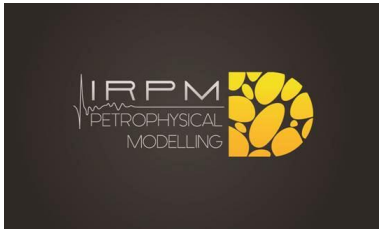
Formation Evaluation Society of Australia

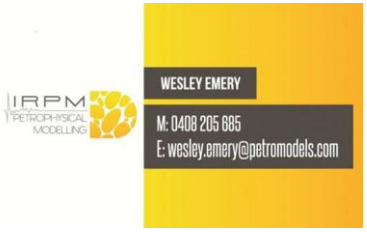
A chapter of the Society of Petrophysicists and Well Log Analysts

Core to Log
Up-scaling and Uncertainty

Wesley Emery

Director of iRPM Pty Ltd





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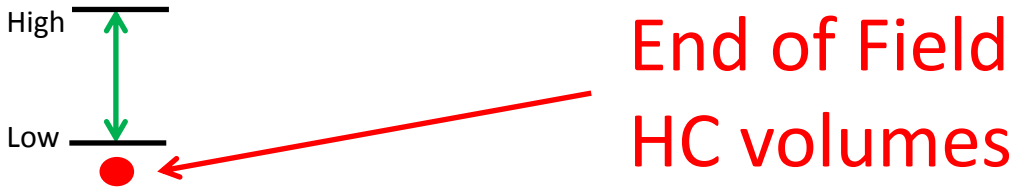
1. Introduction

- The “end of field” HC volumes from too many MCP’s are found to be outside the initial uncertainty range and most of these are below the initial low case.

  Initial HC volume uncertainty range



- We need to identify areas of greatest uncertainty and reduce this uncertainty first.

2. Log and Core Data Uncertainty

1. Introduction
2. Core and Log Data Uncertainty
   a) Core Porosity and Permeability Prediction Uncertainty
   b) Log Density Porosity Uncertainty
3. Uncertainty due to “Up-scaling”
   a) Core to Log Scale
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4. Uncertainty due to Averaging
   a) Formation Averages – VSH, PHIT, PERM and SWT
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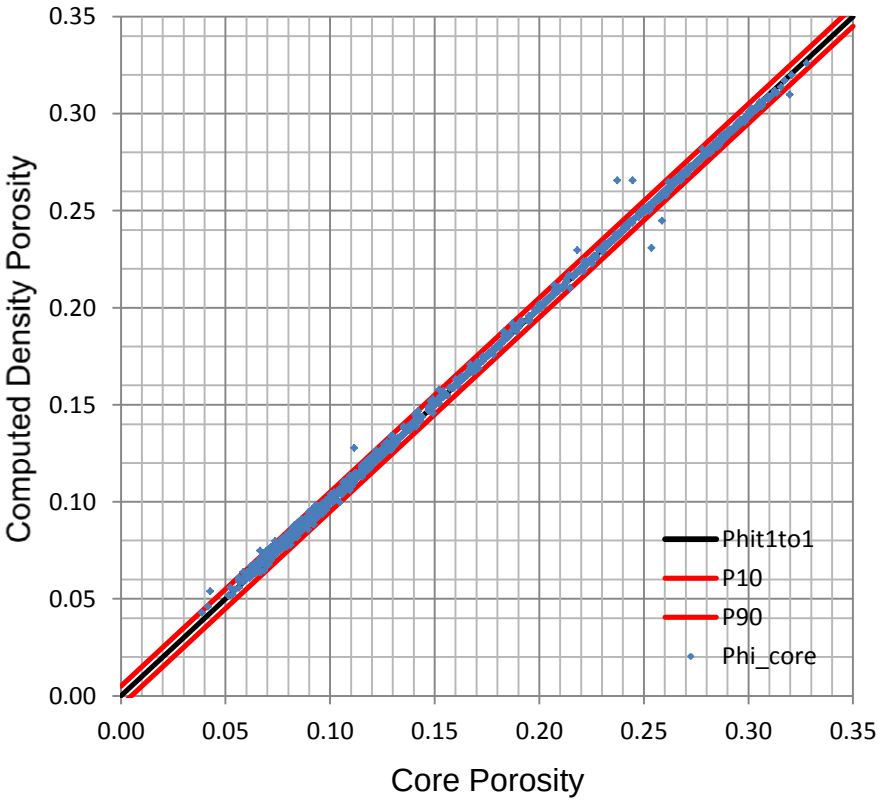
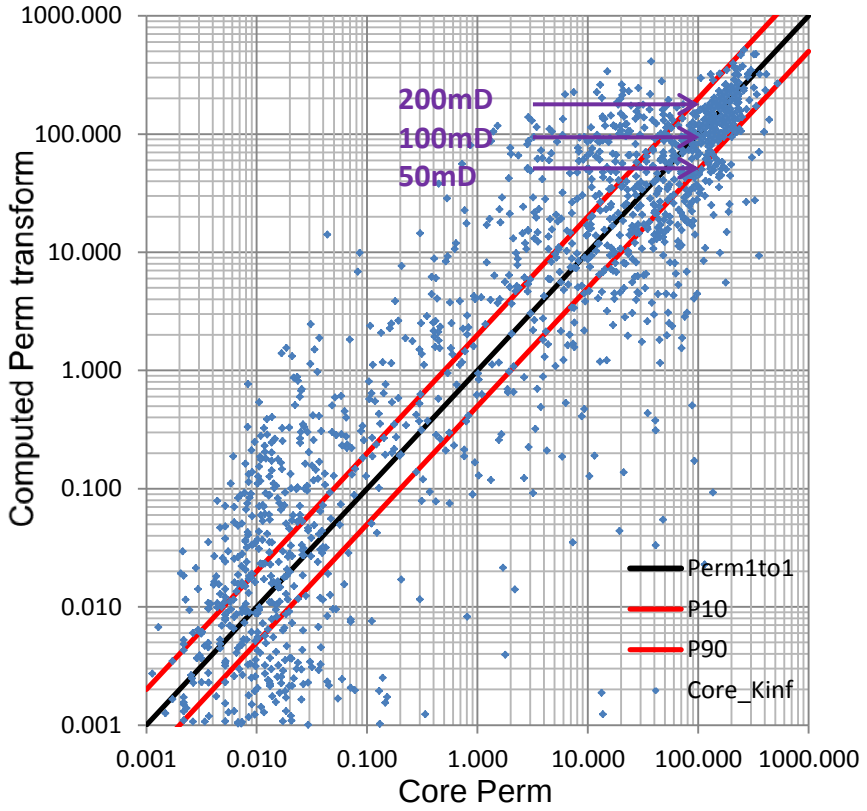
   a) Permeability Cloud Transform – Match to Well Test
6. Conclusions

2a. Core Porosity and Permeability Prediction Uncertainty

PHIT_RHOB=(RHOMA-RHOB)/(RHOMA-1)

Uncertainty in Core Density Porosity is
+/- 3.5%
Equivalent to Density measurement Uncertainty
+/- 0.005g/cc



