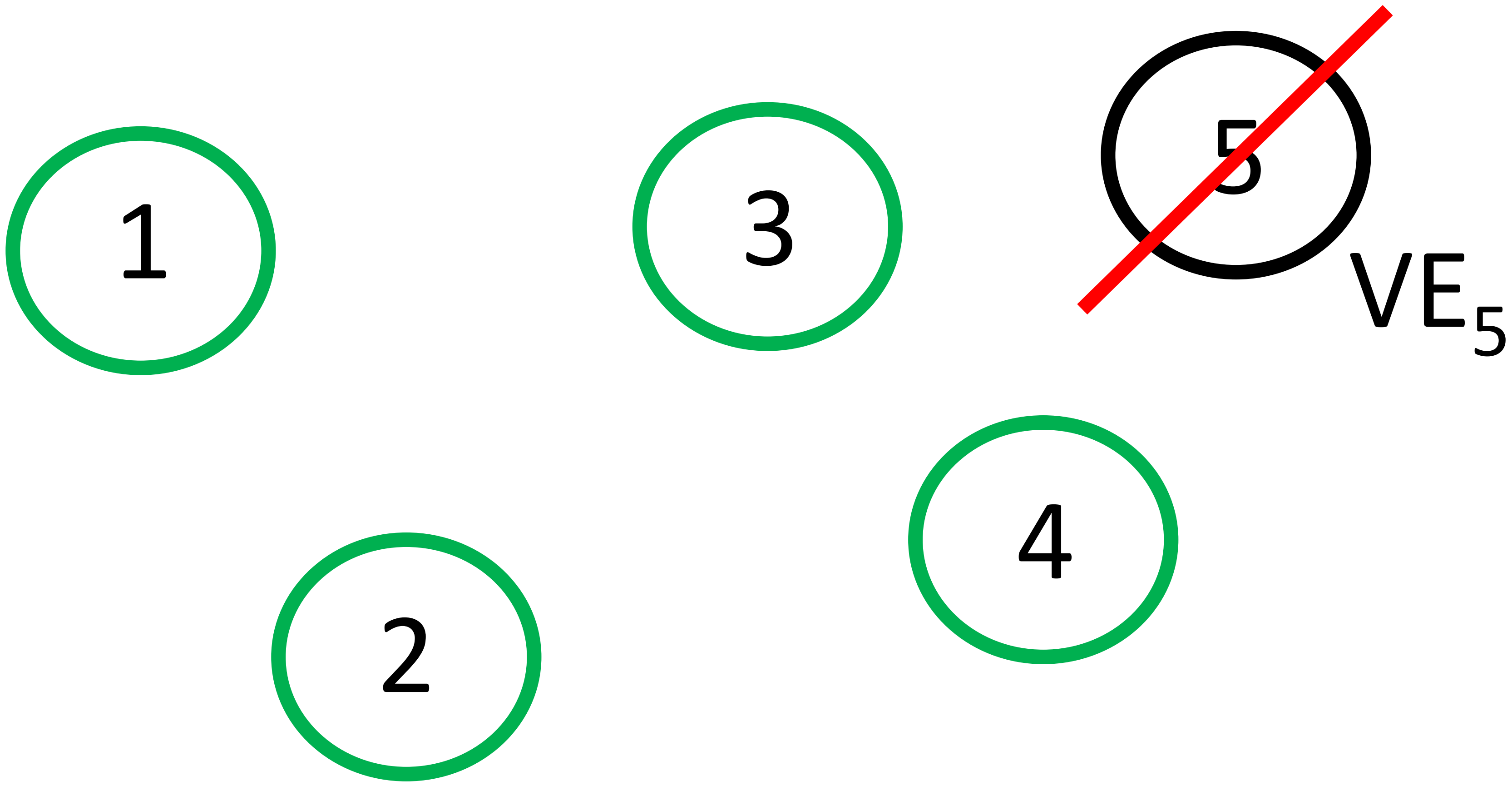
Cross Validation (5 Well example)



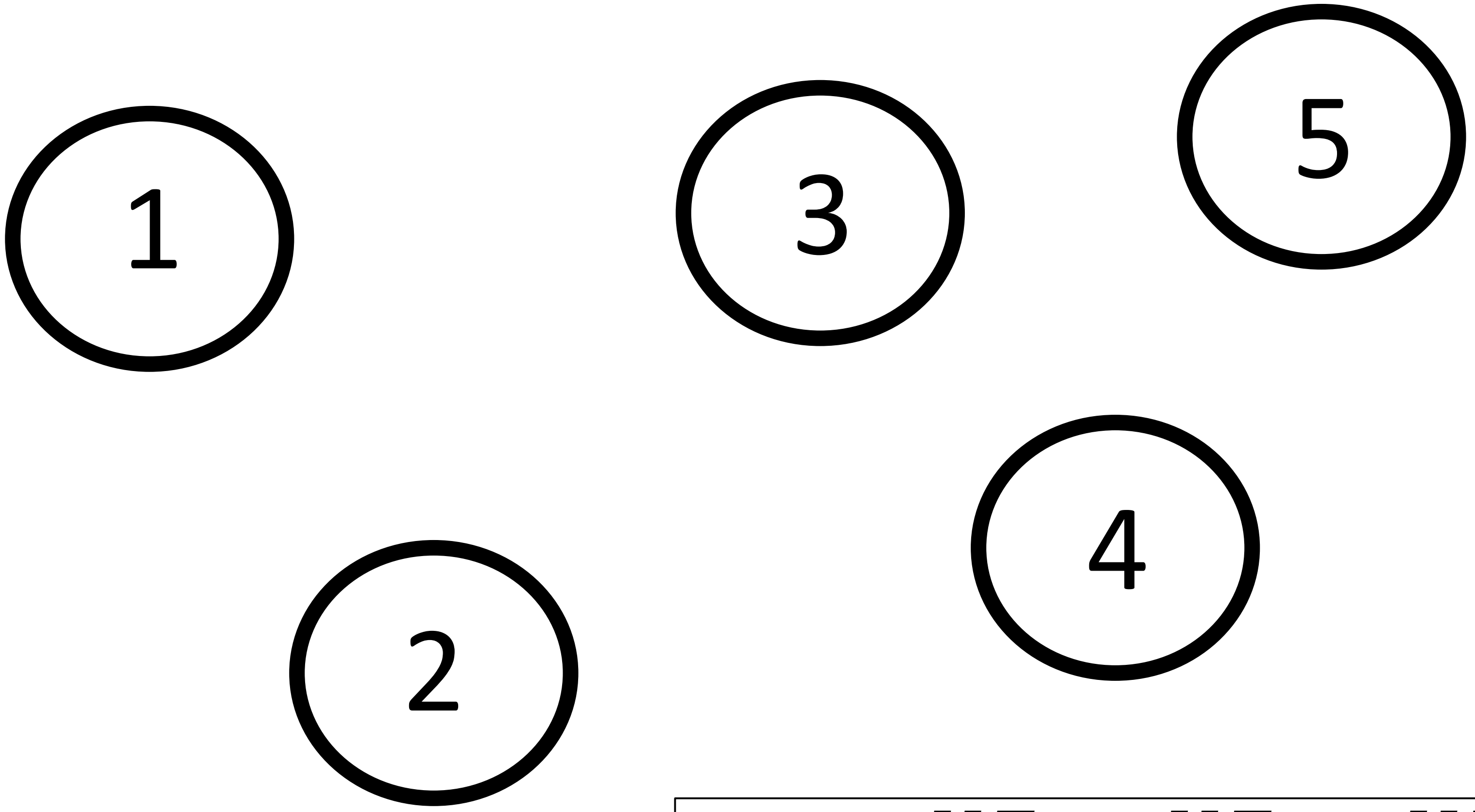
Cross Validation (5 Well example)



Cross Validation (5 Well example)



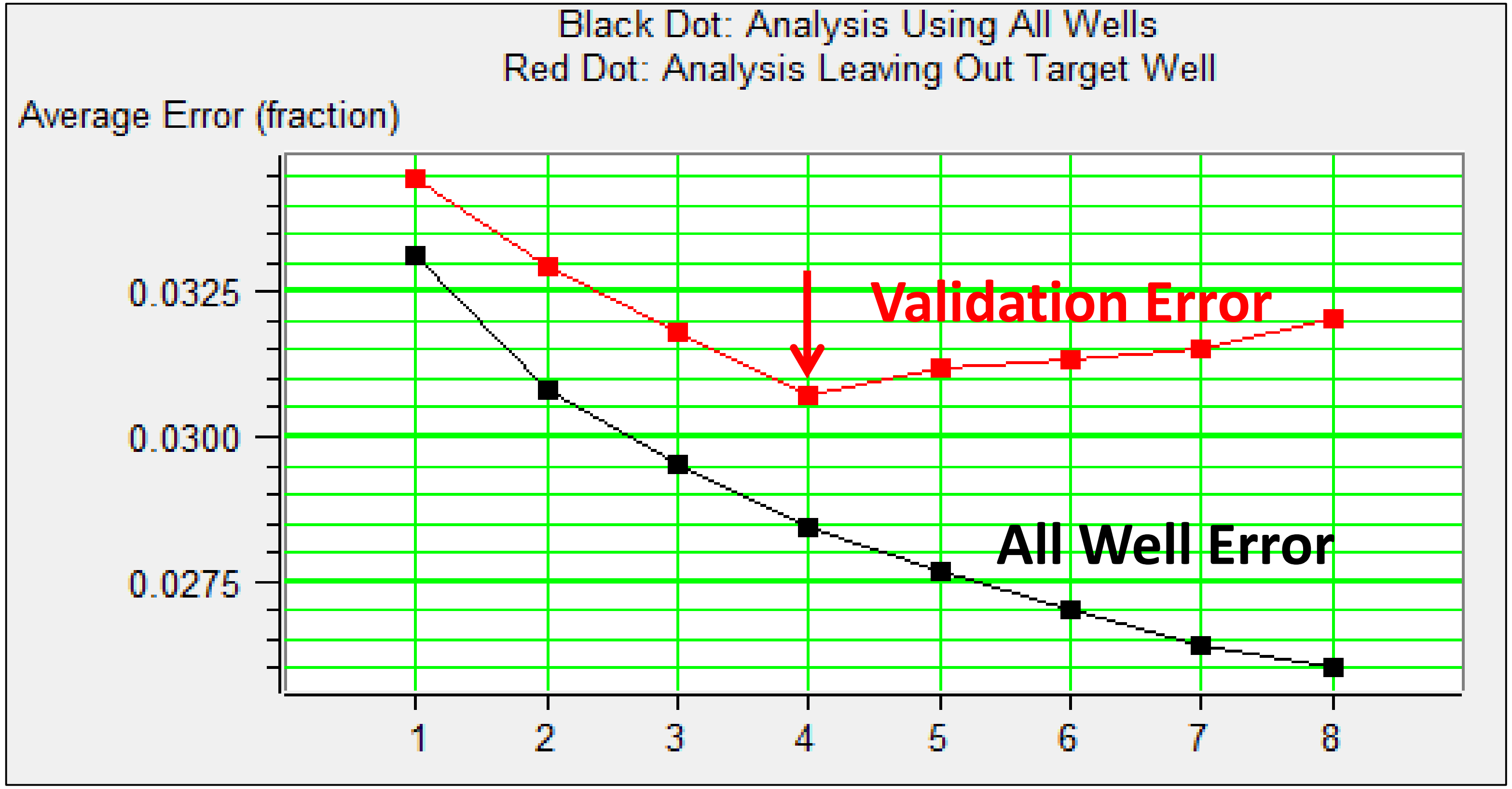
Cross Validation (5 Well example)



$$VE = \frac{VE_1 + VE_2 + VE_3 + VE_4 + VE_5}{5}$$

Validation Error Plot

- Can plot the validation error as a function of number of attributes
- Here, anything more than 4 attributes *over-trains* the data

