VALUE OF INFORMATION (VOI) ANALYSIS USING FIELD DATA:

Accounting for Multiple Interpretations & Determining New Drilling Locations

Whitney Trainor-Guitton[1], G. Michael Hoversten[2], Gregg Nordquist[3], Robert Mellors[1] & Rindu Grahabhaki Intani[3]

[1] Lawrence Livermore National Laboratory, Livermore, CA, wtrainor@gmail.com

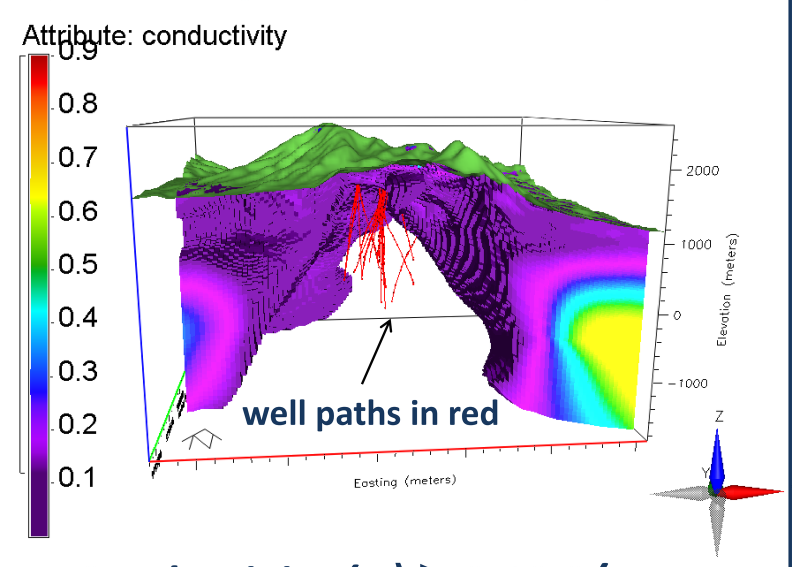
[2] Chevron Energy Technology Company, San Ramon, CA, [3]Chevron Geothermal Power Indonesia, Jakarta, Indonesia

Role of geophysical data in geothermal prospecting

Location of Darajat Field

- Darajat is a volcanic geothermal field, with total production capacity of 271 MW [1].
- **Clay cap =** high electrical conductivity feature in volcanic geothermal settings; can be indicative of geochemical alteration above the resource [2].
- MT data were collected to interpret the extension of the clay cap beyond the first development area and inverted to an electrical conductivity model[1].
- The conductivity model is used to determine relationships between the conductance & the overlying steam flow rates.

"Clay Cap" from Magnetotelluric (MT) data

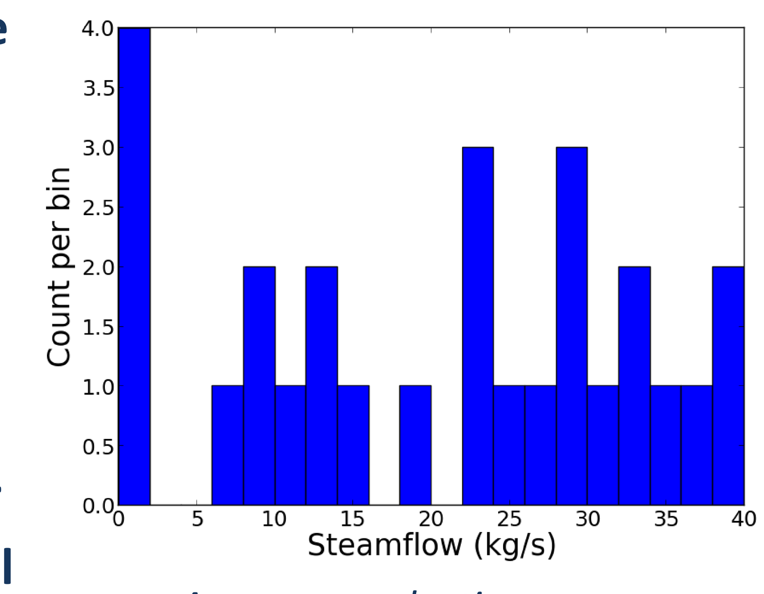


Conductivity (σ) ≥ 0.12 S/m

Project Questions

- **How well does geophysical data improve the outcome of our geothermal prospecting decisions?**
- **How much is this information worth ($)?**
- **How can we quantify the "past performance" of MT data to predict geothermal production?**