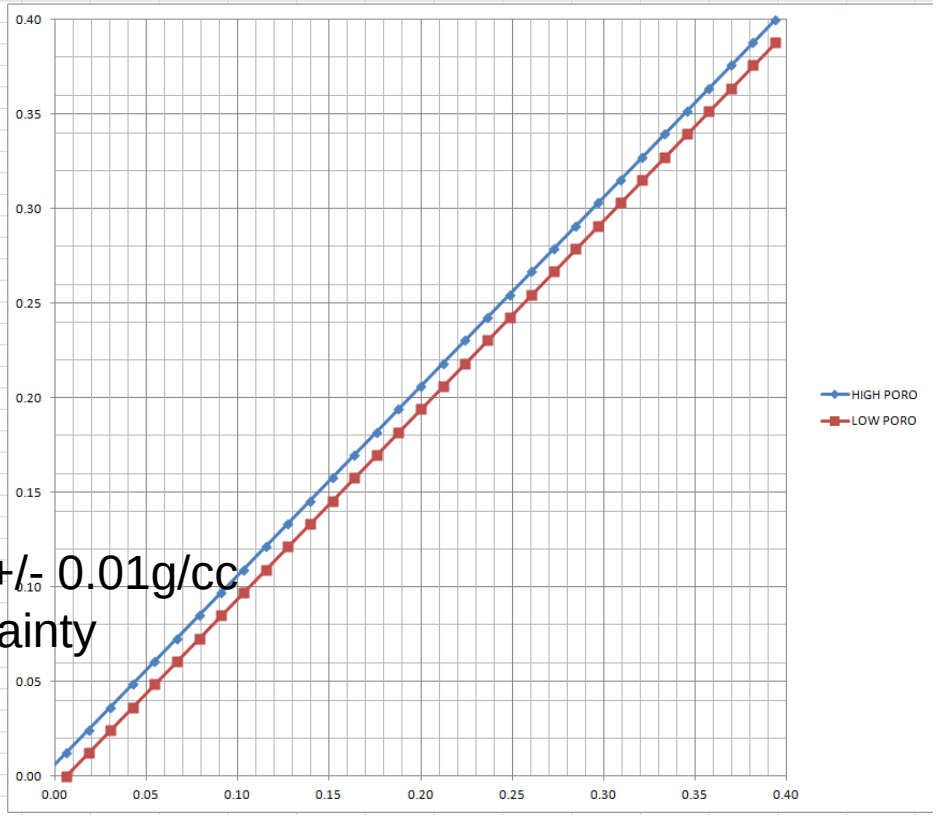


Uncertainty in Permeability is
+/- scale *2

2b. Log Density Porosity Uncertainty

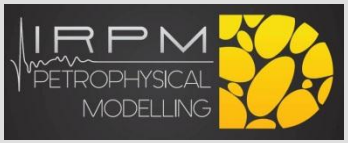
RHOMA	RHOFL	RHOB	POROSITY	HIGH RHO	HIGH POR	LOW RHO	LOW PORO	RHOB +/-
2.65	1	2.00	0.394	1.99	0.400	2.01	0.388	0.01
2.65	1	2.02	0.382	2.01	0.388	2.03	0.376	
2.65	1	2.04	0.370	2.03	0.376	2.05	0.364	
2.65	1	2.06	0.358	2.05	0.364	2.07	0.352	
2.65	1	2.08	0.345	2.07	0.352	2.09	0.339	
2.65	1	2.10	0.333	2.09	0.339	2.11	0.327	
2.65	1	2.12	0.321	2.11	0.327	2.13	0.315	
2.65	1	2.14	0.309	2.13	0.315	2.15	0.303	
2.65	1	2.16	0.297	2.15	0.303	2.17	0.291	
2.65	1	2.18	0.285	2.17	0.291	2.19	0.279	
2.65	1	2.20	0.273	2.19	0.279	2.21	0.267	
2.65	1	2.22	0.261	2.21	0.267	2.23	0.255	
2.65	1	2.24	0.248	2.23	0.255	2.25	0.242	
2.65	1	2.26	0.236	2.25	0.242	2.27	0.230	
2.65	1	2.28	0.224	2.27	0.230	2.29	0.218	
2.65	1	2.30	0.212	2.29	0.218	2.31	0.206	
2.65	1	2.32	0.200	2.31	0.206	2.33	0.194	
2.65	1	2.34	0.188	2.33	0.194	2.35	0.182	
2.65	1	2.36	0.176	2.35	0.182	2.37	0.170	
2.65	1	2.38	0.164	2.37	0.170	2.39	0.158	
2.65	1	2.40	0.152	2.39	0.158	2.41	0.145	
2.65	1	2.42	0.139	2.41	0.145	2.43	0.133	
2.65	1	2.44	0.127	2.43	0.133	2.45	0.121	
2.65	1	2.46	0.115	2.45	0.121	2.47	0.109	
2.65	1	2.48	0.103	2.47	0.109	2.49	0.097	
2.65	1	2.50	0.091	2.49	0.097	2.51	0.085	
2.65	1	2.52	0.079	2.51	0.085	2.53	0.073	
2.65	1	2.54	0.067	2.53	0.073	2.55	0.061	
2.65	1	2.56	0.055	2.55	0.061	2.57	0.048	
2.65	1	2.58	0.042	2.57	0.048	2.59	0.036	
2.65	1	2.60	0.030	2.59	0.036	2.61	0.024	
2.65	1	2.62	0.018	2.61	0.024	2.63	0.012	
2.65	1	2.64	0.006	2.63	0.012	2.65	0.000	
2.65	1	2.66	-0.006	2.65	0.000	2.67	-0.012	
2.65	1	2.68	-0.018	2.67	-0.012	2.69	-0.024	

Density Log +/- 0.01g/cc uncertainty



Density Log **+/- 0.01g/cc** uncertainty
equivalent to **+/- 5.5%** Log Density Porosity uncertainty

3. Uncertainty due to “Up-Scaling”



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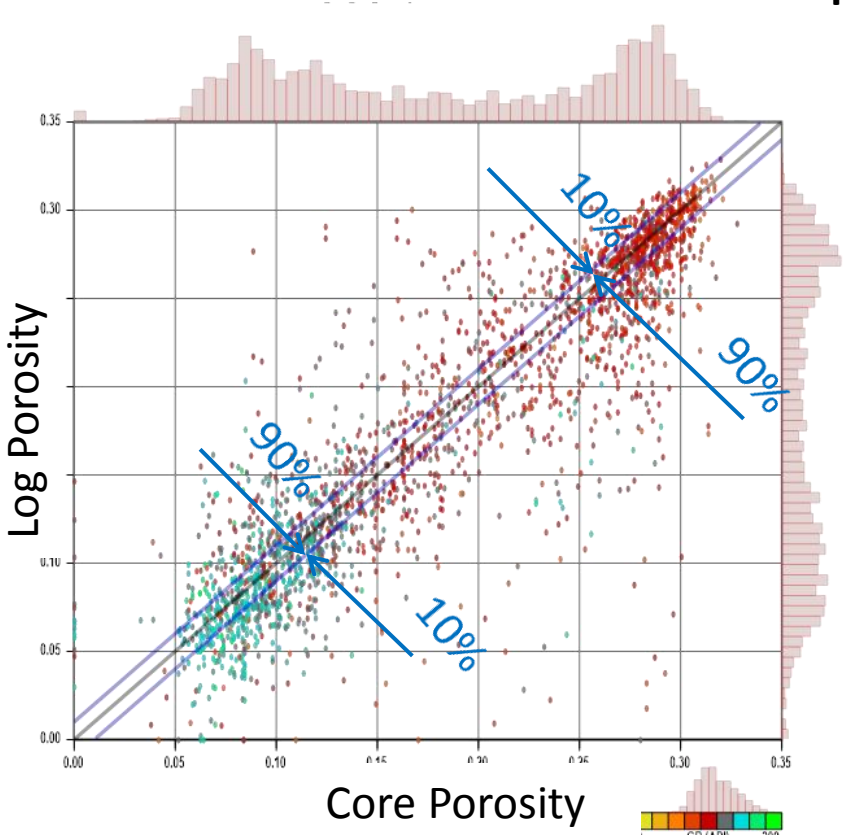
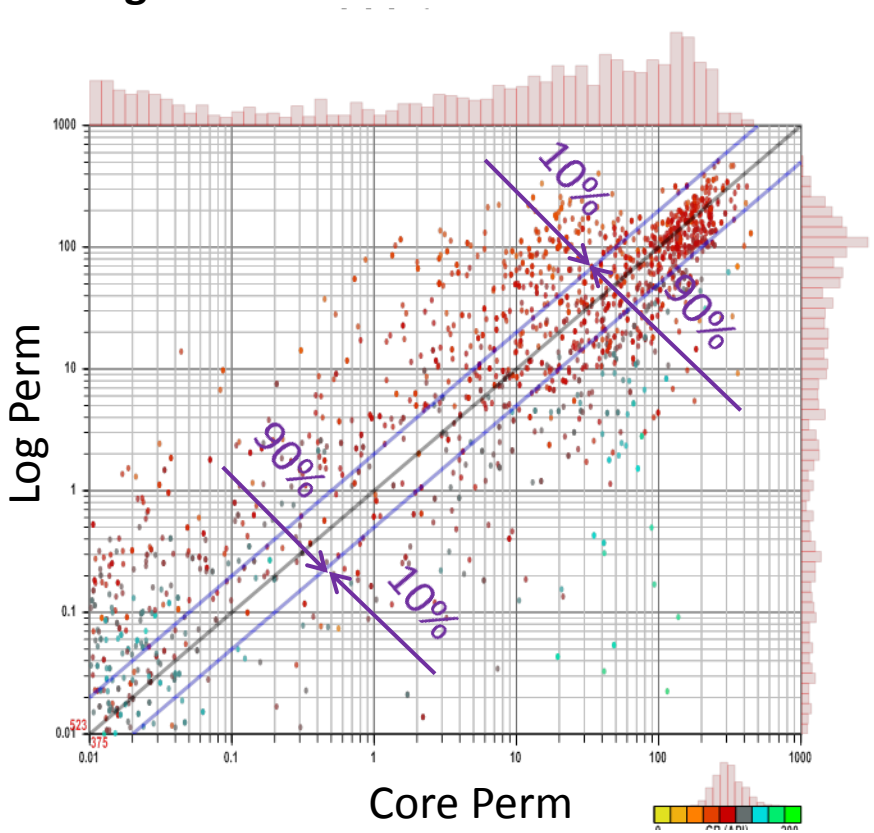
3a. Core to Log Scale

Core scale 3cm sampling compared to log scale 0.5ft(15.25cm) sampling.
5x up-scaling.

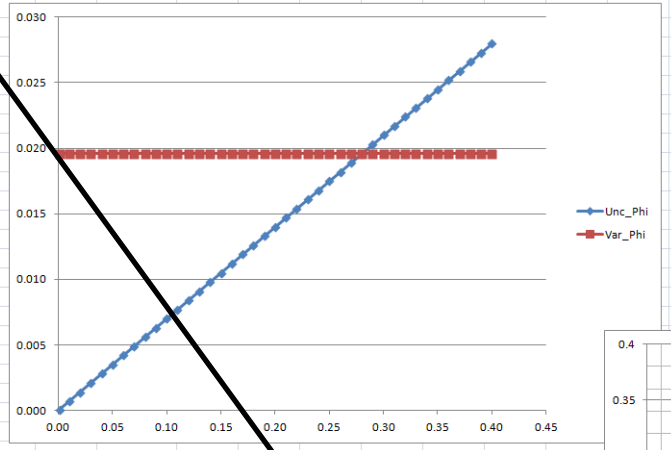




Porosity Unc = **+/-7%** (1.7pu @ 25pu) LogPerm Unc = +/-Log2(or **scale*2**)

3a. Core to Log Scale

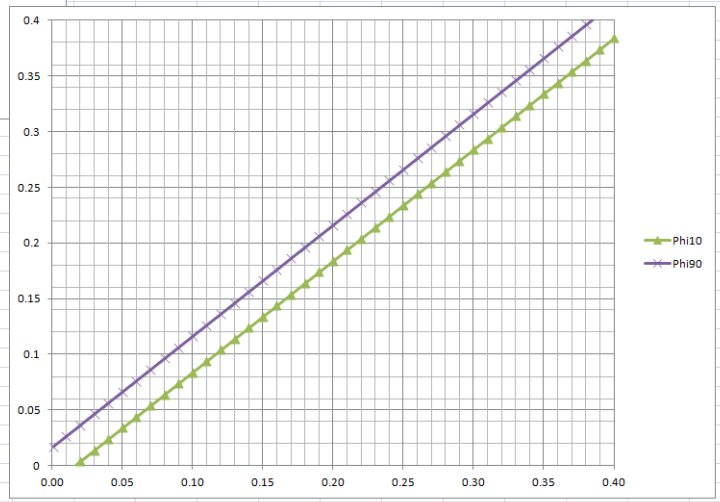
Porosity	Unc_Phi	Var_Phi	Phi10	Phi90	PHI_UNC(%)
0.00	0.00	0.0196	-0.01512	0.017121	7
0.01	0.00	0.0196	-0.00612	0.026121	M
0.02	0.00	0.0196	0.003879	0.036121	2
0.03	0.00	0.0196	0.013879	0.046121	
0.04	0.00	0.0196	0.023879	0.056121	
0.05	0.00	0.0196	0.033879	0.066121	
0.06	0.00	0.0196	0.043879	0.076121	
0.07	0.00	0.0196	0.053879	0.086121	
0.08	0.01	0.0196	0.063879	0.096121	
0.09	0.01	0.0196	0.073879	0.106121	
0.10	0.01	0.0196	0.083879	0.116121	
0.11	0.01	0.0196	0.093879	0.126121	
0.12	0.01	0.0196	0.103879	0.136121	
0.13	0.01	0.0196	0.113879	0.146121	
0.14	0.01	0.0196	0.123879	0.156121	
0.15	0.01	0.0196	0.133879	0.166121	
0.16	0.01	0.0196	0.143879	0.176121	
0.17	0.01	0.0196	0.153879	0.186121	
0.18	0.01	0.0196	0.163879	0.196121	
0.19	0.01	0.0196	0.173879	0.206121	
0.20	0.01	0.0196	0.183879	0.216121	
0.21	0.01	0.0196	0.193879	0.226121	
0.22	0.02	0.0196	0.203879	0.236121	
0.23	0.02	0.0196	0.213879	0.246121	
0.24	0.02	0.0196	0.223879	0.256121	
0.25	0.02	0.0196	0.233879	0.266121	
0.26	0.02	0.0196	0.243879	0.276121	
0.27	0.02	0.0196	0.253879	0.286121	
0.28	0.02	0.0196	0.263879	0.296121	
0.29	0.02	0.0196	0.273879	0.306121	
0.30	0.02	0.0196	0.283879	0.316121	
0.31	0.02	0.0196	0.293879	0.326121	
0.32	0.02	0.0196	0.303879	0.336121	
0.33	0.02	0.0196	0.313879	0.346121	
0.34	0.02	0.0196	0.323879	0.356121	
0.35	0.02	0.0196	0.333879	0.366121	
0.36	0.03	0.0196	0.343879	0.376121	
0.37	0.03	0.0196	0.353879	0.386121	
0.38	0.03	0.0196	0.363879	0.396121	
0.39	0.03	0.0196	0.373879	0.406121	
0.40	0.03	0.0196	0.383879	0.416121	