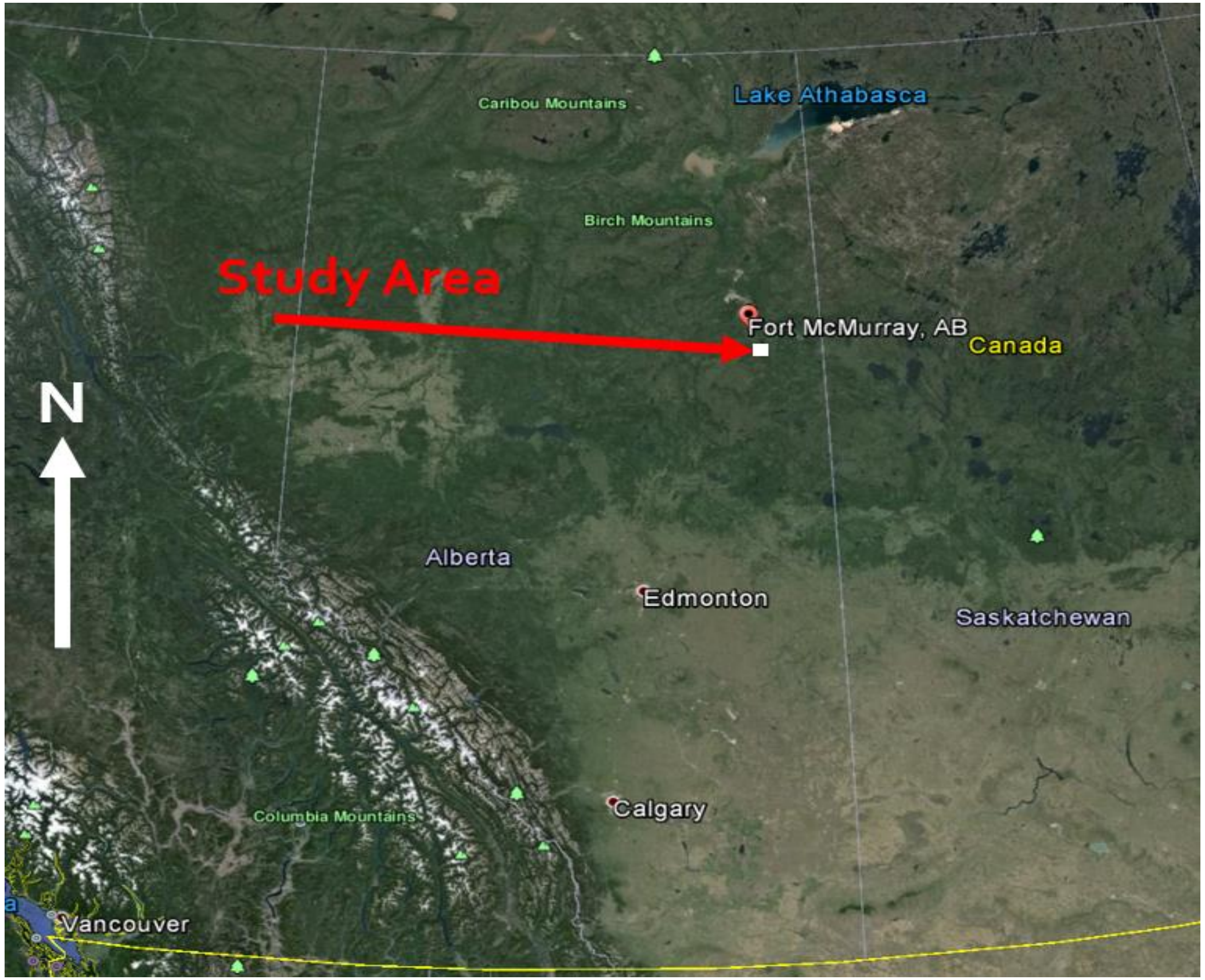


Number of attributes

Athabasca North Viscosity Predictions

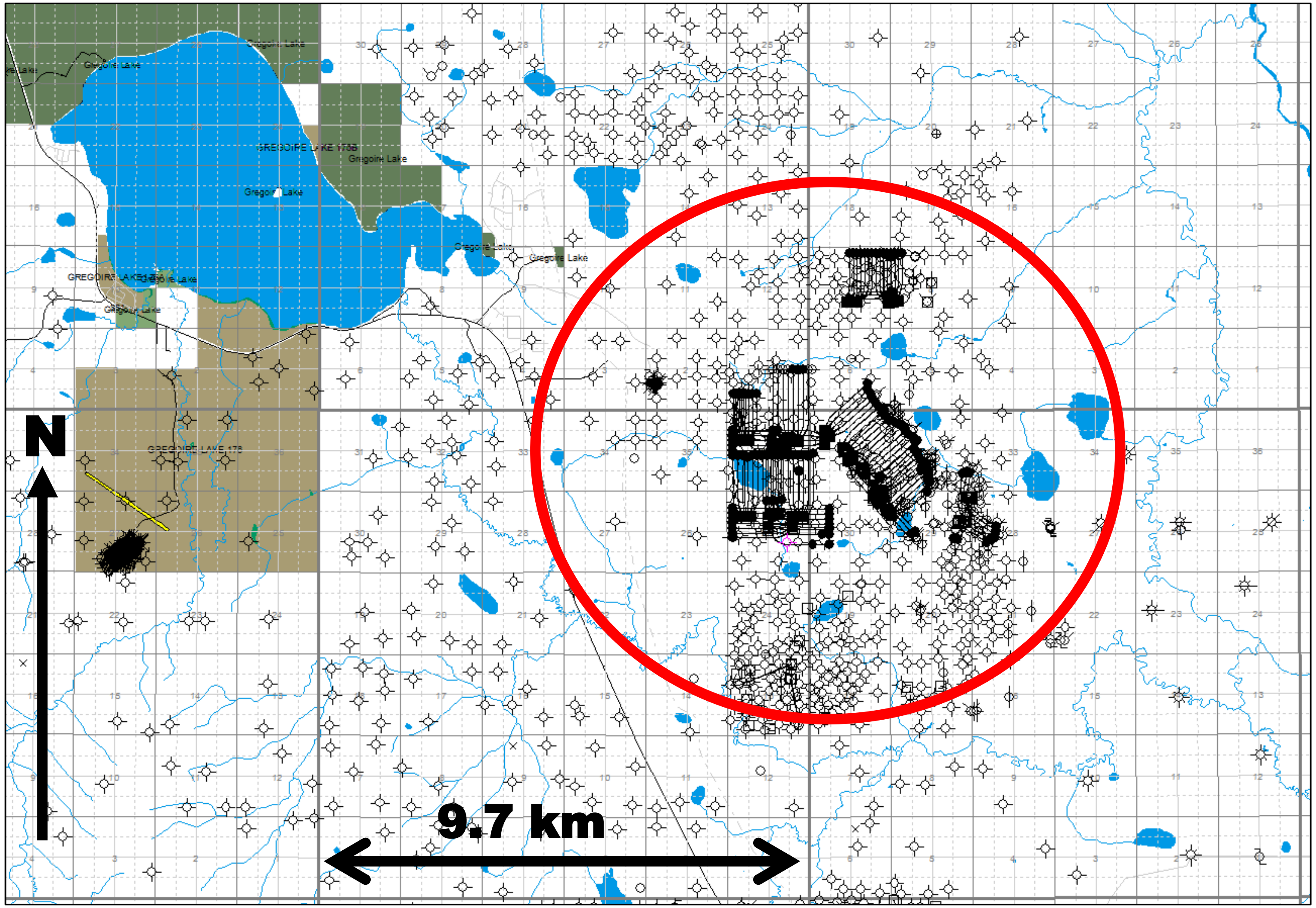
Project Location

Located about 40km SE of Fort McMurray



Google Earth®

Athabasca North Study Area

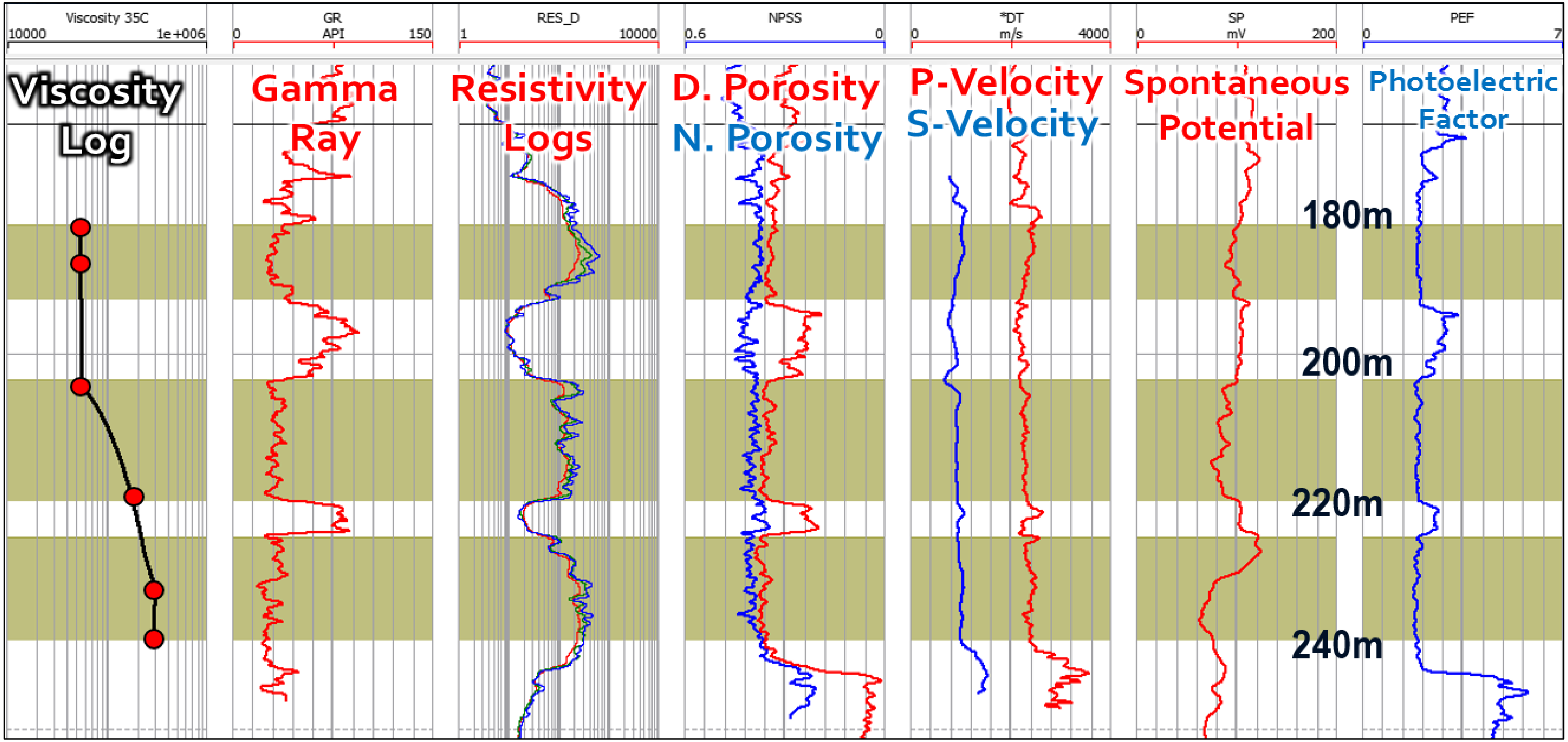


geoSCOUT™

- **25** wells with multiple viscosity measurements and all logs INCLUDING shear sonic
- **45** TOTAL wells in this area with viscosity measurements
- Viscosity range from **35,000 cP to 802,000 cP** *(Measured at 35⁰C)*