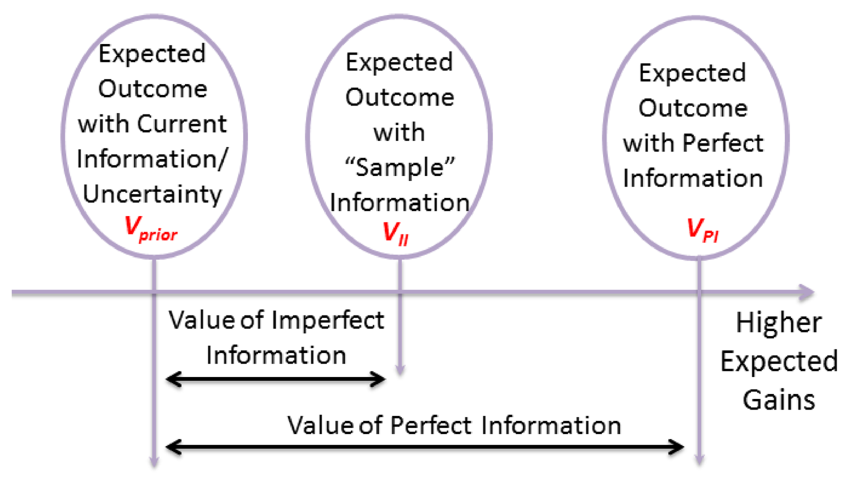
Observed Steam Flow Rates



Average production over one year for 27 different wells

Value of Information

Does the information improve (on average) our chances of drilling economic wells?

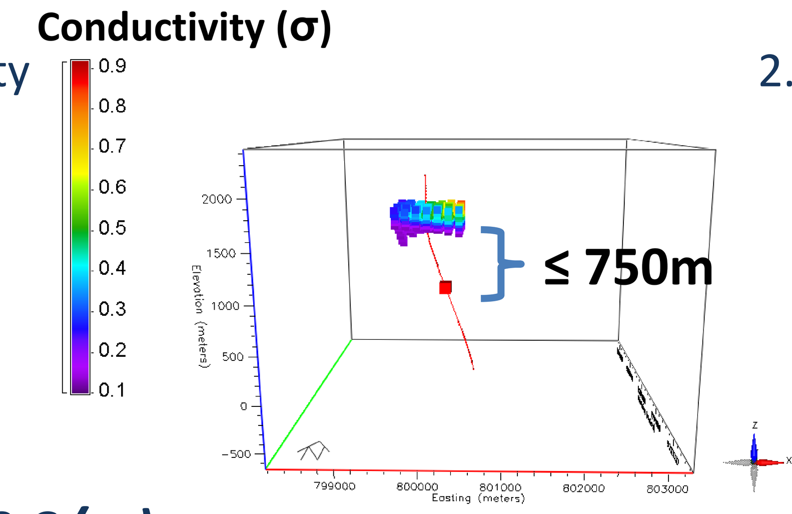


$Pr(\Theta = \theta_i)$ *Prior probabilities of 7 steam flow categories (θ)*

Steam flow category	Steam Flow Rate (kg/s)	Nominal value gain/loss	a) Prior from steam flow data	b) Alternate prior
$\theta_{i=7}$	$30 < \theta_i$	$ 700K	26%	10%
$\theta_{i=6}$	$25 \le \theta_i \le 30$	$ 300K	15%	10%
$\theta_{i=5}$	$20 \le \theta_i \le 25$	$ 125K	15%	10%
$\theta_{i=4}$	$15 \le \theta_i \le 20$	$ 40K	7%	10%
$\theta_{i=3}$	$10 \le \theta_i \le 15$	$ 0	11%	10%
$\theta_{i=2}$	$5 \le \theta_i \le 10$	$ -200K	11%	10%
$\theta_{i=1}$	$\theta_i \le 5$	$ -500K	15%	40%