Existing 7% uncertainty

UNC_PHI=PHI*PHI_UNC/100
VAR_PHI=(UNC_PHI*2//PHI)^2

UncØ = 7%*Ø
VarØ = (UncØ*2/Ø)^2
P10 = -0.8225*VarØ
P90 = +0.8225*VarØ



Sensitivity Analysis of the Parameters in Archie's water saturation Equation –
H.C.CHEN and J.H.FANG University of Alabama – The Log Analyst Sep-Oct 1986

3a. Core to Log Scale

RHOMA	RHOFL	RHOB	POROSITY	HIGH RHO	HIGH POR	LOW RHO	LOW PORO	RHOB +/-
2.65	1	2.00	0.394	1.97	0.412	2.03	0.376	0.03
2.65	1	2.02	0.382	1.99	0.400	2.05	0.364	
2.65	1	2.04	0.370	2.01	0.388	2.07	0.352	
2.65	1	2.06	0.358	2.03	0.376	2.09	0.339	
2.65	1	2.08	0.345	2.05	0.364	2.11	0.327	
2.65	1	2.10	0.333	2.07	0.352	2.13	0.315	
2.65	1	2.12	0.321	2.09	0.339	2.15	0.303	
2.65	1	2.14	0.309	2.11	0.327	2.17	0.291	
2.65	1	2.16	0.297	2.13	0.315	2.19	0.279	
2.65	1	2.18	0.285	2.15	0.303	2.21	0.267	
2.65	1	2.20	0.273	2.17	0.291	2.23	0.255	
2.65	1	2.22	0.261	2.19	0.279	2.25	0.242	
2.65	1	2.24	0.248	2.21	0.267	2.27	0.230	
2.65	1	2.26	0.236	2.23	0.255	2.29	0.218	
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2.65	1	2.32	0.200	2.29	0.218	2.35	0.182	
2.65	1	2.34	0.188	2.31	0.206	2.37	0.170	
2.65	1	2.36	0.176	2.33	0.194	2.39	0.158	
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2.65	1	2.46	0.115	2.43	0.133	2.49	0.097	
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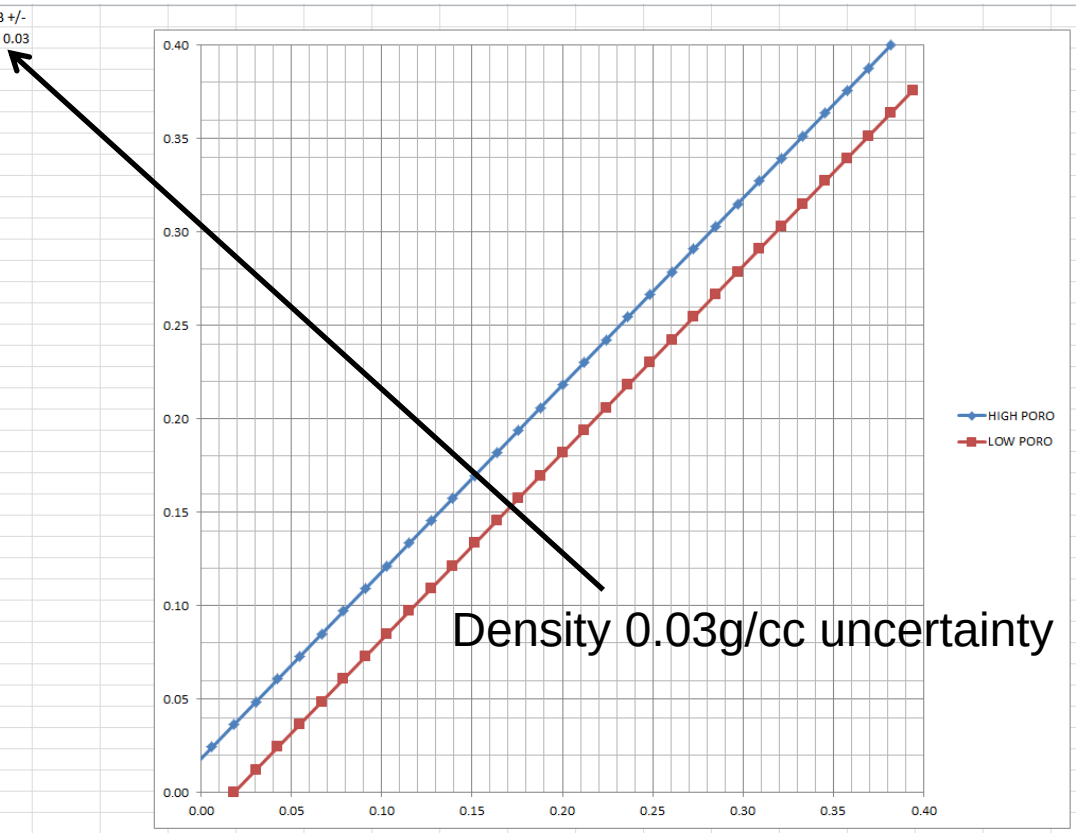
2.65	1	2.58	0.042	2.55	0.061	2.61	0.024	
2.65	1	2.60	0.030	2.57	0.048	2.63	0.012	
2.65	1	2.62	0.018	2.59	0.036	2.65	0.000	
2.65	1	2.64	0.006	2.61	0.024	2.67	-0.012	
2.65	1	2.66	-0.006	2.63	0.012	2.69	-0.024	
2.65	1	2.68	-0.018	2.65	0.000	2.71	-0.036	

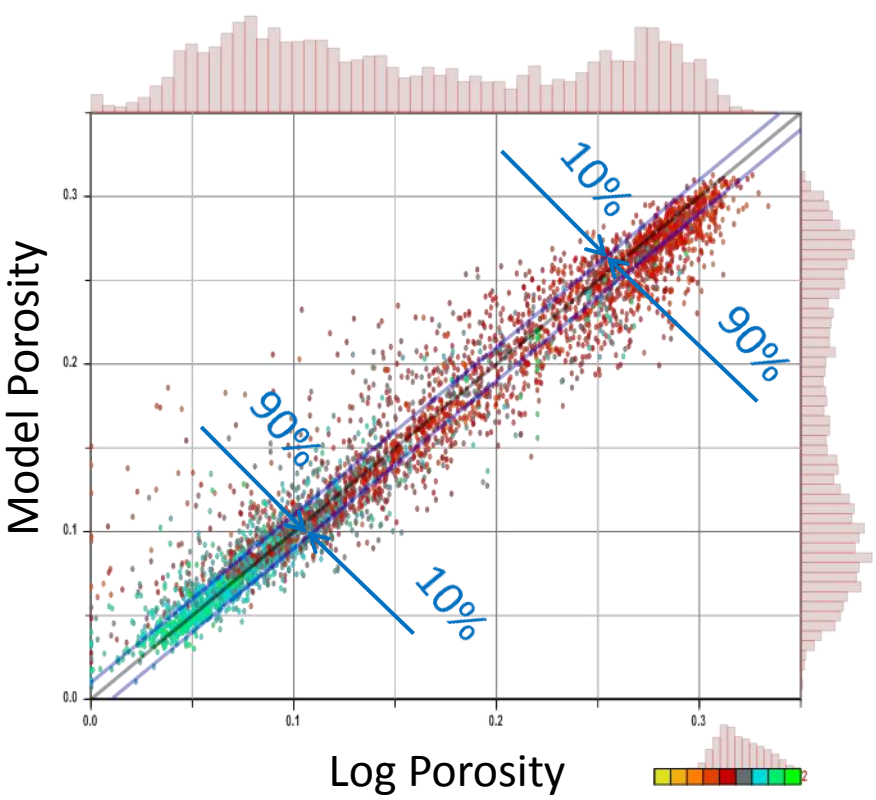


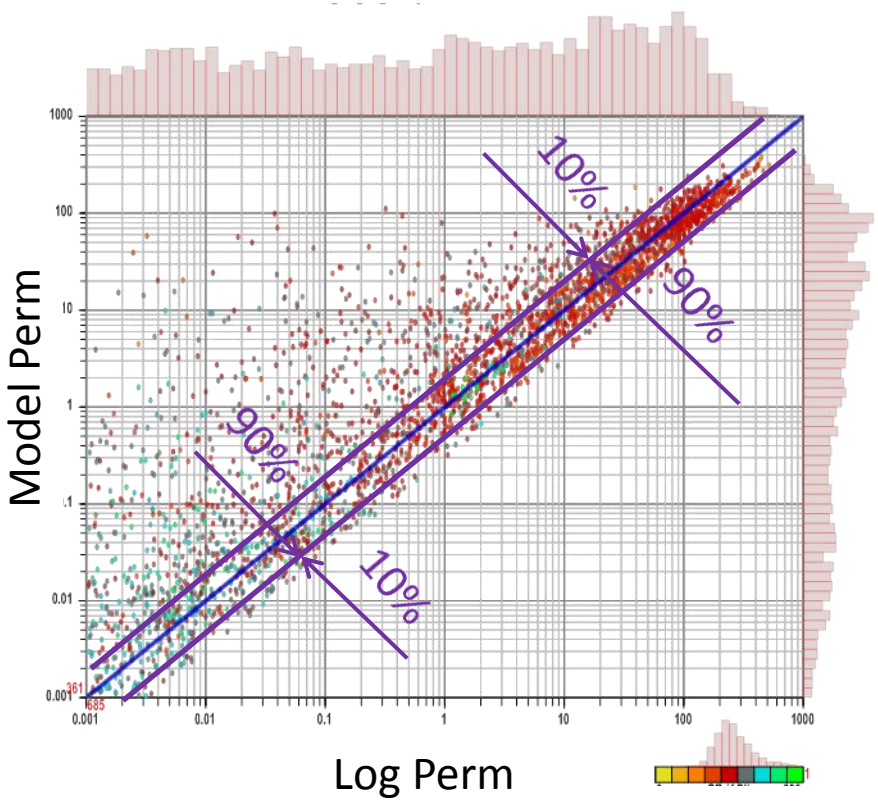
Density 0.03g/cc uncertainty incorporating core-log resolution uncertainty
i.e. 1.7pu porosity uncertainty
Essentially no difference to existing 7% uncertainty

3b. Log to 3D Static Model Scale

Log scale 0.5ft (15.24cm) sampling compared to model scale 1m sampling.

