Properbase

A new property upscaling guideline for the geothermal industry

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IF Technology **Creating energy**

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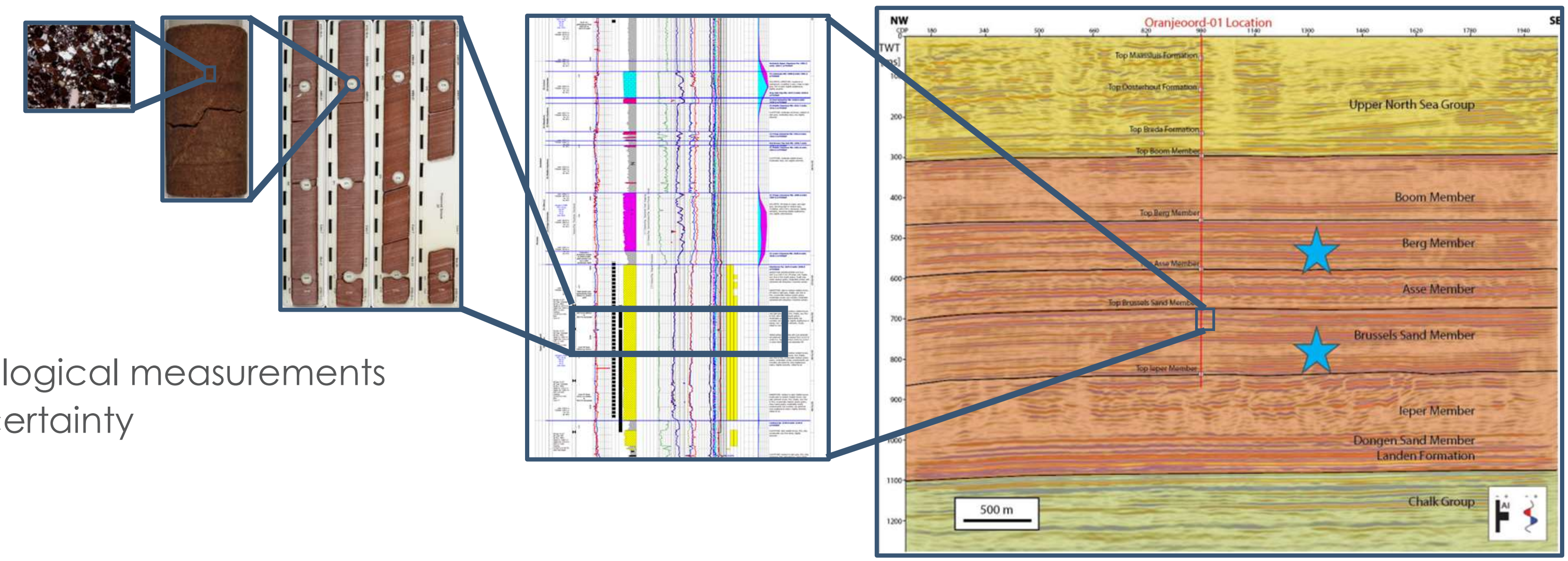
Introduction

Subsurface measurements are sparse in time and space

Observations on different scales and different resolutions

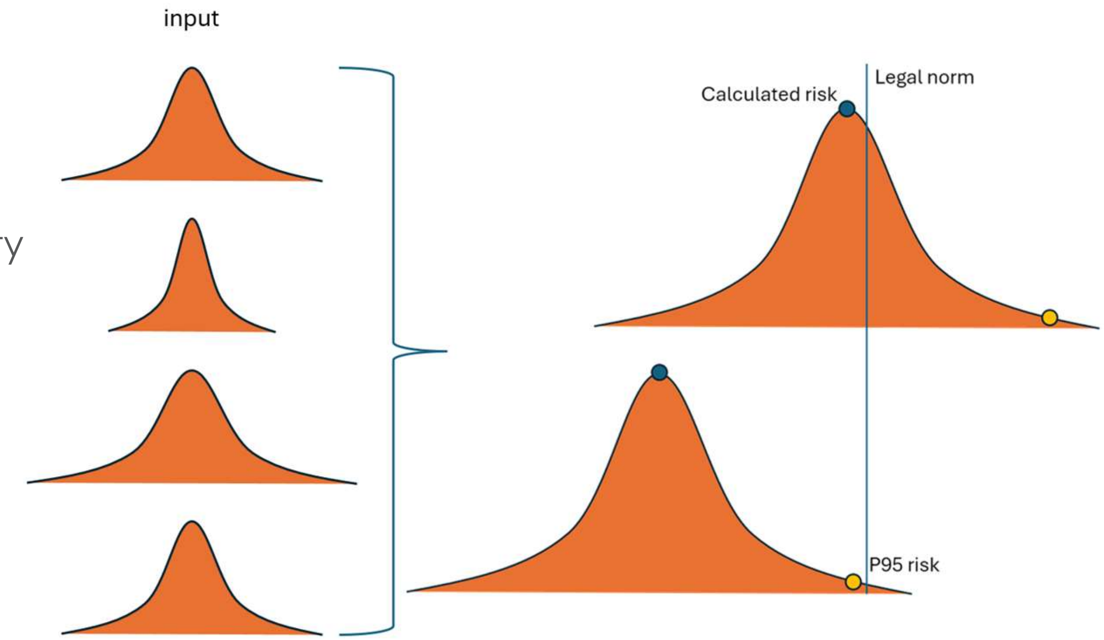
- Microscopic
- Plug scale
- Core scale
- Log scale
- Well-test scale
- Reservoir scale