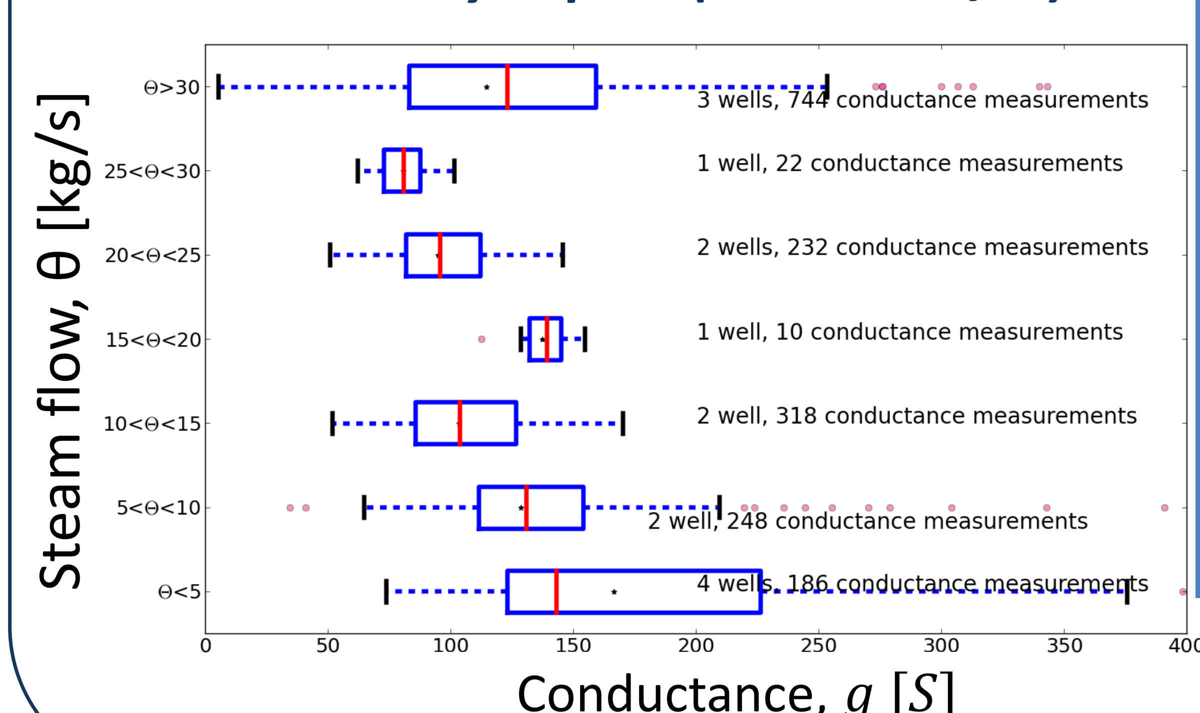
Deduce trends between conductance (g) & steam flow (θ)

1. Define 2 clay caps with 2 conductivity cutoffs (thresholds):
   - ≥ 0.12 S/m
     - *Delineates thinner cap*
   - ≥ 0.10 S/m
     - *Delineates thicker cap*