6x up-scaling





Porosity Unc = **+/-7%** (1.7pu @ 25pu)

LogPerm Unc = +/-Log2(or **scale*2**)

4. Uncertainty due to “Averaging”

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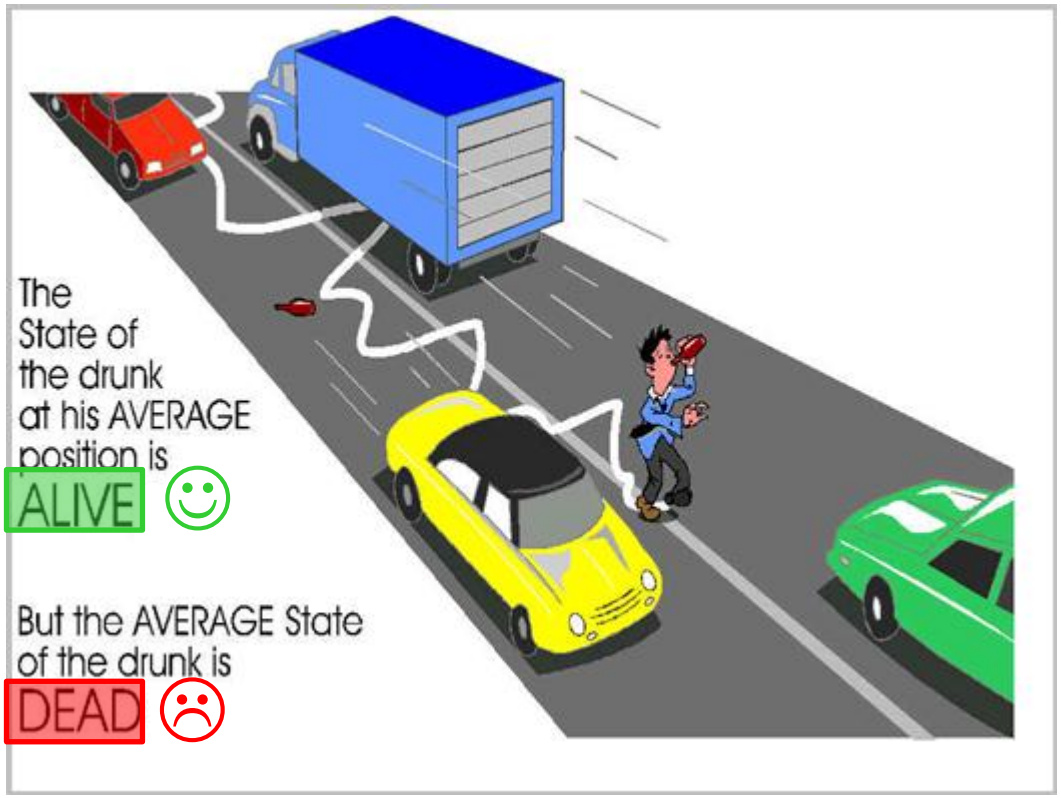
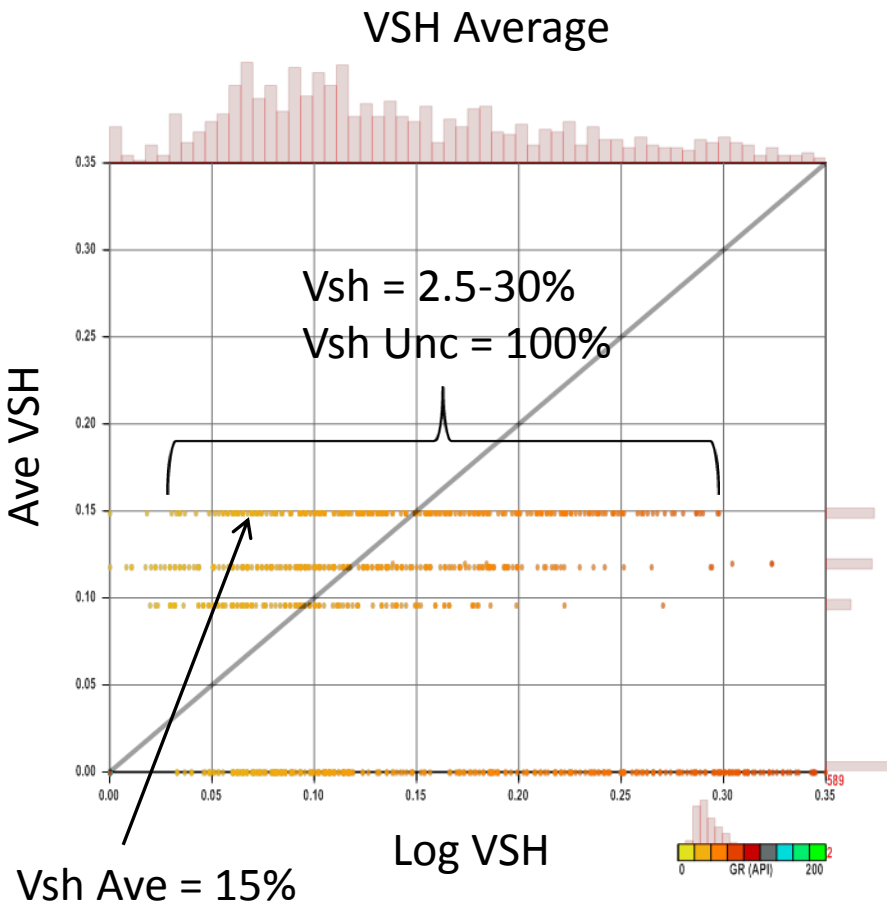
4. Uncertainty due to “Averaging”

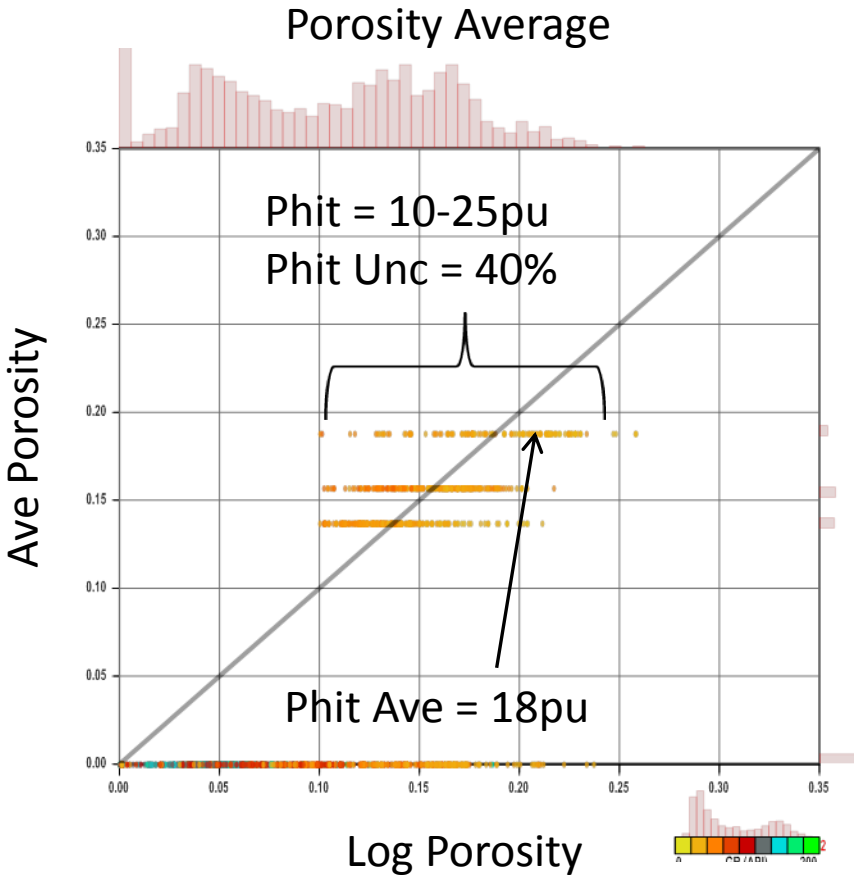
Consider the state of a drunk, wandering around on a busy highway. His average position is the centerline, so.....



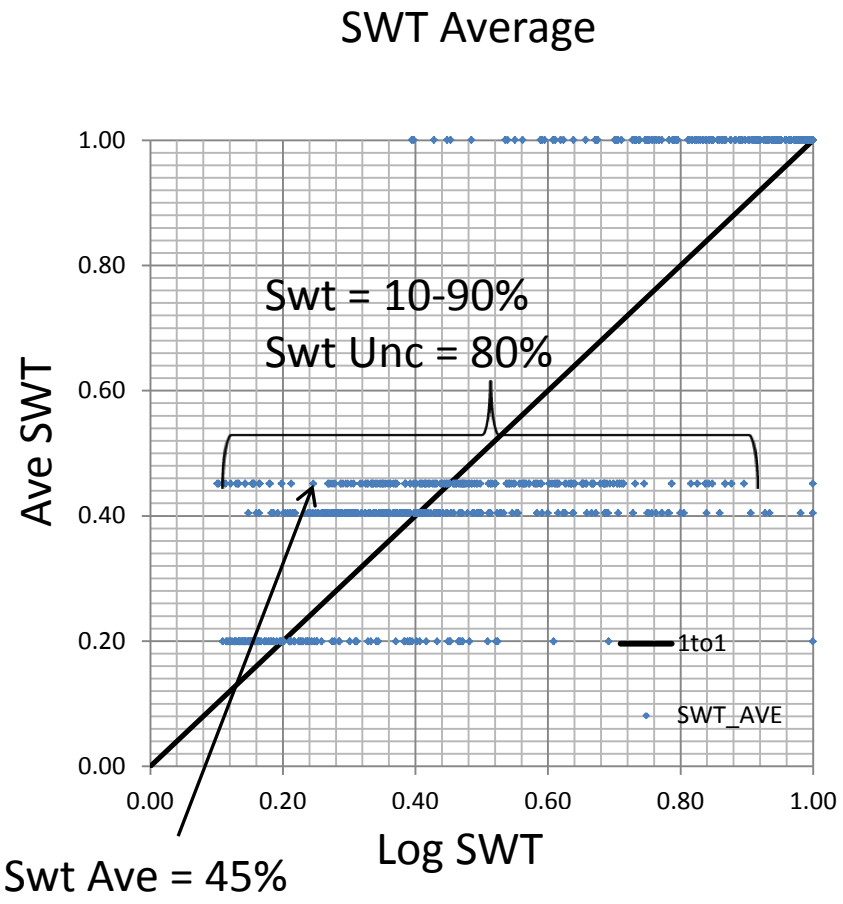
The Flaw of Averages, Sam Savage - Consulting Professor at Stanford University