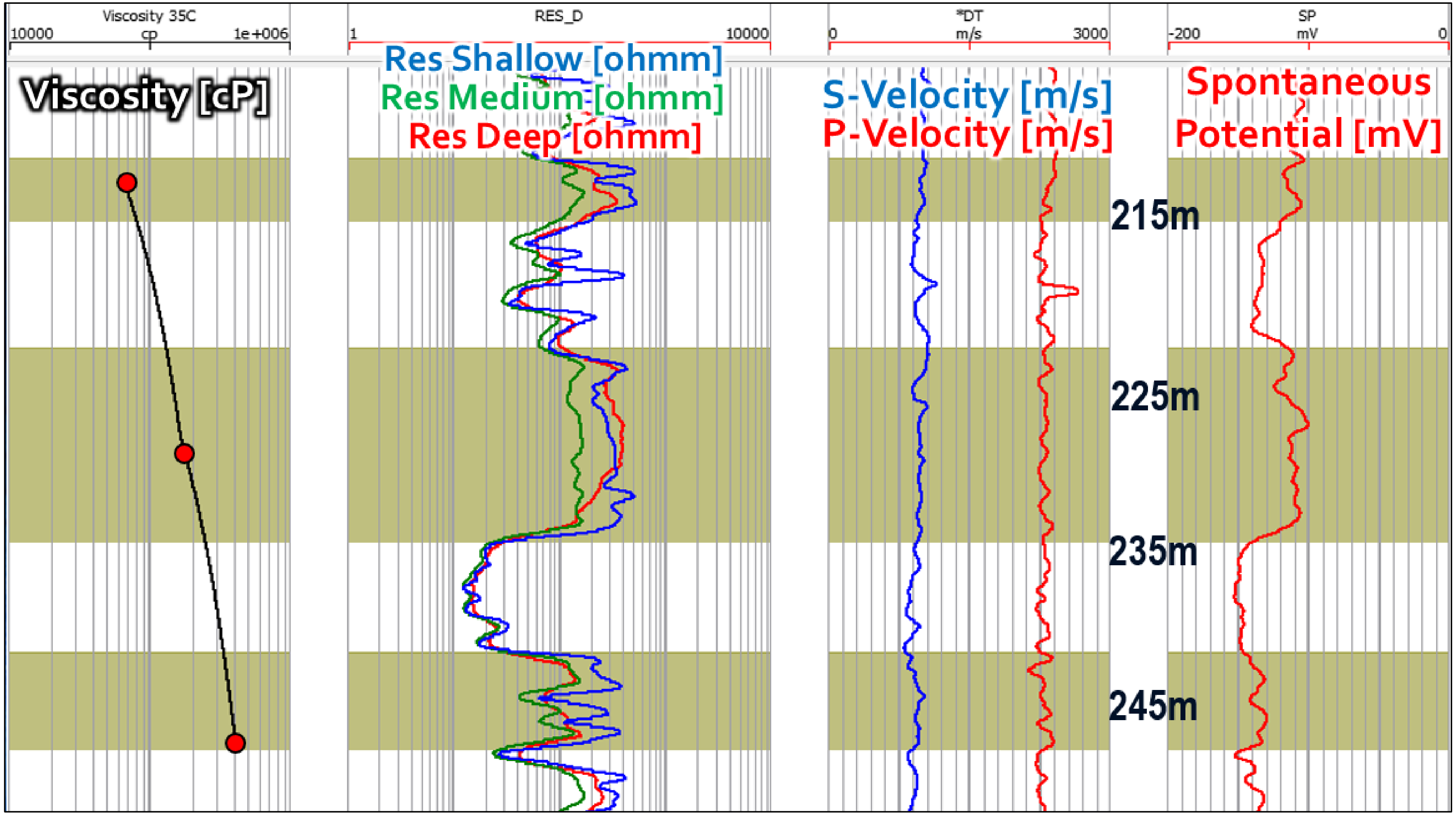
Training the relationship

- Mud barriers must be avoided when defining training intervals



Weird log behavior in Athabasca North

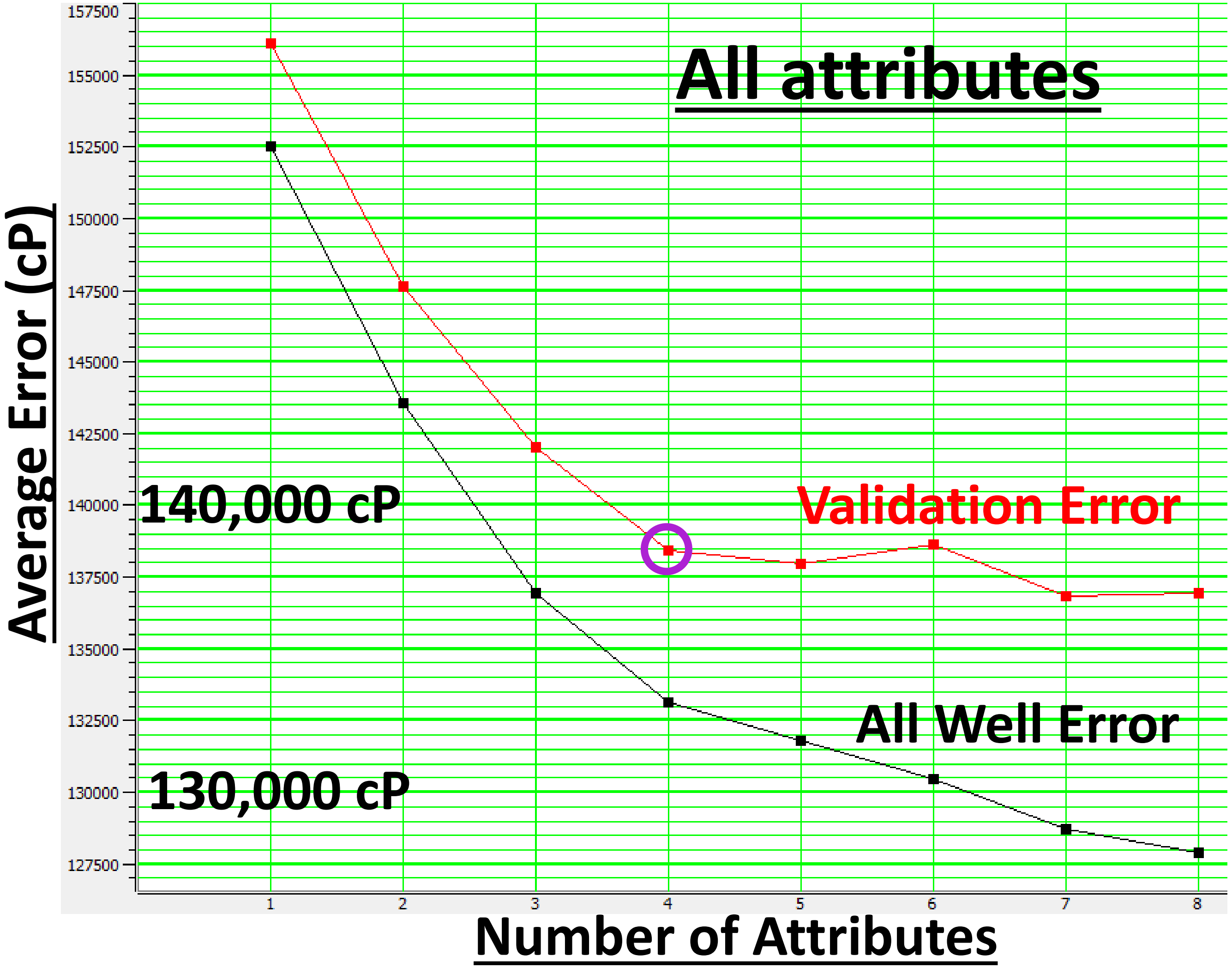
Resistivity, shear sonic, and SP logs are questionable



Athabasca North Training Results (all log attributes)

- Optimum viscosity prediction is found using **4 attributes**

Attribute	Units
1. 1 / (P-wave sonic)	1/[us/m]
2. (Density Porosity)^2	[%]^2
3. ln(|SP|)	[none]
4. (Neutron Porosity)^2	[%]^2



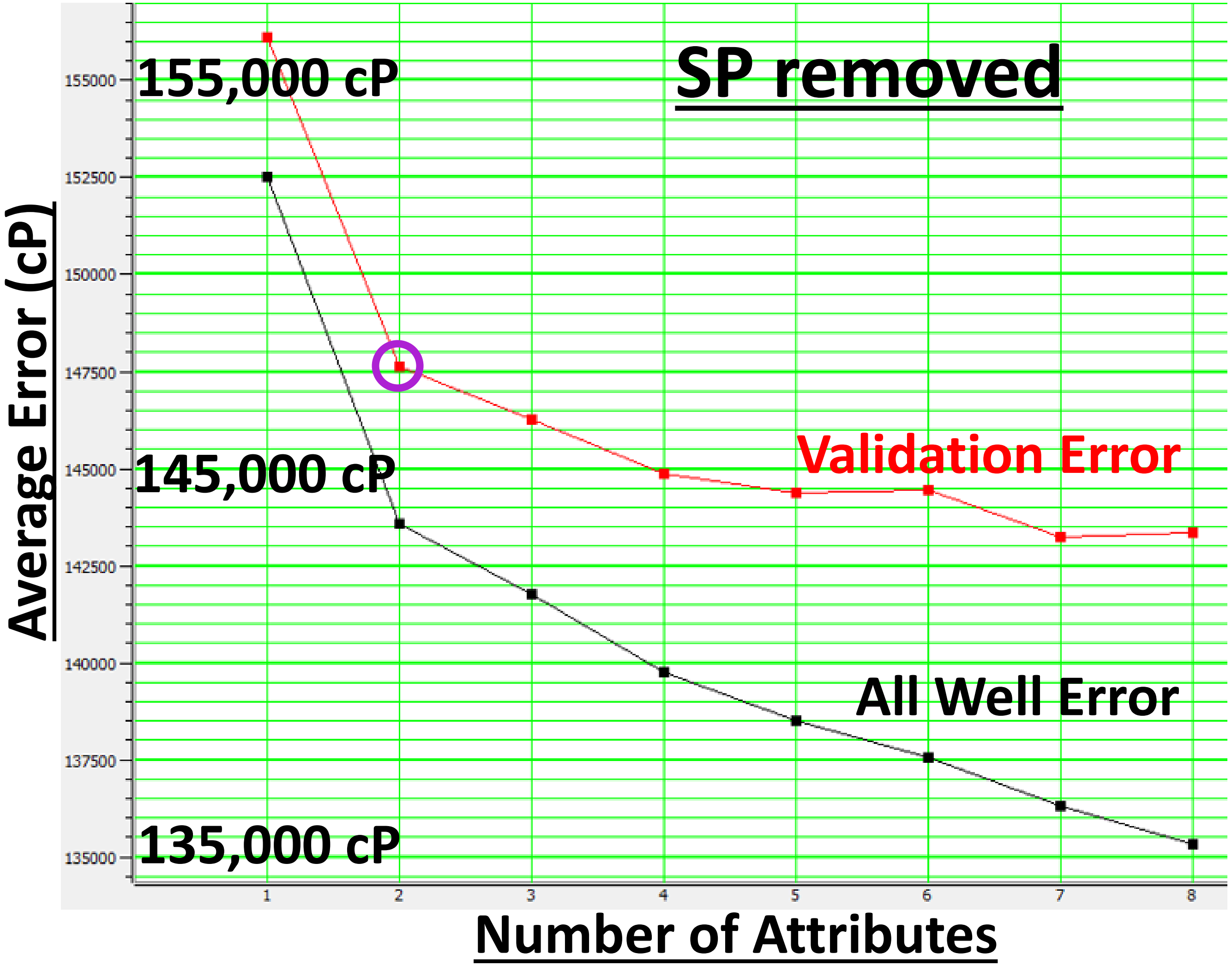
Athabasca North Training Results (SP removed)

- Optimum viscosity prediction is found using **2 to 4 attributes**

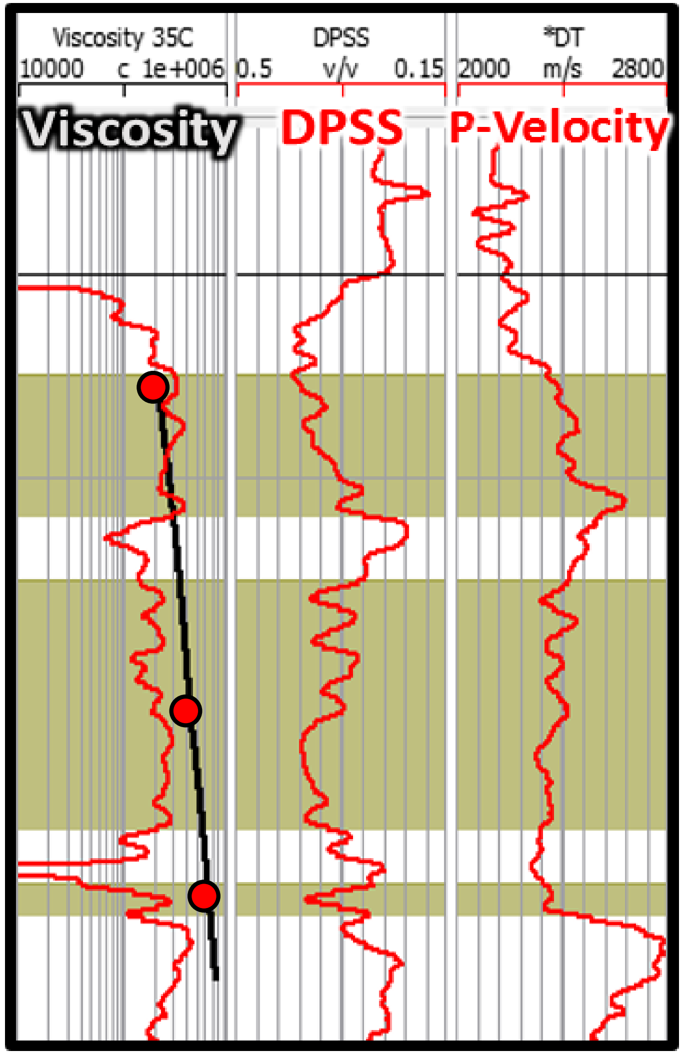
Attribute	**Units**
1. 1 / (P-wave sonic)	*1/[us/m]*
2. (Density Porosity)^2	*[%]^2*
3. (Neutron Porosity)^2	*[%]^2*
4. ln(Res Separation)	*[none]*