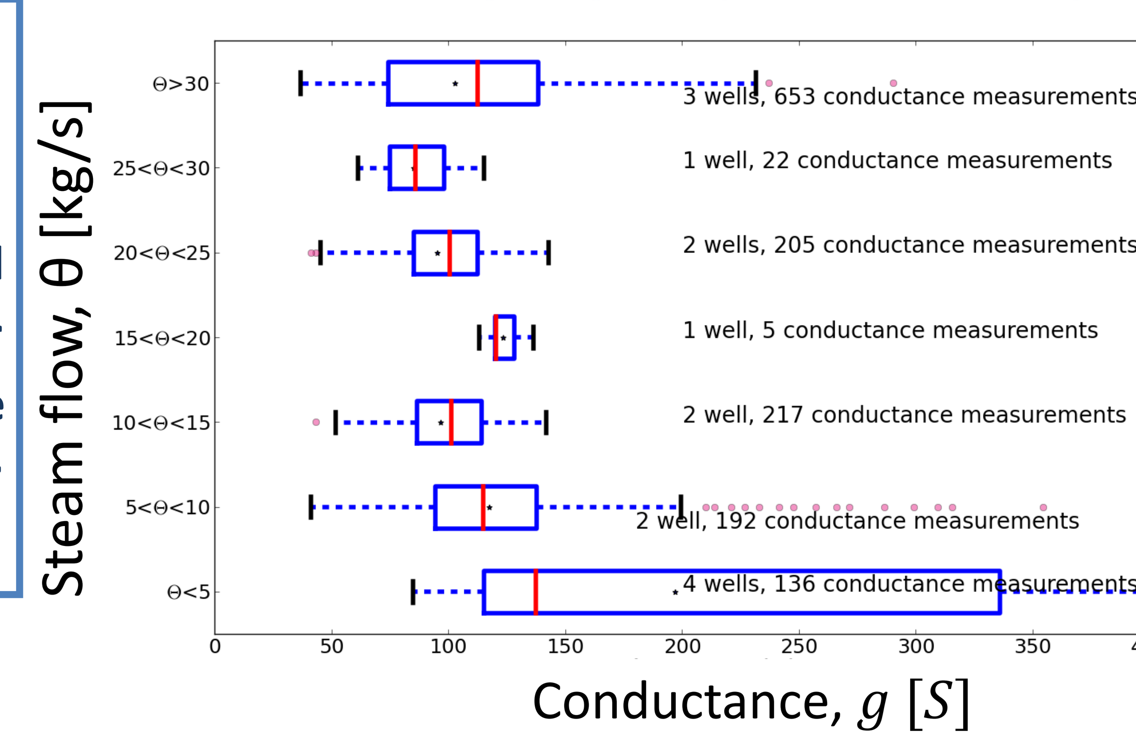
2. Determine co-located steam rates & conductance (thickness x conductivity):
   - 750m as cutoff distance
   - Represents lower quartile (Q1) of distances between midpoint of feed zones and conductance voxels

Clay cap #1 (σ ≥ 0.12 S/m)



In general, higher steam flow is associated with smaller conductance (e.g. thinner clay cap) [3]

Clay Cap #2 (σ ≥ 0.10 S/m)