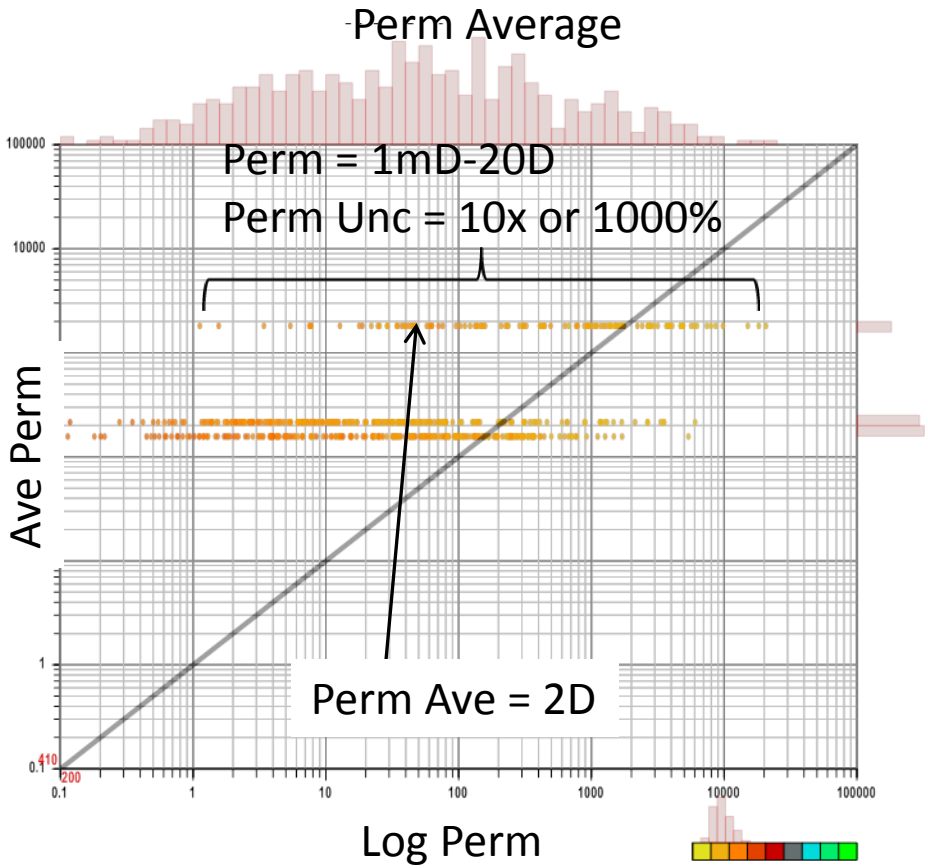
4a. Formation Averages





4b. Formation Averages





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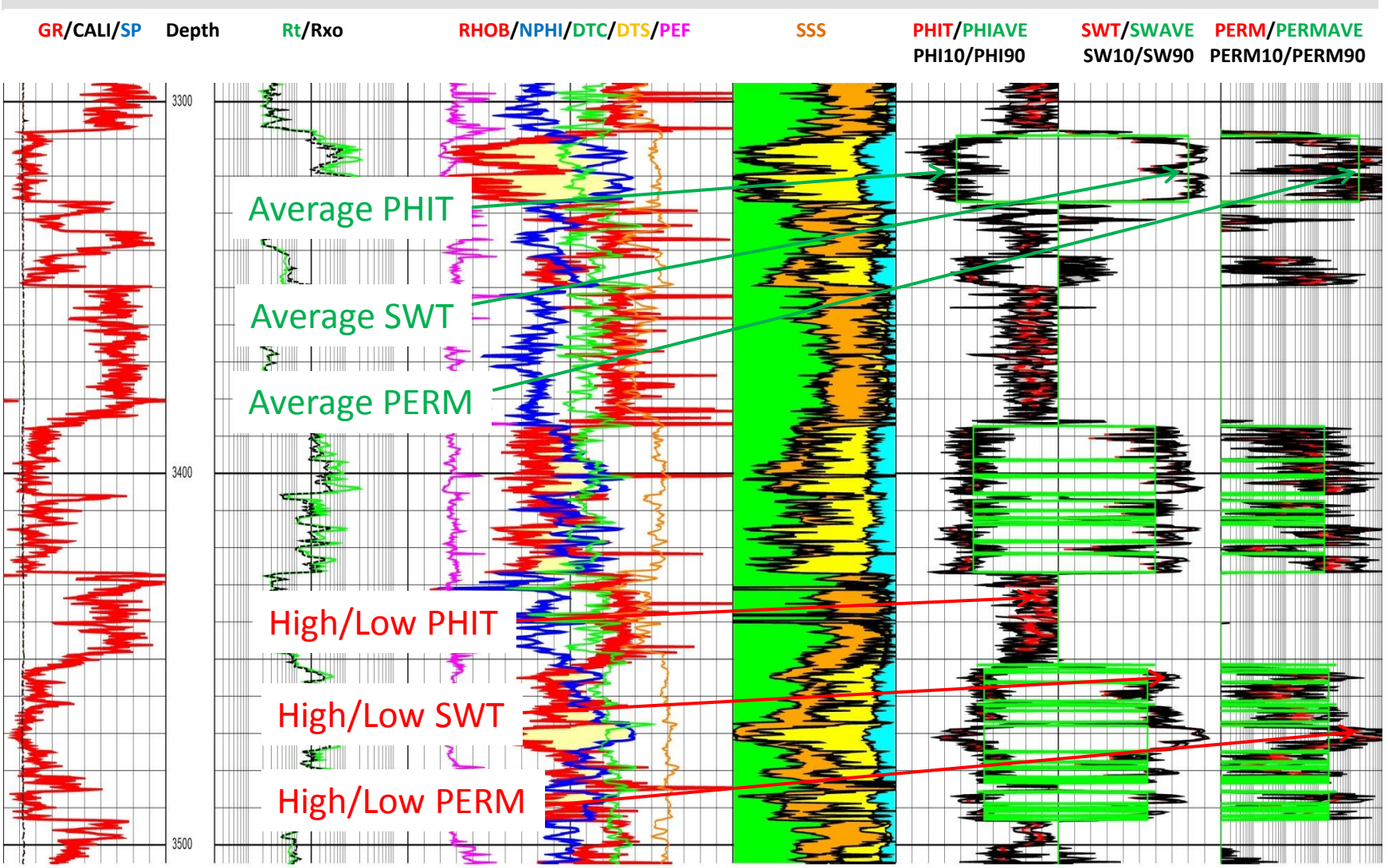
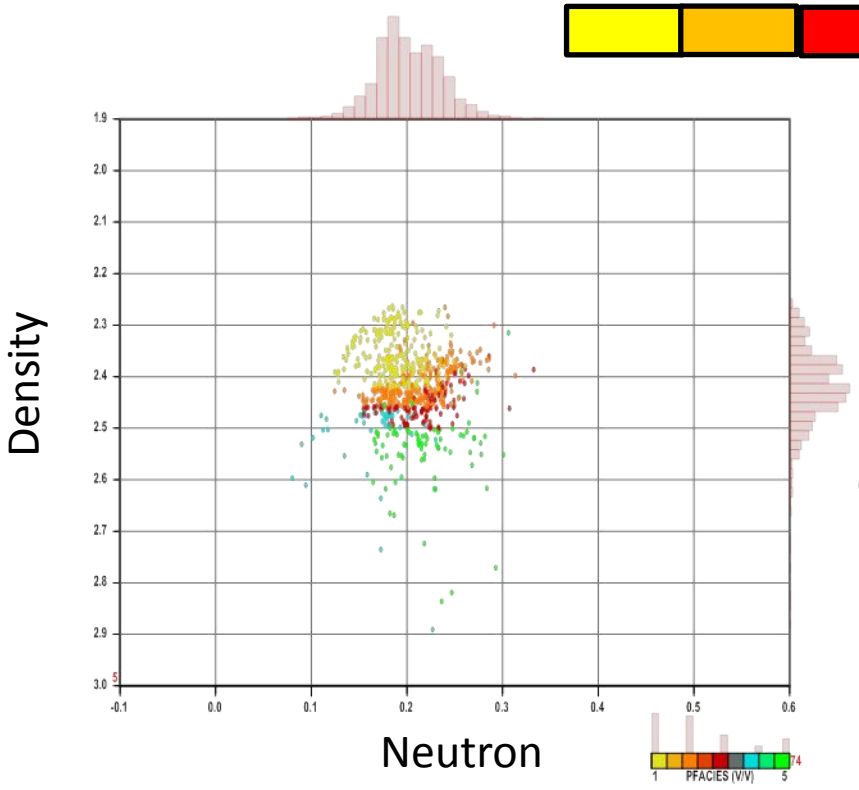
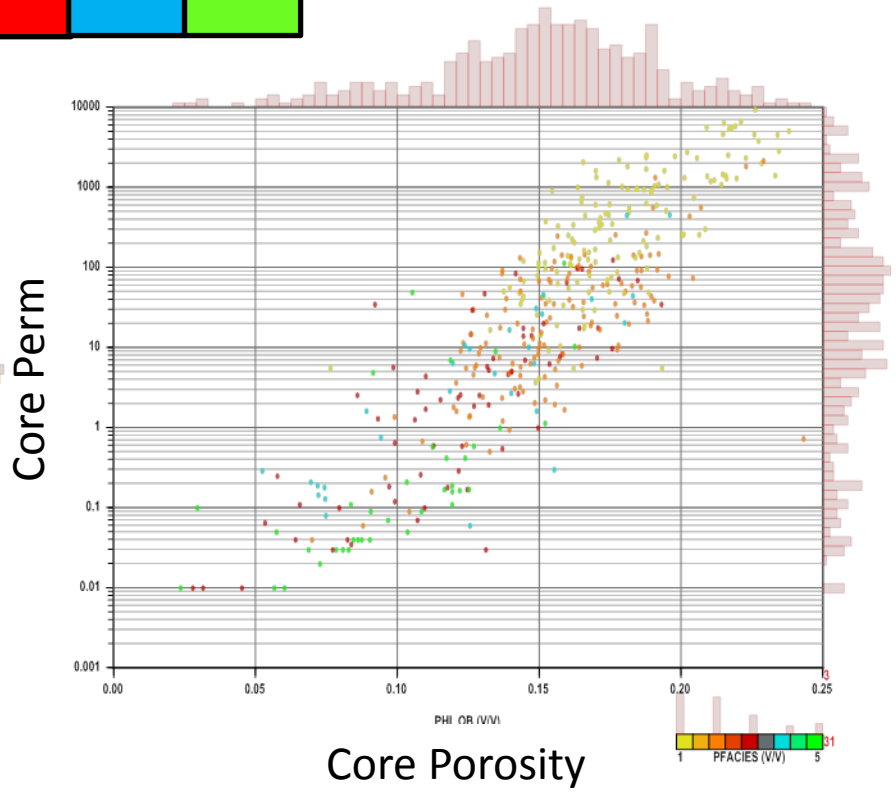