Viscosity prediction equation

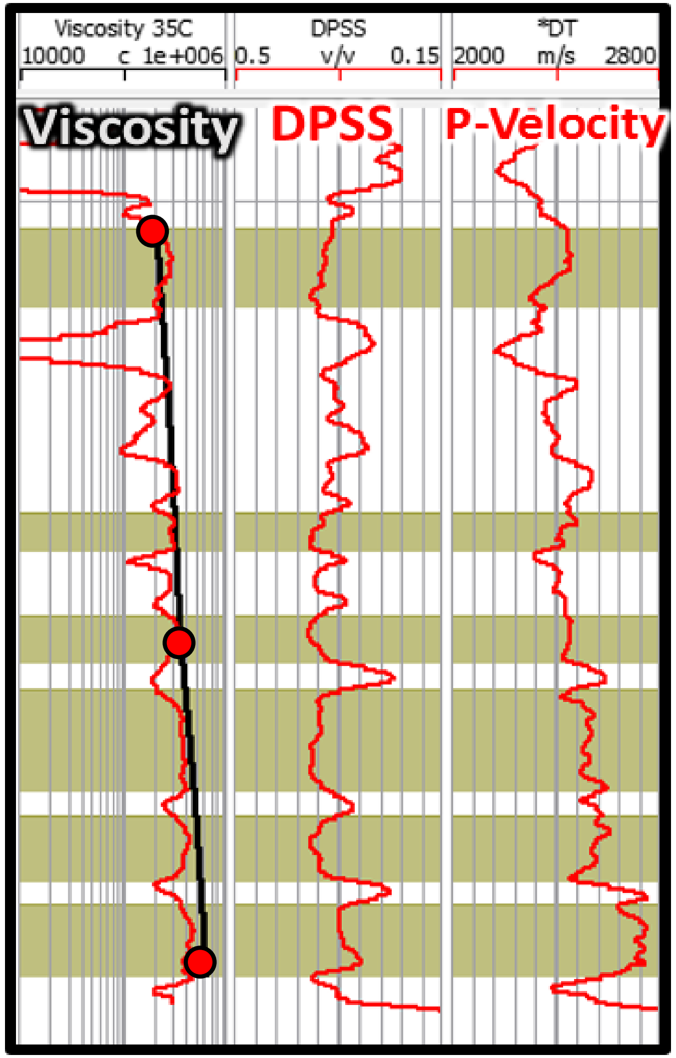
$$\eta = -2170000 + 851000000\left(\frac{1}{\boldsymbol{P - wave\ sonic}}\right) + 3200000(\boldsymbol{DPSS})^2$$



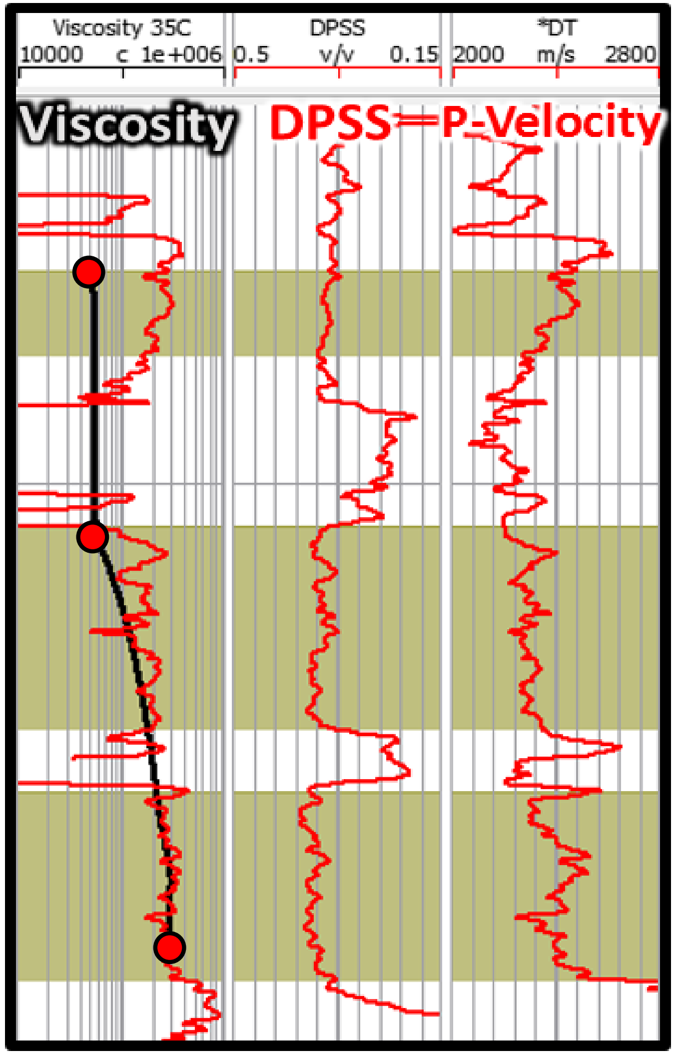
Viscosity Prediction (validation) results



Bad Well
Avg Error: 288,000 cP



Good Well
Avg Error: 95,000 cP

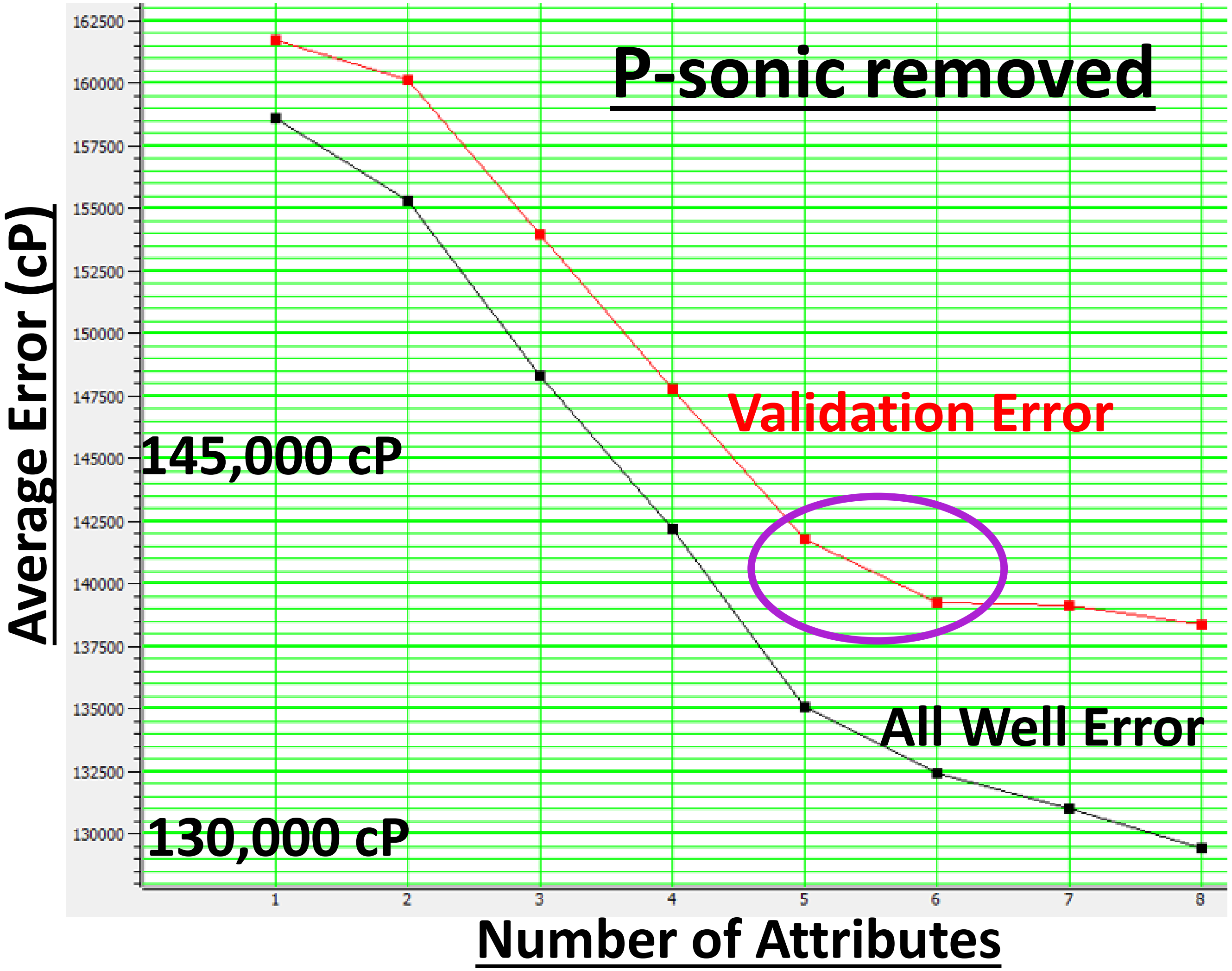


Average Well
Avg Error: 120,000 cP

Experiment – Remove the top attribute (P-wave Sonic)

Attribute	Units
1. ln(Water Saturation)	*[none]*
2. 1 / (S-wave sonic)	*1/[us/m]*
3. ln(S-P sonic diff.)	*[none]*
4. (Neutron Porosity)^2	*[%]^2*
5. ln(|SP|)	*[none]*

$$S_w = \sqrt{\frac{F R_w}{R_t}}$$



Athabasca South Viscosity Predictions

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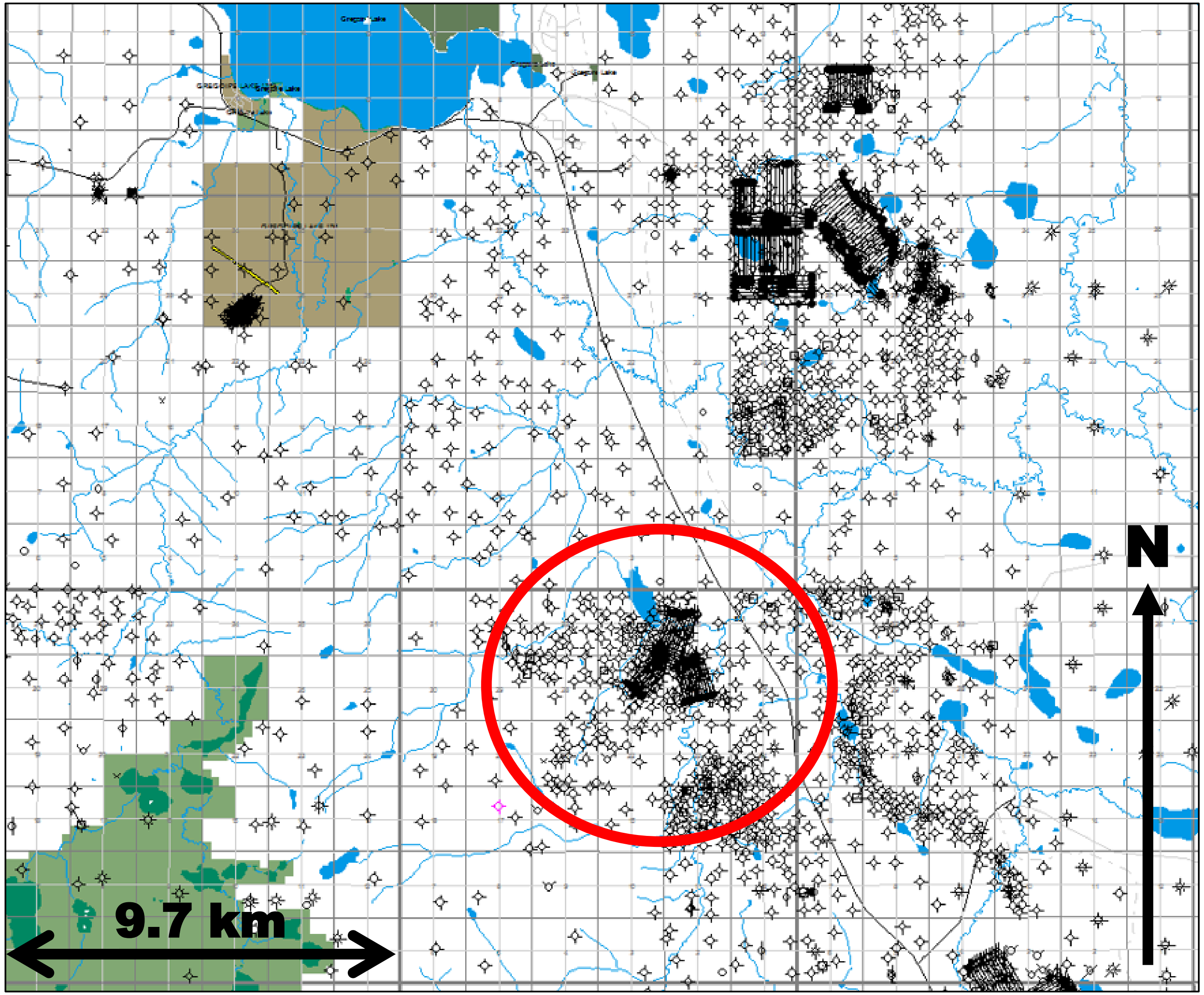
Athabasca South Study Area