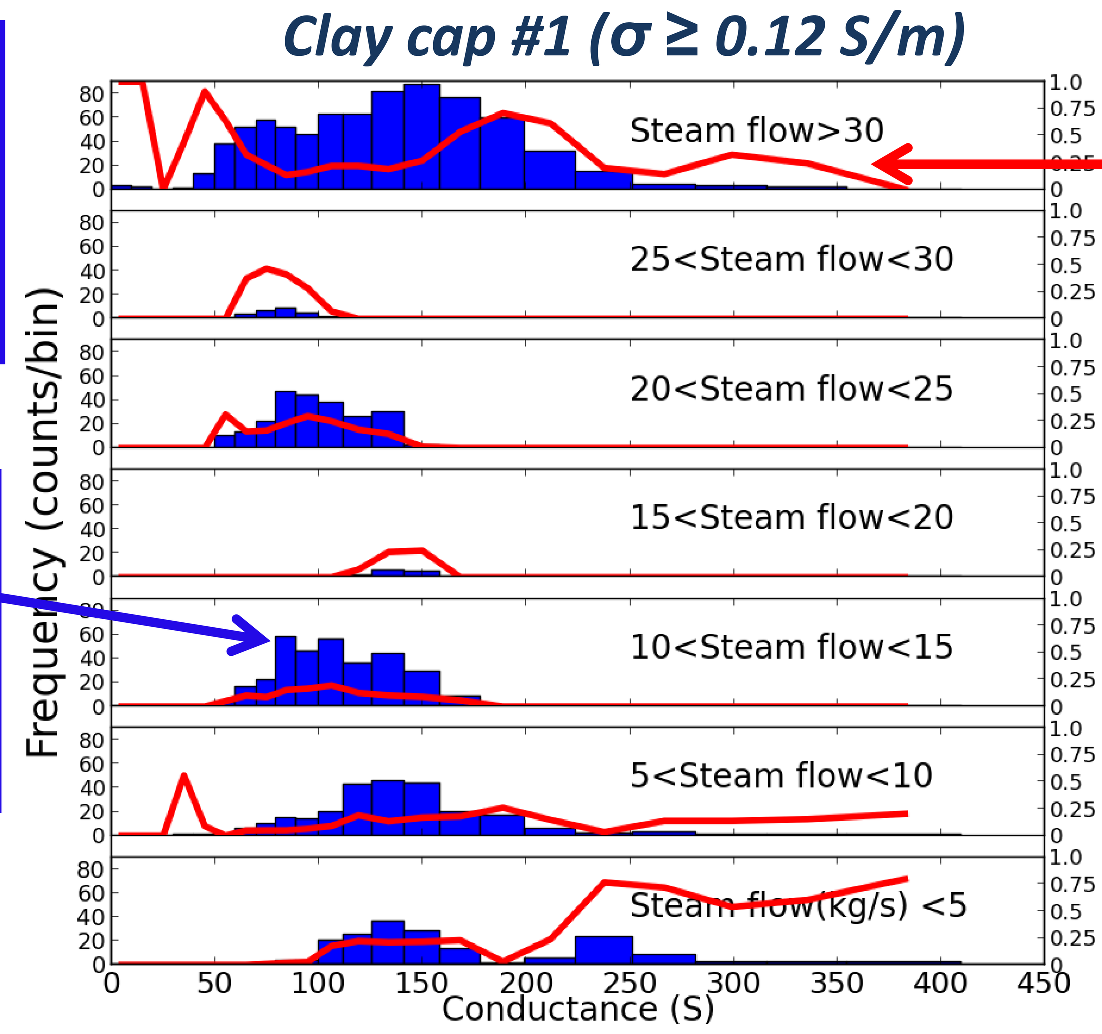


Quantify probabilistic relationships between g and θ

How likely are certain conductance value bins (g_j) given we know the associated steam flow categories (θ_i)?

Each bar represents number (c_{ij}) of conductance voxels associated with each steam flow category

Clay cap #1 (σ ≥ 0.12 S/m)



How unique is each conductance bin relative to all steam flow categories?

Bayes Law to combine likelihood and prior:

Likelihood

$$\mathbf{Pr(G = g_j | \Theta = \theta_i) = \frac{c_{ij}}{\sum_i c_{ij}}}$$

Count of Conductance of bin j

Sum over all 7 steam categories

Posterior Probability

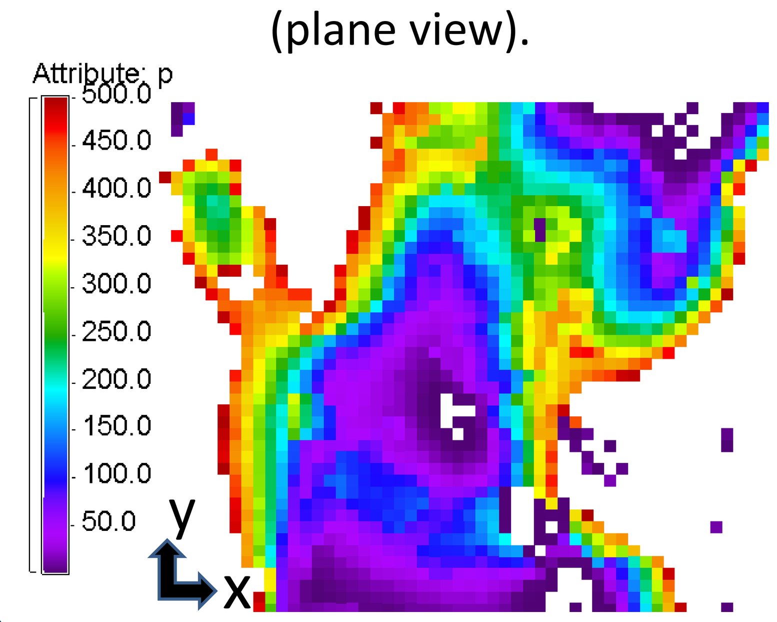
$$\mathbf{Pr(\Theta = \theta_i | G = g_j)}$$

When posterior ~1, conductance is more reliable in determining steam flow category

Determine next drilling campaign

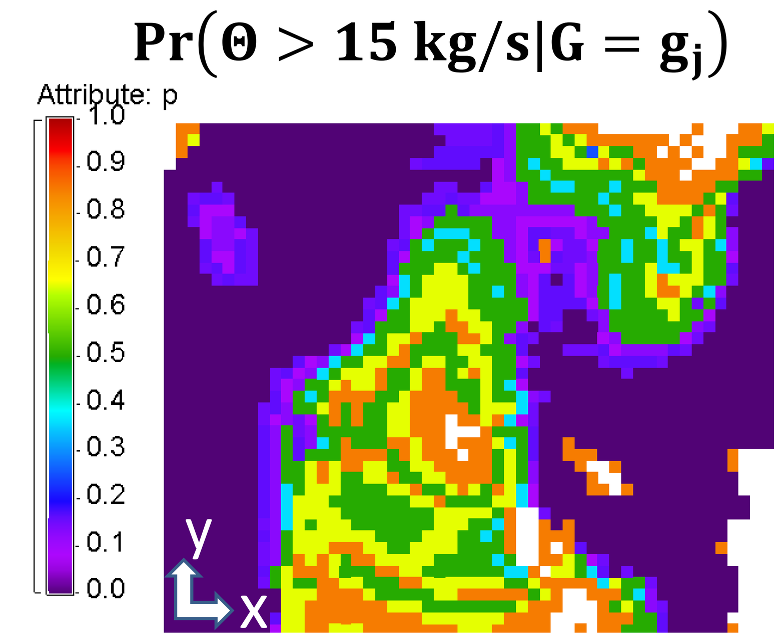
Conductance (g) [S]

0.12 S/m clay cap (plane view).



Probability Map

$$\mathbf{Pr(\Theta > 15\ kg/s | G = g_j)}$$



VOI Nominal Results & Summary

$$V_{imperfect} = \sum_{j=1}^{J} Pr(G = g_j) \sum_{i=1}^{7} [\mathbf{Pr}(\Theta = \theta_i | G = g_j) v_a(\theta)]$$

Prior Probability:	Clay Cap defined by threshold:	0.12 Siemens/ m	0.10 Siemens/ m
According to data	V_{prior}	$151,550	$151,550
	$V_{imperfect}$	$162,580	$171,500
	$VOI_{imperfect}$	**$11,030**	**$19,950**
Alternate prior	V_{prior}	$0	$0
	$V_{imperfect}$	$48,775	$37,090
	$VOI_{imperfect}$	**$48,775**	**$37,090**

- MT data has more value if probability of "dry hole" is larger, e.g. alternate prior
- The $VOI_{imperfect}$ using 0.1 S/m clay cap calibration is higher when $\mathbf{Pr}(\Theta > 30)$ is higher: the conductance for this category has less overlap with others
- This reverses for alternate prior with higher $\mathbf{Pr}(\Theta < 5)$.

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