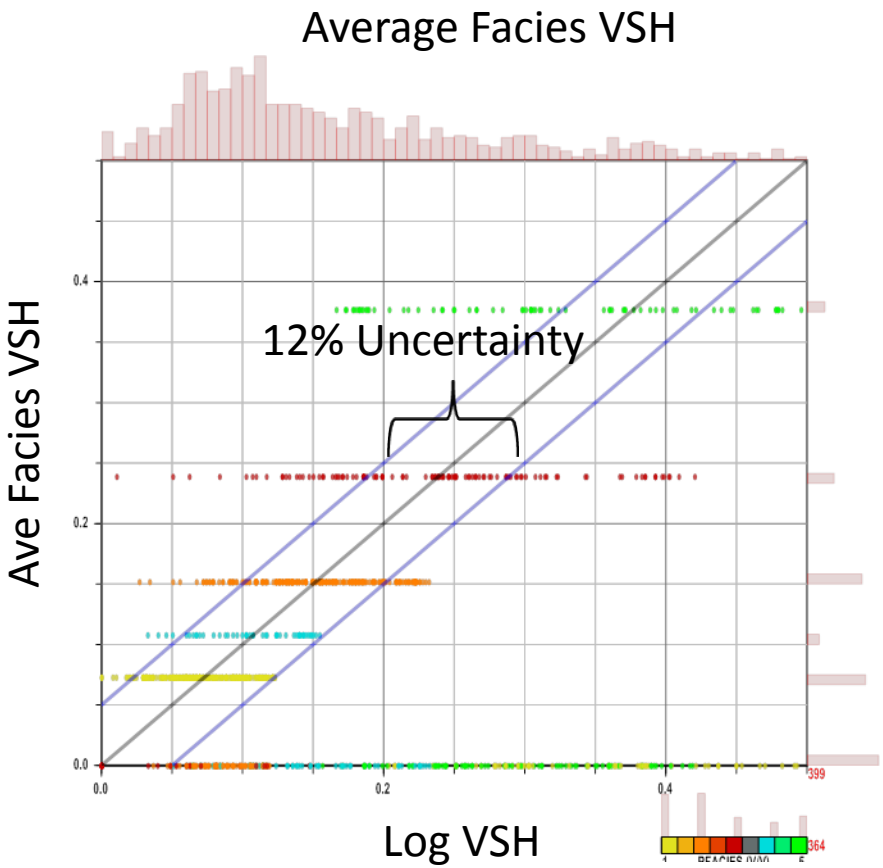
4b. Facies (Reservoir Quality) Averages

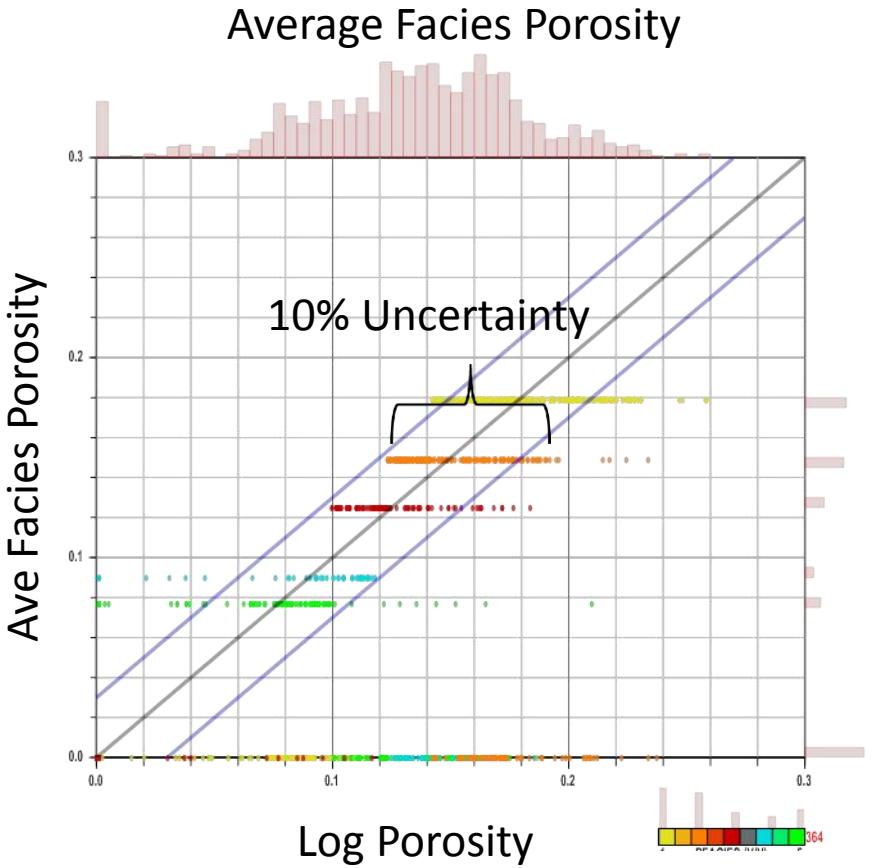
5 Reservoir Quality Facies





4b. Facies (Reservoir Quality) Averages

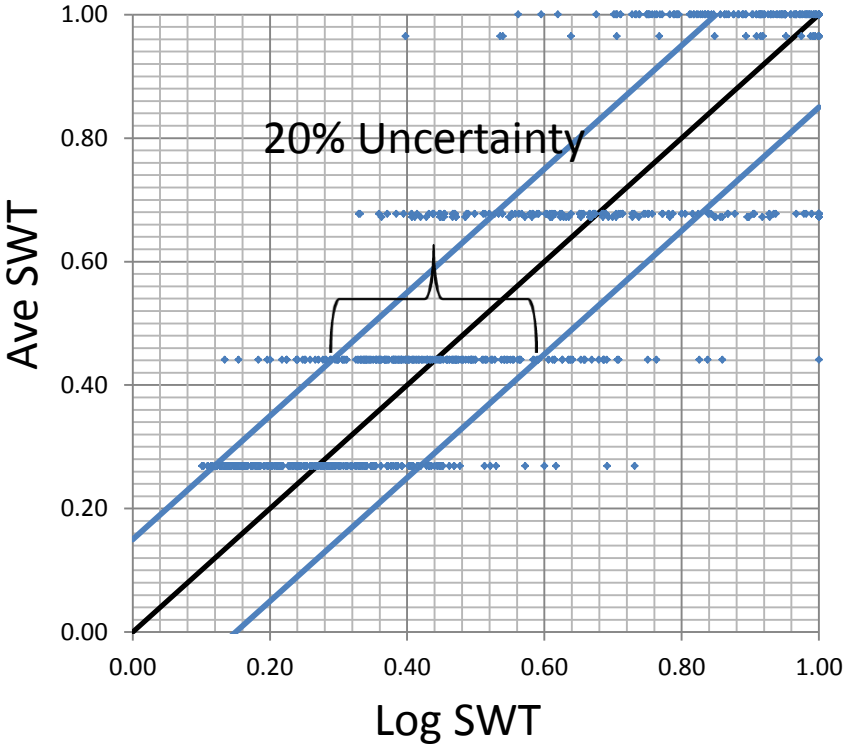




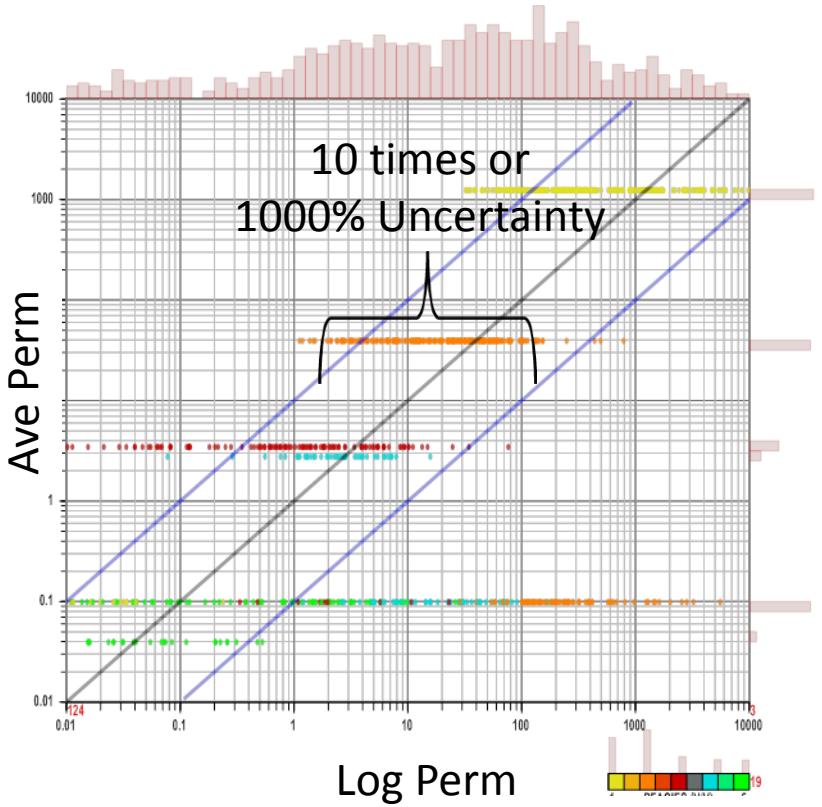
Average with Facies still cannot predict the min and max values