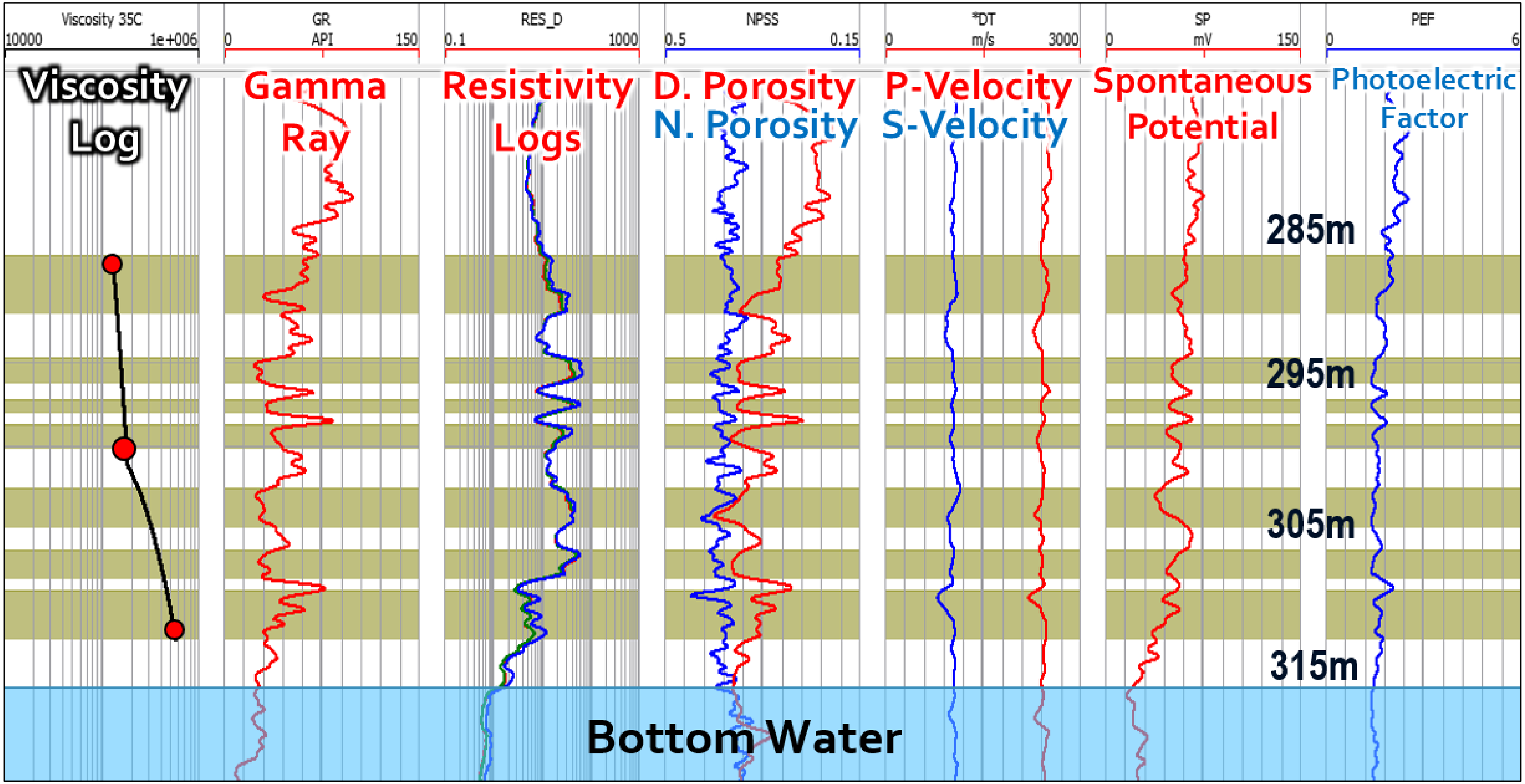


geoSCOUT™

- **40** **wells with multiple viscosity measurements and all logs INCLUDING shear sonic**
- **78** **TOTAL wells in this area with viscosity measurements**
- **Viscosity range from** **9,000 cP to 541,000 cP**
  (Measured at 35^{0}C)

Training the relationship

Resistivity logs more consistent than in Athabasca North



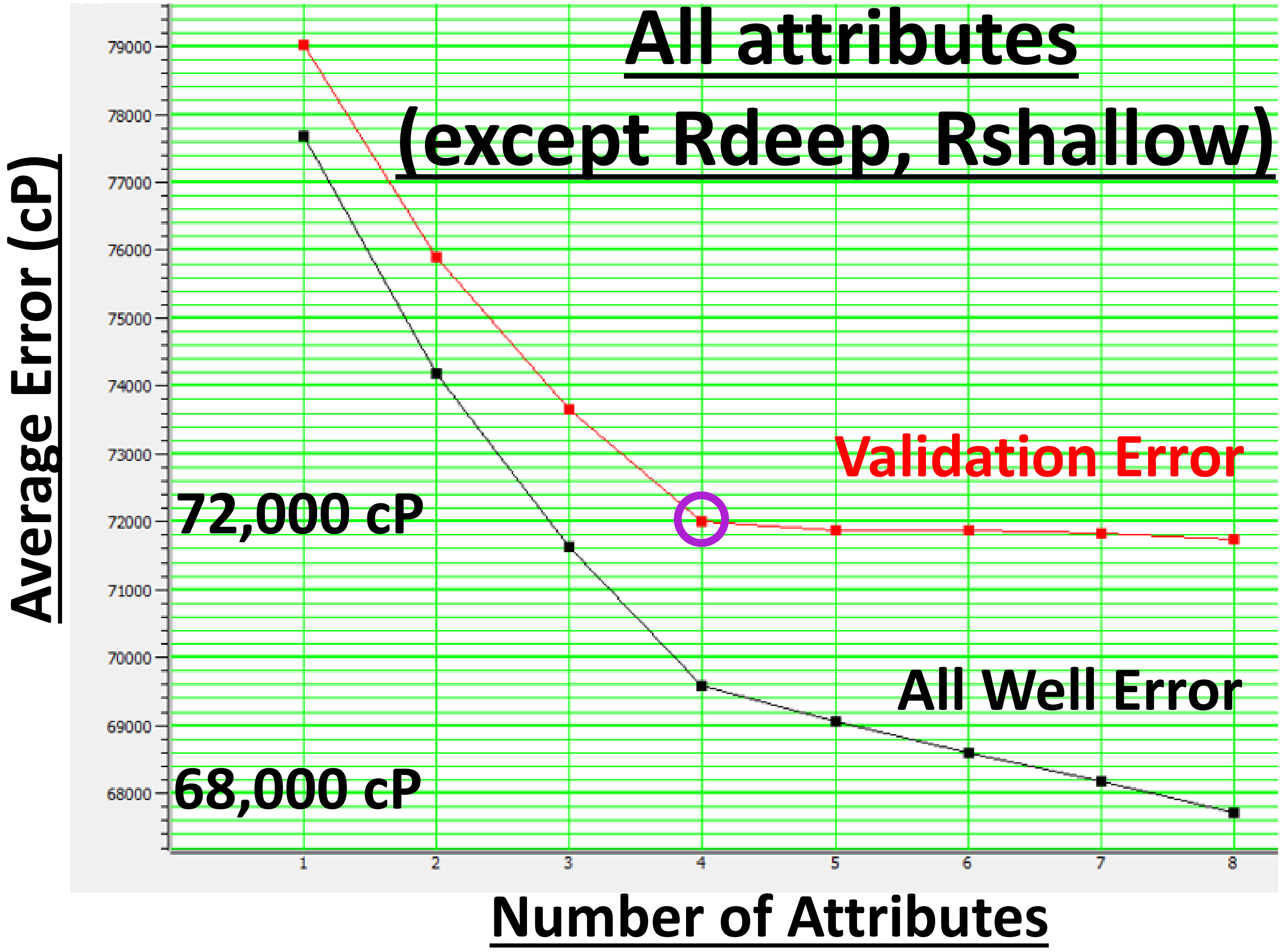
Athabasca South Training Results

- Optimum viscosity prediction is found using **4 attributes**

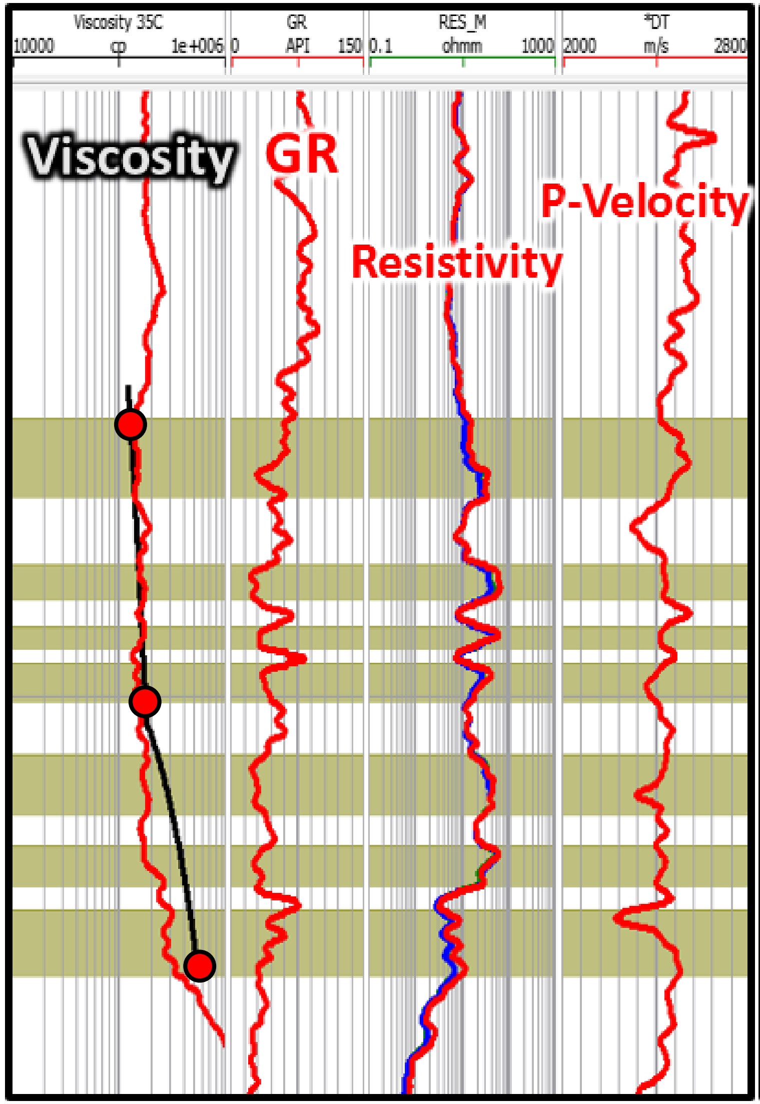
Attribute	Units
1. 1 / (ResMedium)	*1/[ohm-m]*
2. $(GammaRay)^{1/2}$	*$[API]^{1/2}$*
3. 1 / (P-wave sonic)	*1/[us/m]*
4. ln(Res Separation)	*[none]*

Viscosity prediction equation

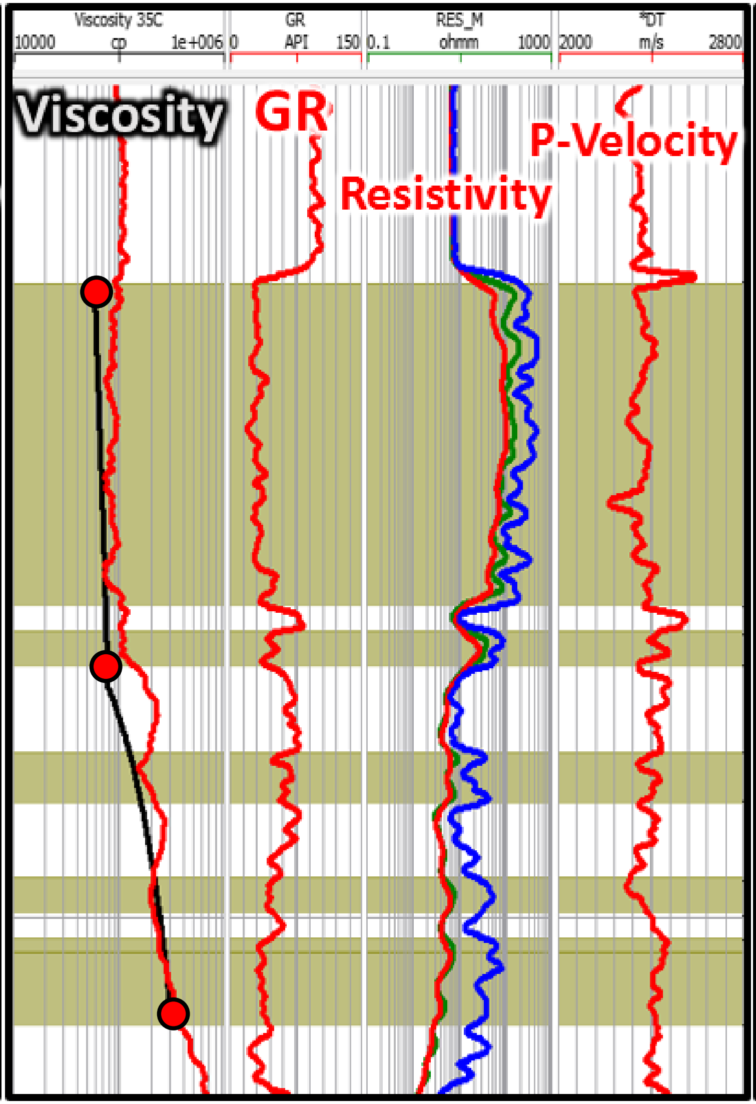
$$\eta = -96800 + 985000\left(\frac{1}{ResMedium}\right) - 31600\sqrt{GammaRay} + 176000000\left(\frac{1}{P-sonic}\right) - 10900 ln(|ResSeparation|)$$