4b. Facies (Reservoir Quality) Averages

Average Facies SWT



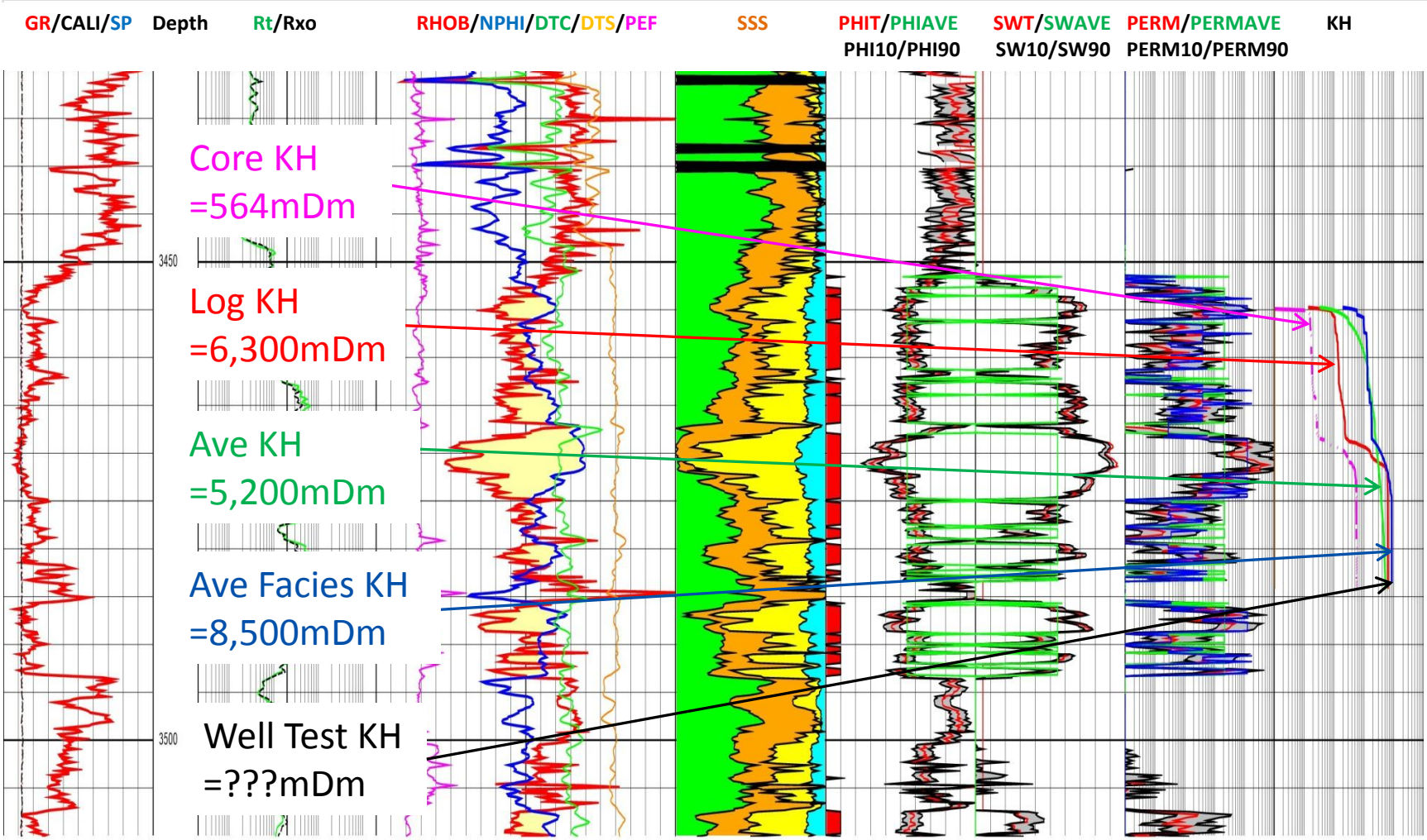
Average Facies Perm



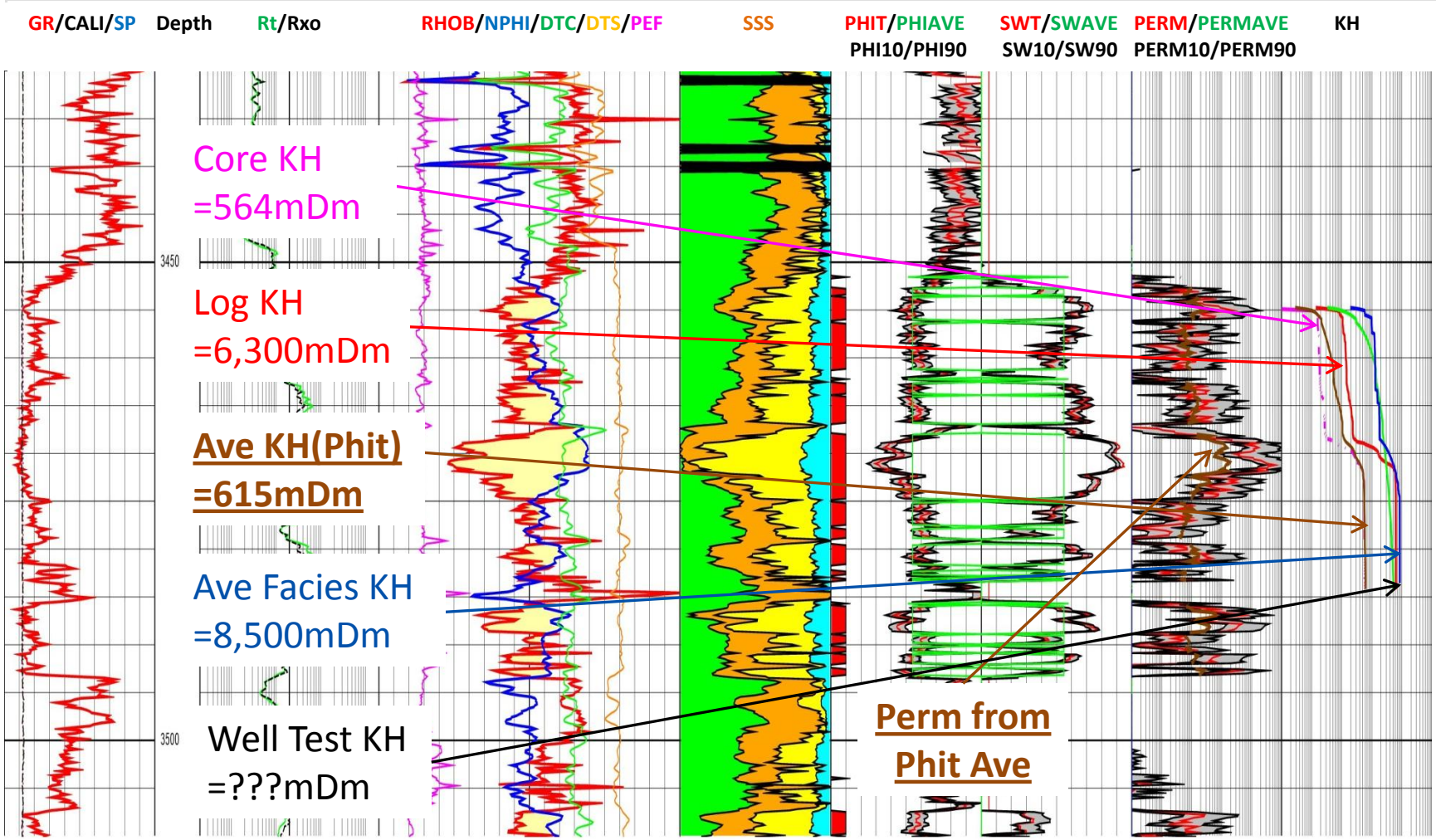
Average with Facies still cannot predict the min and max values

This is critical for perm prediction in dynamic models!

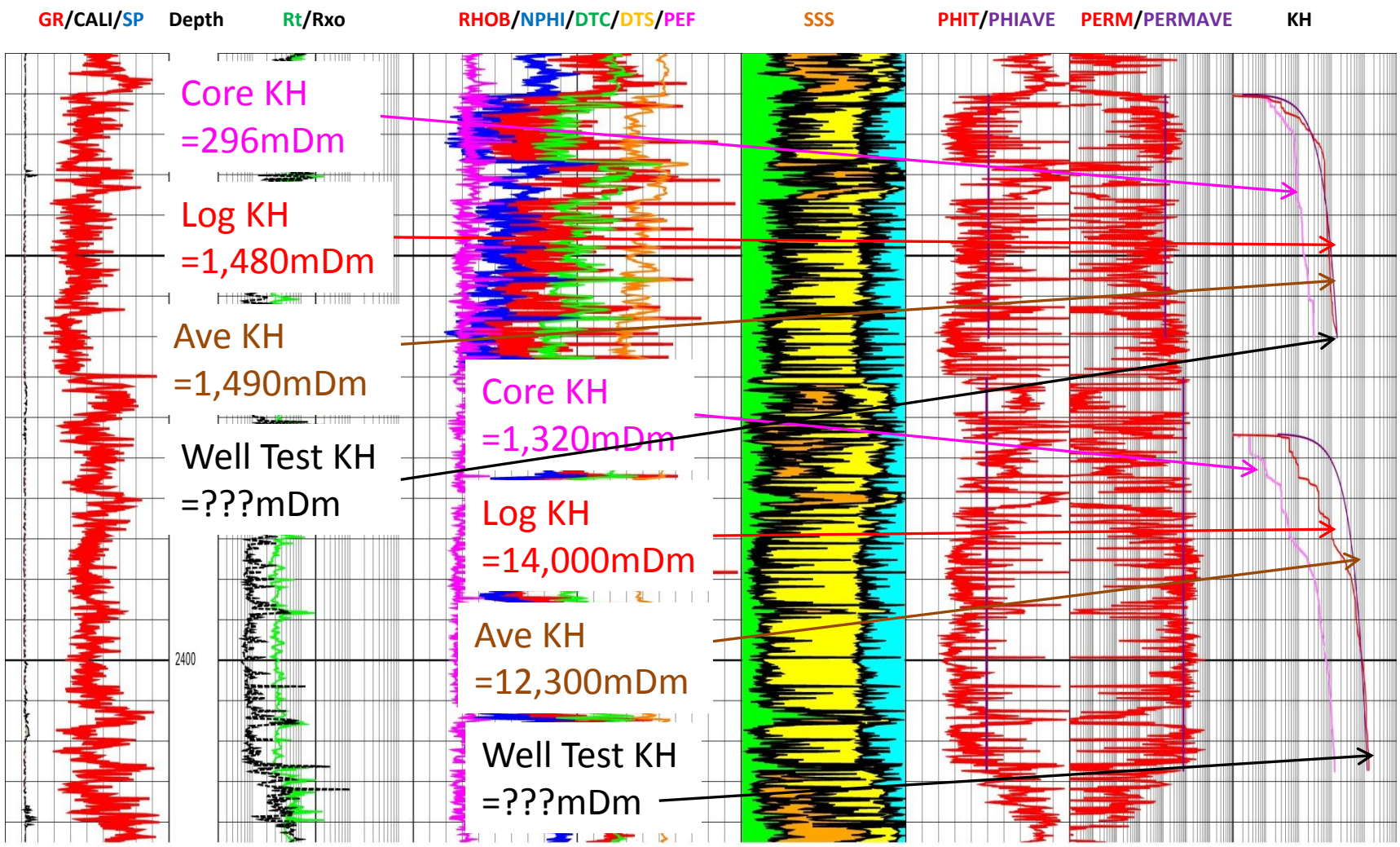
4c. Match to Well Test



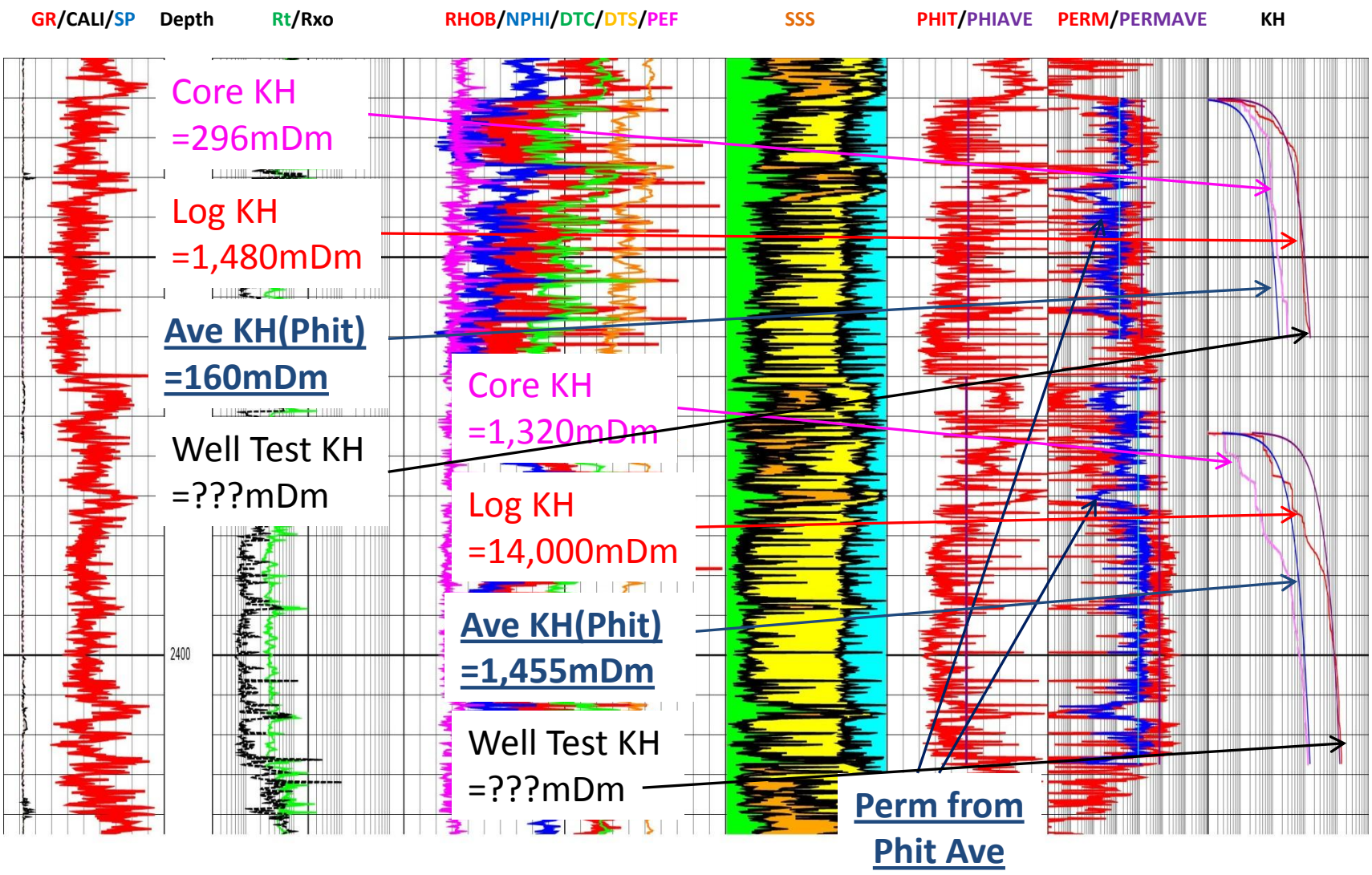
4c. Match to Well Test



4c. Match to Well Test



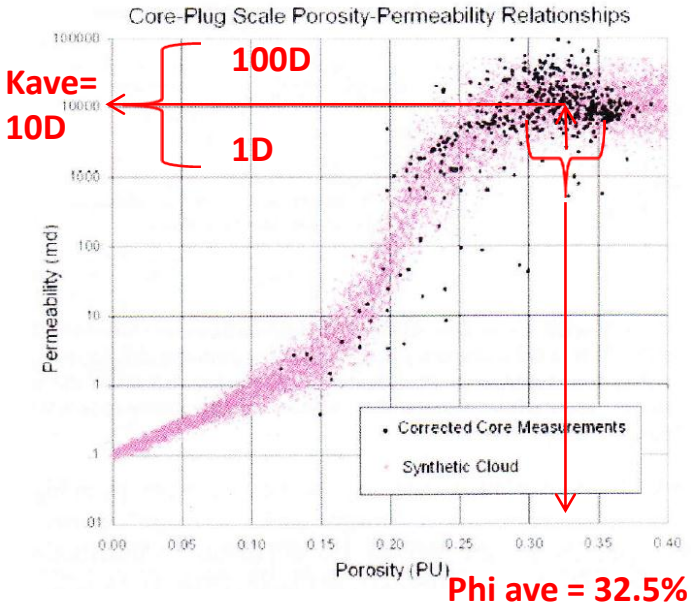
4c. Match to Well Test



5. Efforts Capture Uncertainty

1. Introduction
2. Core and Log Data Uncertainty
   a) Core Porosity and Permeability Prediction Uncertainty
   b) Log Density Porosity Uncertainty
3. Uncertainty due to “Up-scaling”
   a) Core to Log Scale
   b) Log to 3D Static Model Scale
4. Uncertainty due to Averaging
   a) Formation Averages – VSH, PHIT, PERM and SWT
   b) Facies (Reservoir Quality) Averages
   c) Match to Well Test?
5. Efforts to Capture Uncertainty
   a) Permeability Cloud Transform – Match to Well Test
6. Conclusions

5. Permeability Cloud Transform

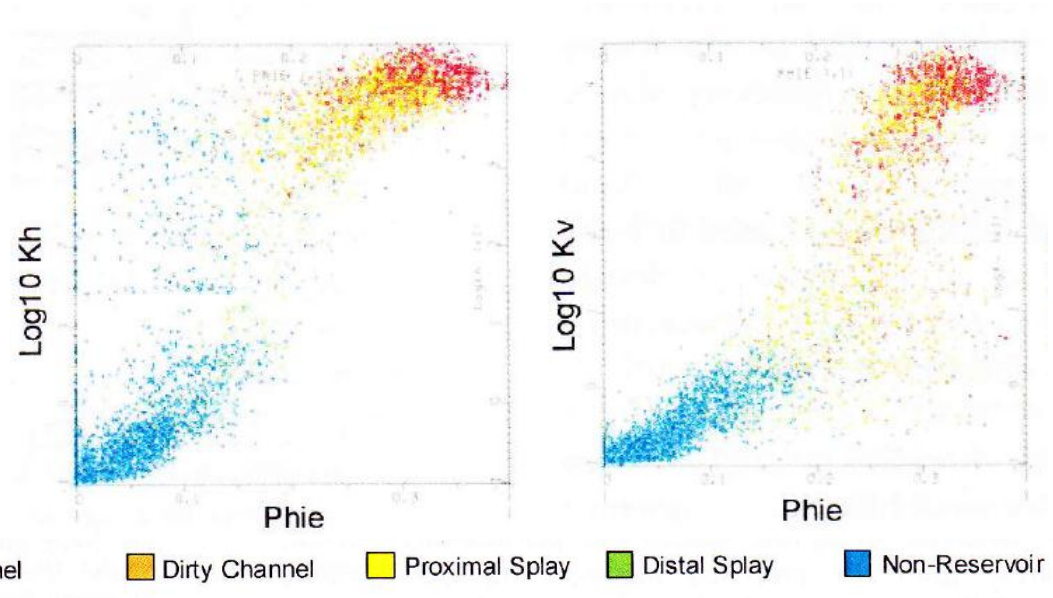


We must x-plot x-axis measured property against y-axis predicted property

"I don't care how accurate, just as long as the average and the range is the same"

We cannot predict outside the sampled range!

How certain can we be that the core or log data has sampled all the reservoir quality?
Ans: Blind testing!



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6. Conclusions

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6. Conclusions

1. Density Porosity equation uncertainty is **+/- 3.5%** and Density Log Porosity uncertainty is +/- 0.01g/cc or **+/- 5.5%.**

2. Porosity Uncertainty due to Core to Log and Log to Model (1m) up-scaling is **+/- 7%** for Porosity and **+/- 2times** for Permeability.

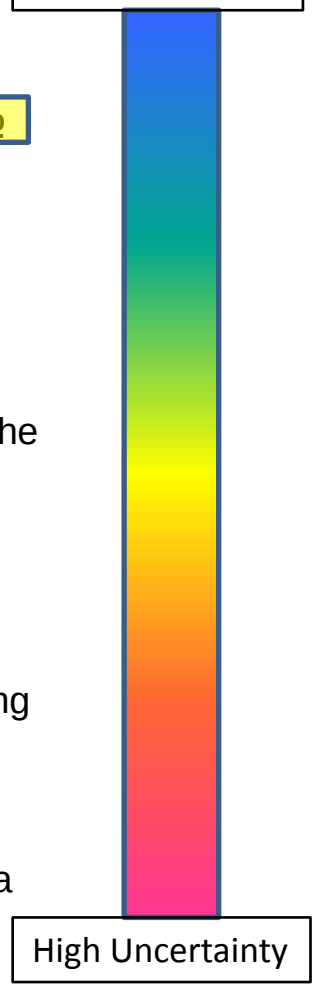
3. The high and low case uncertainties must be justified with a property prediction probability of P10/P90, not just arbitrarily assigning a P10/P90.

4. Uncertainty SHOULD reflect the full range of possible outcomes but also reflect the probability of a **precise** value. Uncertainty is NOT an estimate of the uncertainty in the average value – Re drunk on highway scenario.

5. The use of averages to "smooth out" the non-linearity of the Petrophysical relationships, **inhibits accurately** predicting the **precise** value.

6. Petrophysical continuous porosity curve uncertainty (**5.5%**) is less than the up-scaling uncertainty of **7%** and in turn is less than the uncertainty of using averages **(>20%)** even when using reservoir quality facies and net reservoir.

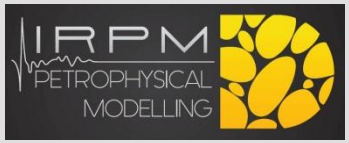
7. Permeability model prediction determined from average porosity, regularly requires a scale factor of typically **10 times** to match the true productivity (well test/dynamic model).



References

1. Sensitivity Analysis of the Parameters in Archie's water saturation Equation – H.C.CHEN and J.H.FANG University of Alabama – The Log Analyst Sep-Oct 1986
2. Modeling of Scale-Dependent Permeability Using Single-Well Micro-Models: Application to Hamaca Field, Venezuela – Mike Waite SPE 86976
3. Quantifying Petrophysical Uncertainties - Steve Adams SPE 93125
4. Quantification of Petrophysical Uncertainty and Its Effect on In-Place Volume Estimate: Numerous Challenges and Some Solutions – Arne Fylling SPE 77637
5. A Serious Look at Repeat Sections – Philippe Theys SPWLA June 1994
6. Pore Scale Estimation, Up Scaling and Uncertainty Modeling for Multiphase Properties – Rustad, Theting, Held SPE 113005
7. The Flaw of Averages and the Pitfalls of Ignoring Variability in Rock Physics Interpretation – Mukerji, Mavko Stanford Rock Physics Laboratory
8. The Application of Cutoffs in Integrated Reservoir Studies – Worthington SPE 95428

Questions?



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