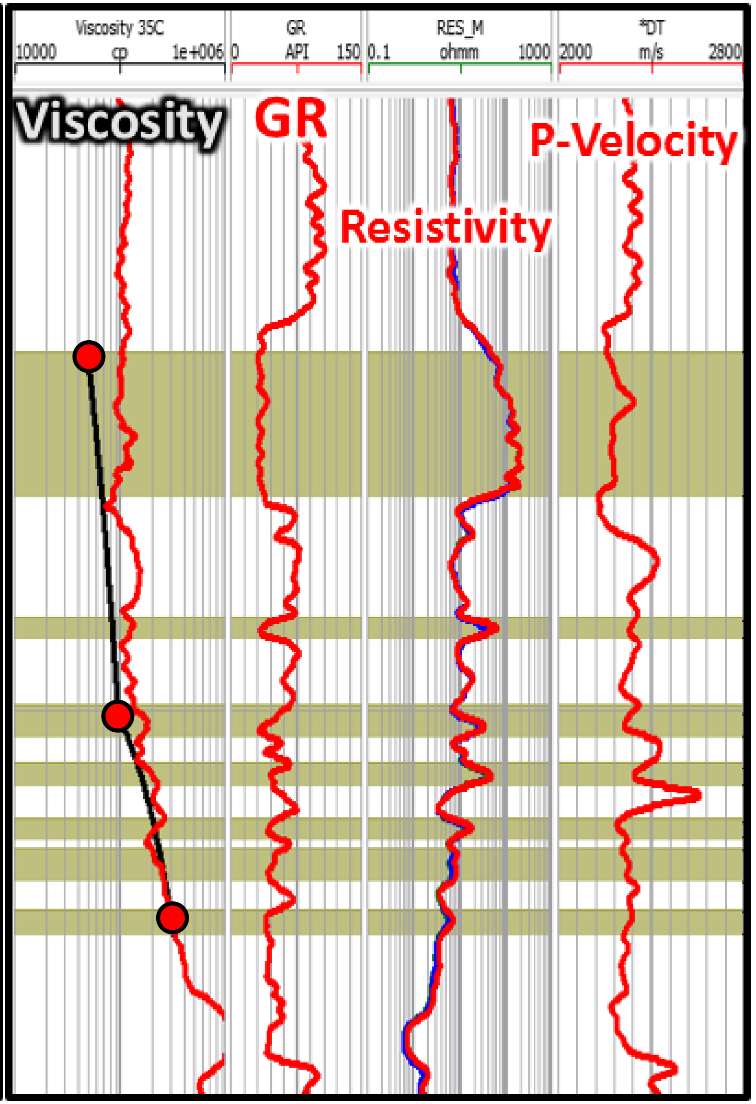
Athabasca South Viscosity Prediction (validation) results



Top good, base very bad



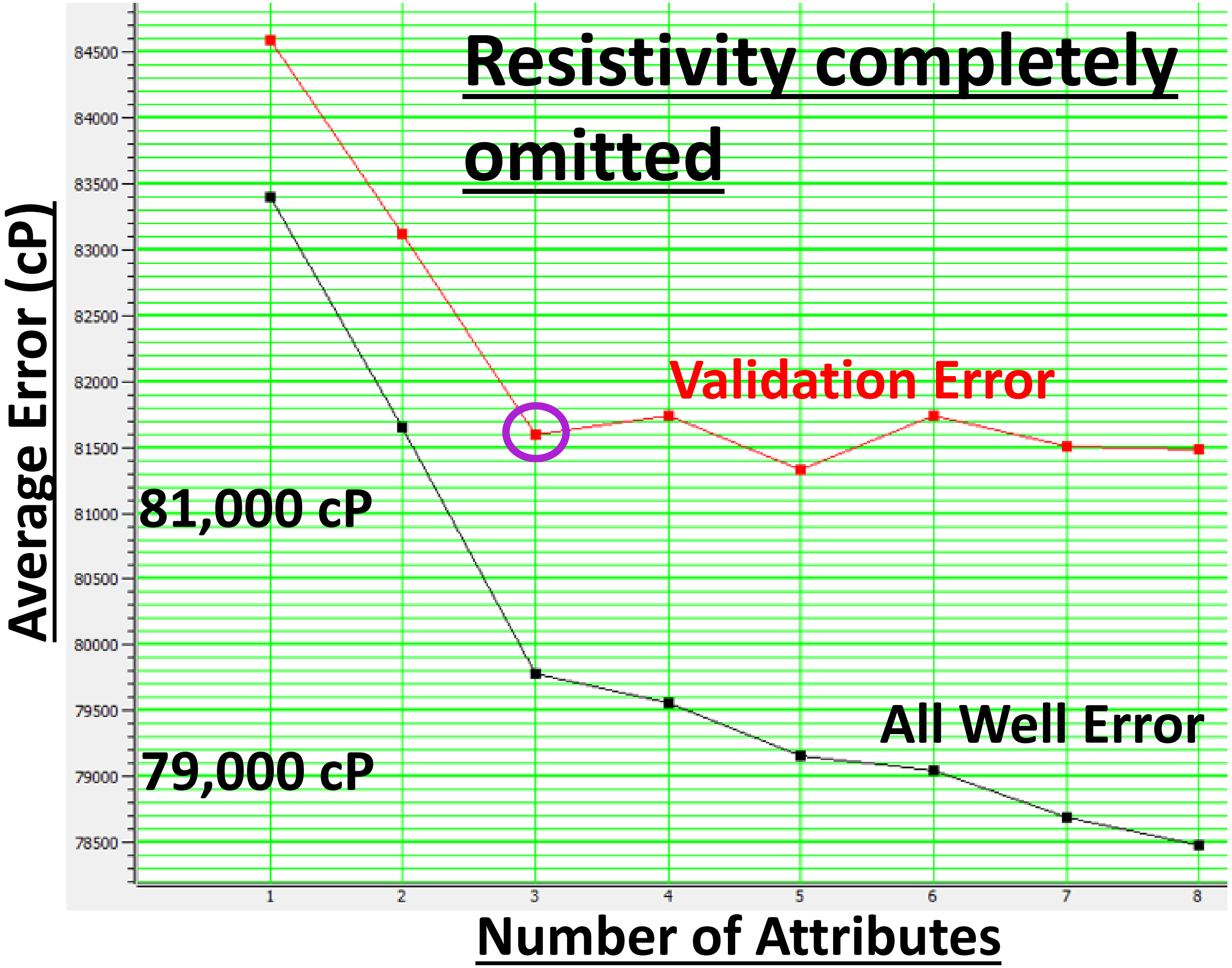
Top and base good



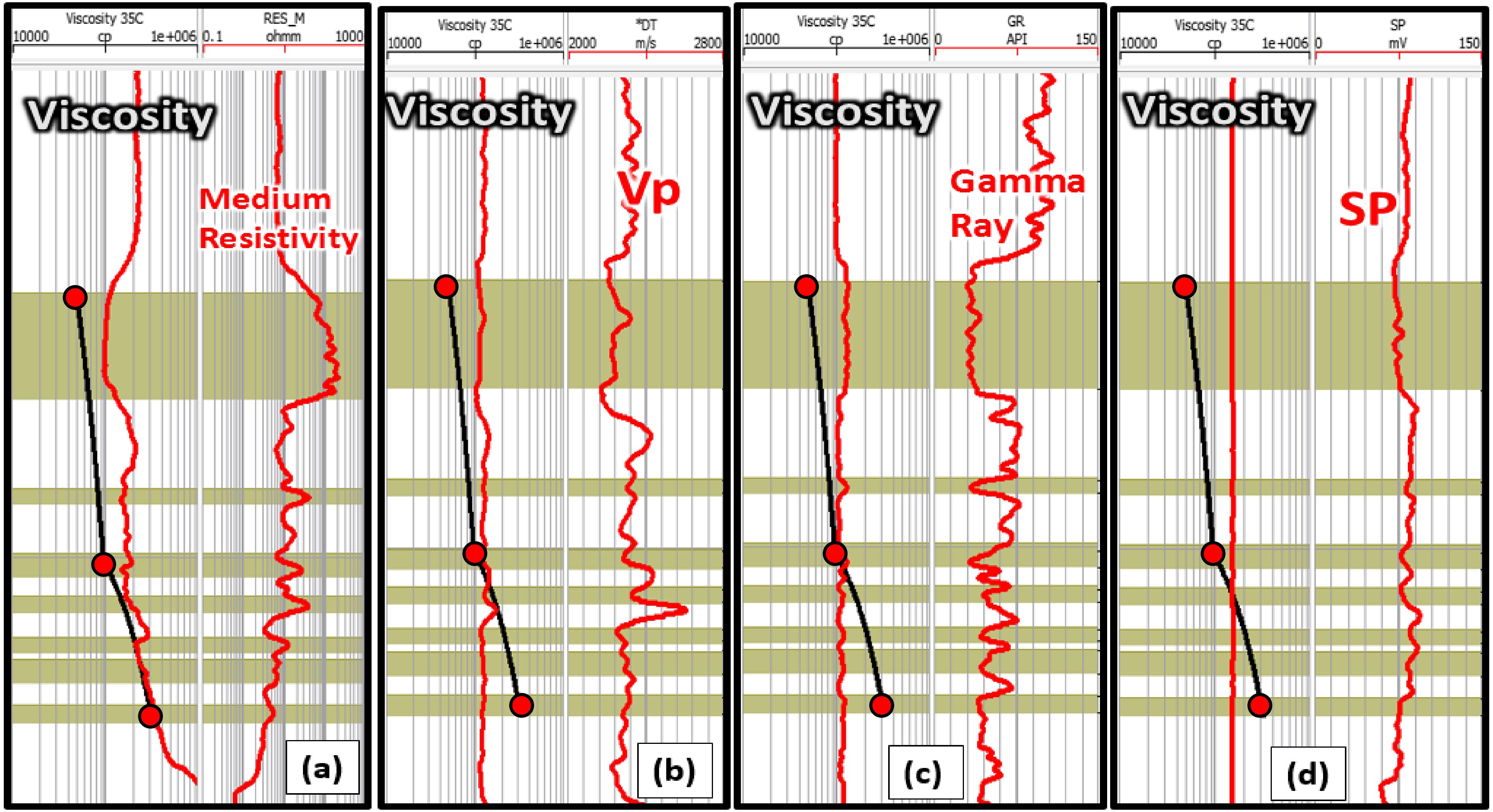
Top okay, base good

Experiment – Remove the top attribute (resistivity)

Attribute	Units
1. ln(|SP|)	*[none]*
2. 1 / (Gamma Ray)	*1/[API]*
3. 1 / (P-wave sonic)	*1/[us/m]*

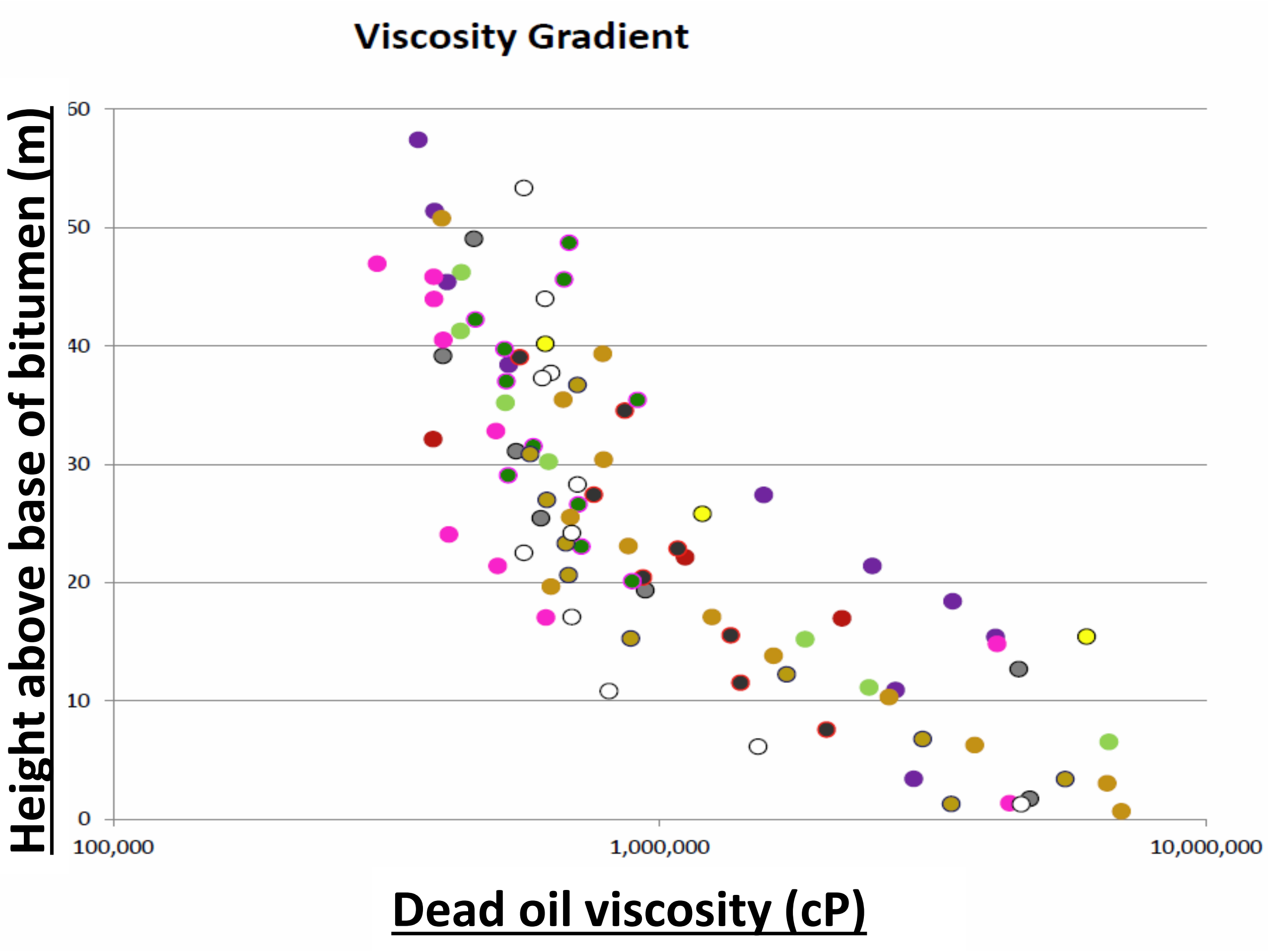


Dynamic behavior of the different predictors



1 / (Medium Resistivity) | 1 / (P-sonic) | 1 / (GR) | ln (SP)

What if we add depth as an attribute?

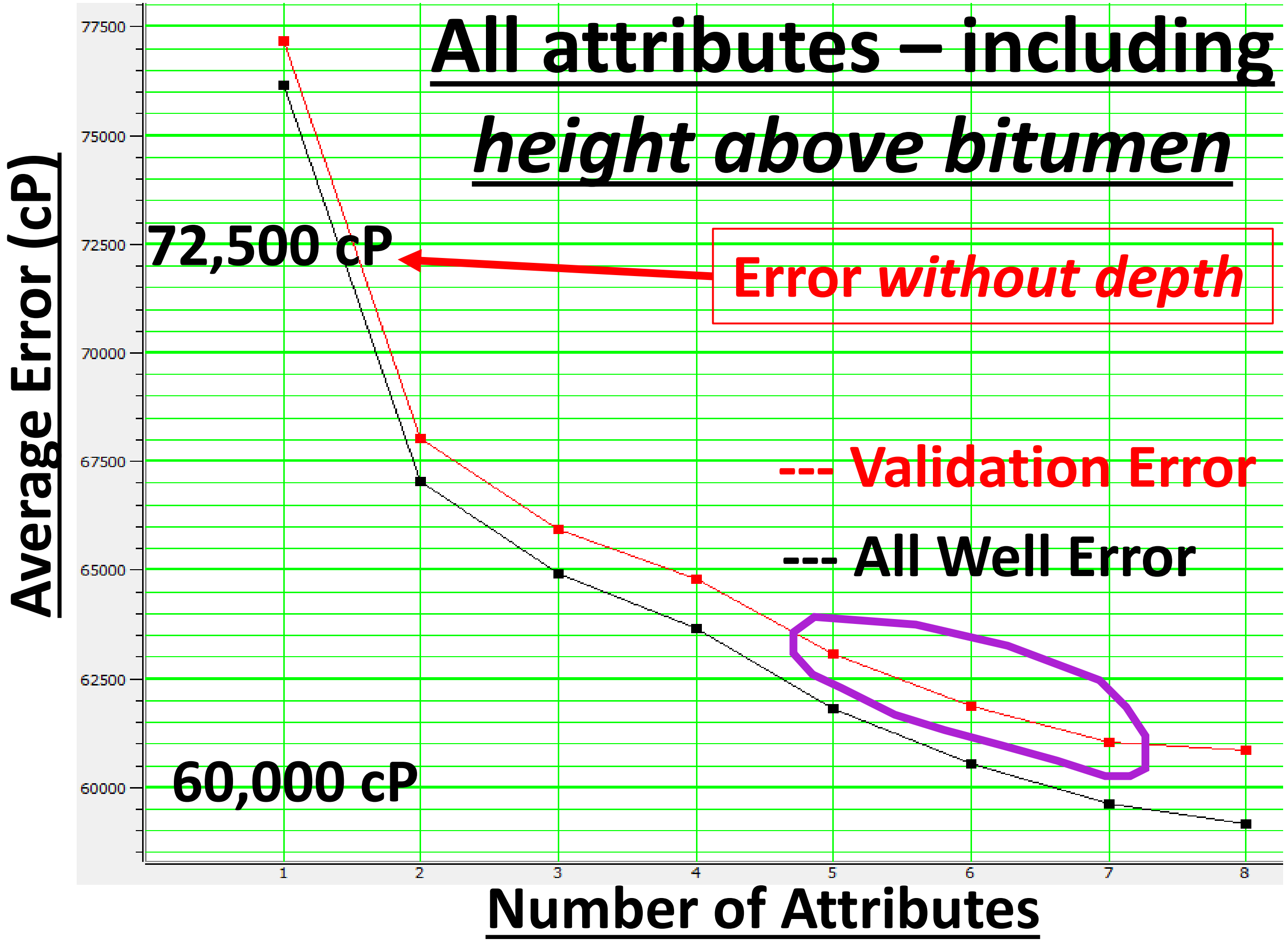


ConocoPhillips AER Report (2015)

Adding *height above bitumen base* as an attribute

- Optimum viscosity prediction is found using **5 to 7 attributes**

Attribute	**Units**
1. ln(Ht. above bitumen)	***[none]***
2. ln(ResMedium)	***[none]***
3. Density Porosity	***[%]***
4. (Porosity Diff.)$^{1/2}$	***[%]$^{1/2}$***
5. (S-wave sonic)$^{1/2}$	***[us/m]$^{1/2}$***
***6.* 1 / (Neutron Porosity)**	***1/[%]***
***7.* 1 / (Water Saturation)**	***1/[%]***



Conclusions

- Both **P-wave sonic** and (some form of) **resistivity** were top viscosity predictors in both Athabasca North and Athabasca South
- Average validation error in Athabasca North: **147,000cP (**19% of total range)
- Average validation error in Athabasca South: **70,000cP** (13% of total range)

- Bringing in **height above bitumen base** improved the validation error in Athabasca South to **60,000cP** (11% of total range)

Future Work

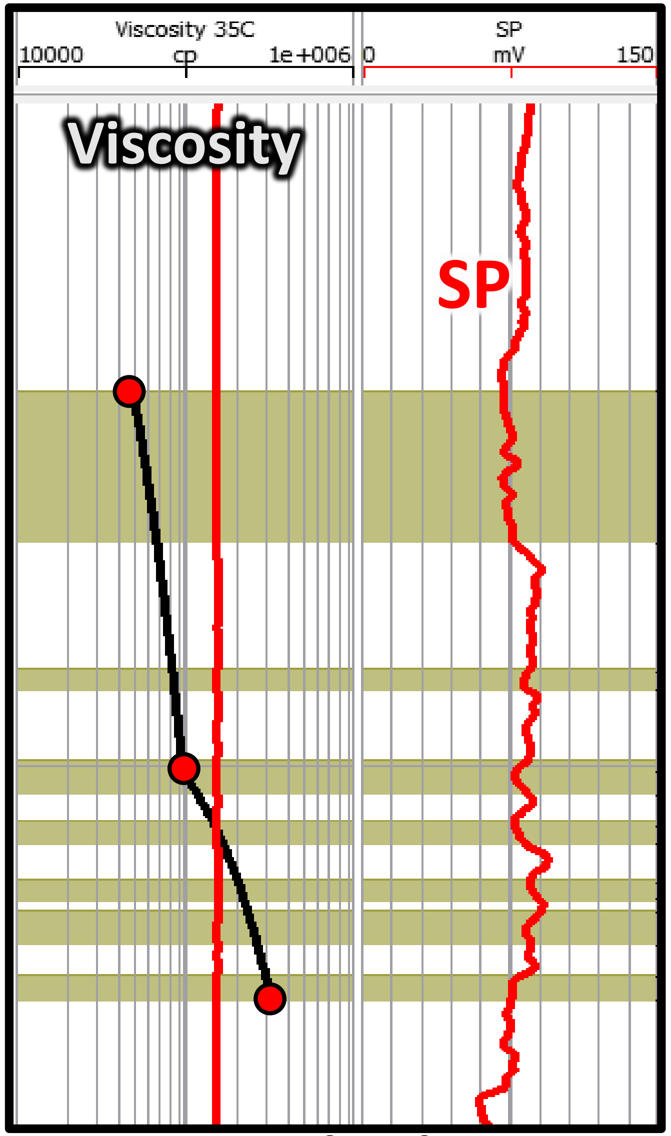
- Extrapolate the viscosity measurements to 10^0C (reservoir conditions) and 220^0C (steaming conditions)
- Determine how **depth** can best be used to predict viscosity in combination with the other logs
- Investigate the importance of the **S-wave sonic** log and **resistivity separation** (with improved log data)
- Try a **neural network** approach to predict viscosity

Acknowledgements

- **CREWES sponsors**
- **NSERC (**grant *CRDPJ 461179-13*)
- **David Gray, Rudy Strobl, Kevin Pyke, & Scott Keating**
- **CREWES staff and students**


We're Done.
Questions?

SP as a predictor



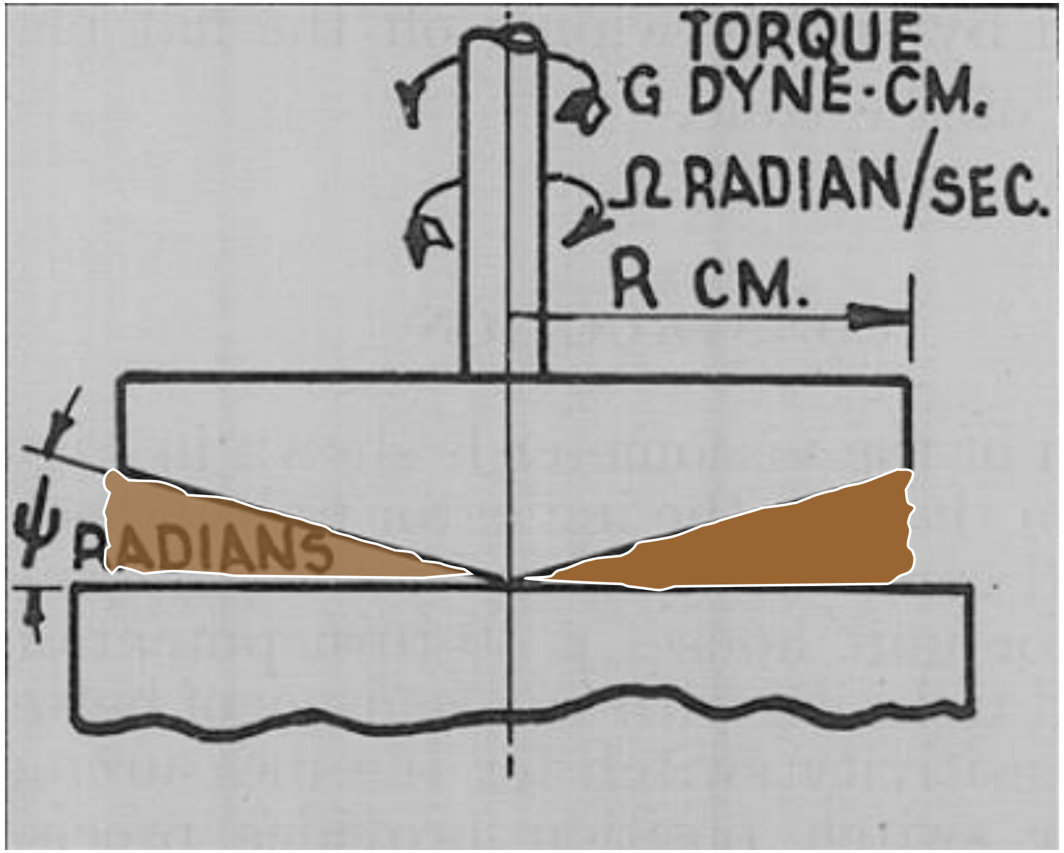
ln (|SP|)

Viscosity prediction equation using only SP:

$$\eta = 136000 + 4940 \, ln(|SP|)$$

Viscosity Measurement

- **<u>Cone and Plate Viscometer</u>** is typically used for heavy oil
- The resistance to the rotation of the cone produces a torque that is proportional to the shear stress in the fluid



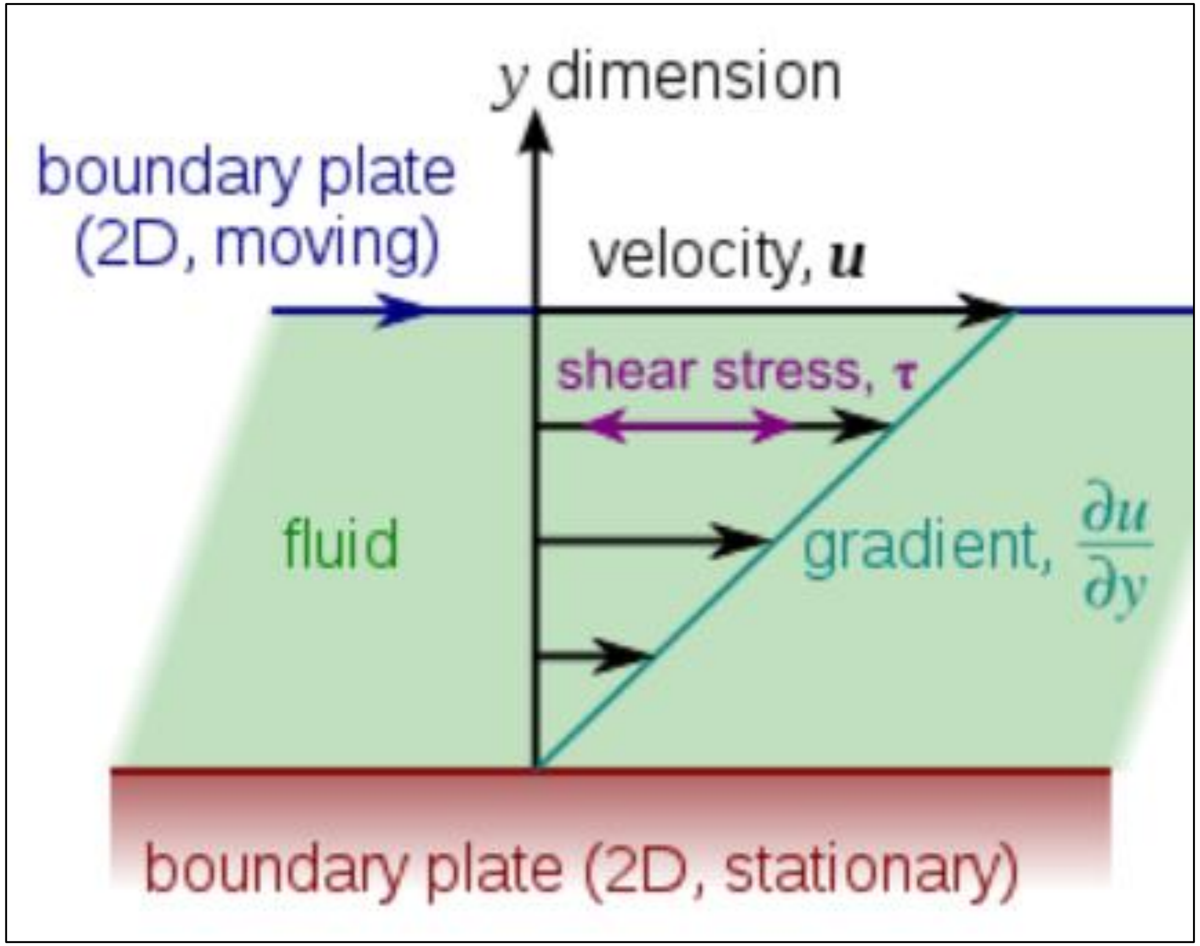
$$Viscosity = \frac{ShearStress}{ShearRate}$$

$$\eta = \frac{3G}{2\pi R^3} \Big/ \frac{\Omega}{\psi}$$

McKennell (1956)

Viscosity Concept

$$1\ cP = 1\ mPa \cdot s = 0.001\ Pa \cdot s = 0.001\ \frac{N}{m^2} \cdot s = 0.001\ \frac{kg}{m \cdot s}$$

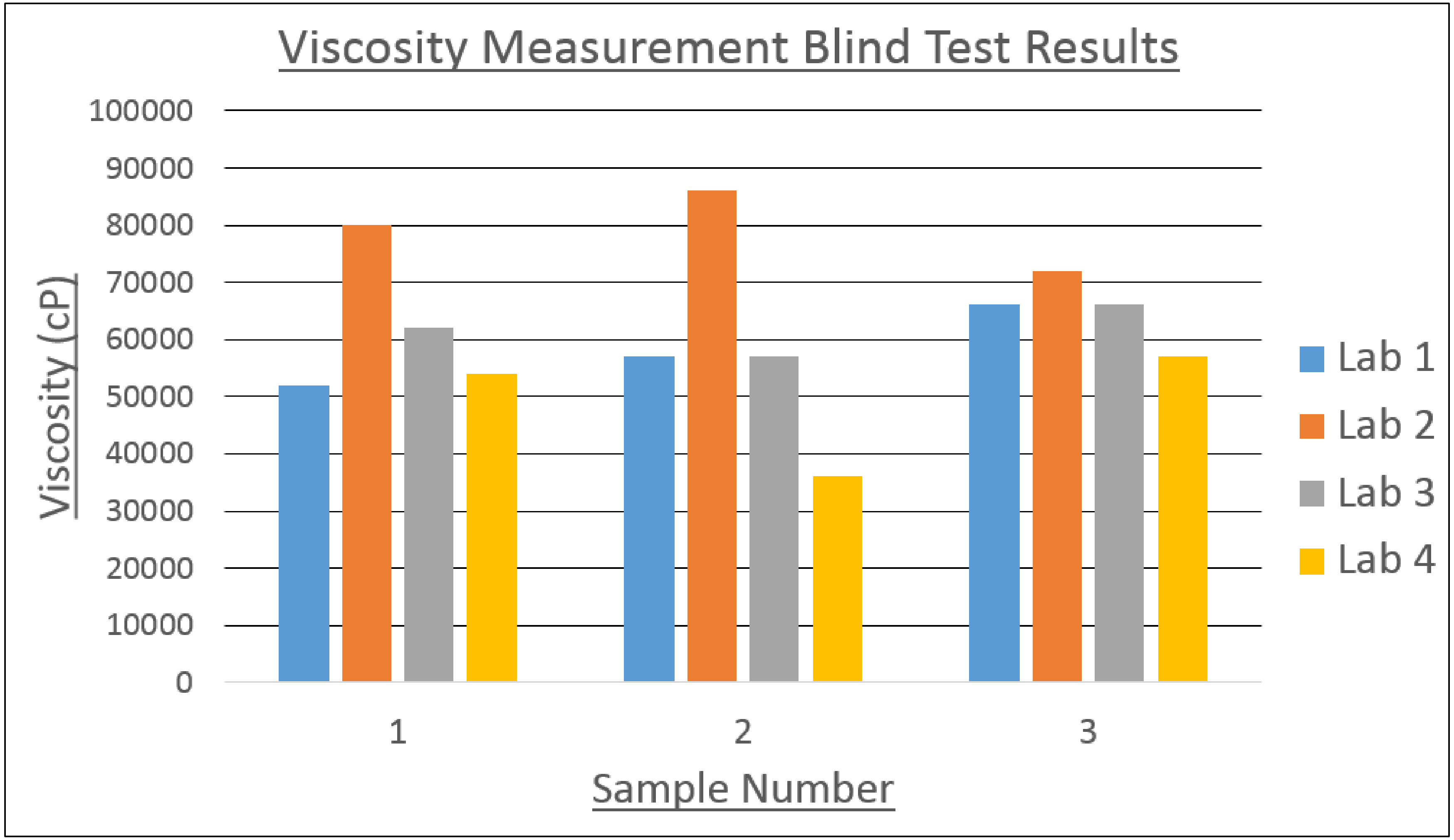


- If a fluid is placed between two plates with distance *1 m*, and one plate is pushed sideways with a shear stress of *1 Pa*, and it moves at *"u" m/s*, then it has viscosity of *"u" Pa·s*

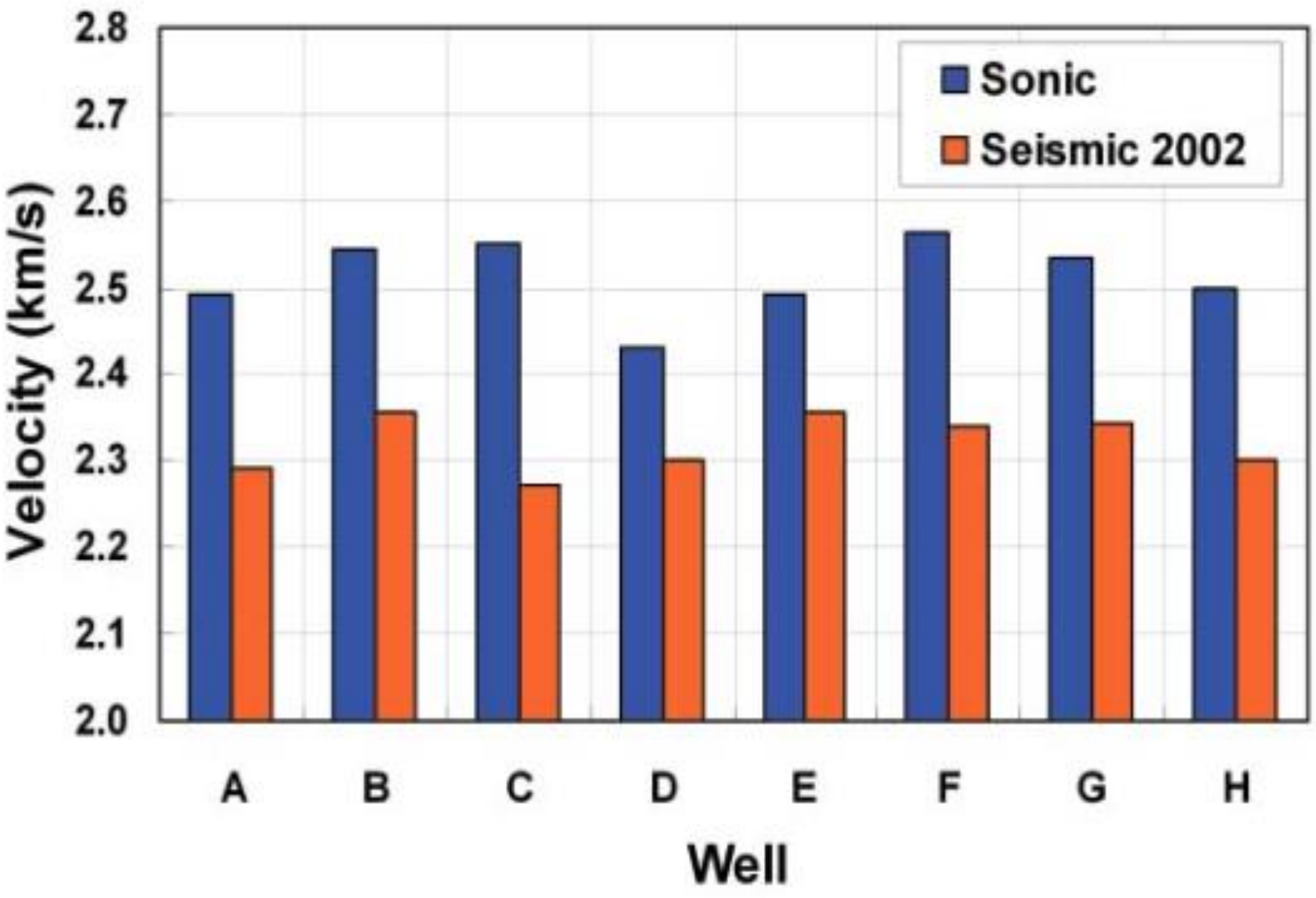
Image credit: Wikipedia

Uncertainty of the Viscosity Measurement

Miller et al (2006): *Should you trust your heavy oil viscosity measurement?*



Velocity Dispersion



Kato & Onozuka & Nakayama (2008)

- Velocities tend to increase with measurement frequency
- Laboratory measurements give higher velocities than sonic logs or seismic data
- Example from a heavy oil field 50km SW of Fort McMurray