The sparsity of geological measurements always create uncertainty

Uncertainty

- Uncertainty is always a part of the decision process
- Knowing the source of your model input parameters is important to estimate uncertainty
- Robust upscaling guidelines help to quantify, and, where possible, reduce uncertainties



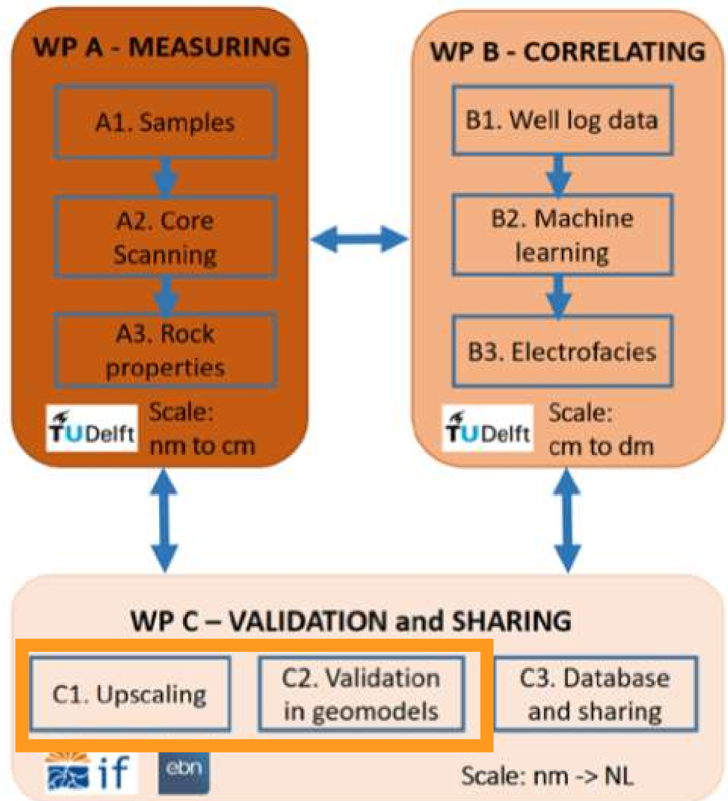
Properbase WP C1 – Upscaling

- Properbase is a TKI-project

- The Properbase project has the ambition to significantly enhance the knowledge, mapping, and prediction of the geological character of Dutch geothermal plays, focusing on thermal and geomechanical properties.

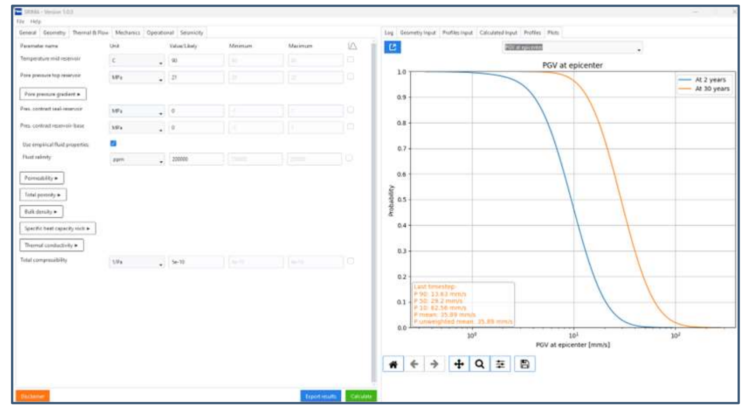
- WP-A & B focus on measuring and correlation (see previous presentation by Parvin)

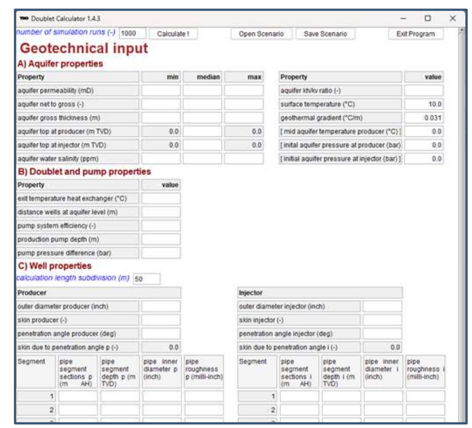
- WP-C is on upscaling and validation



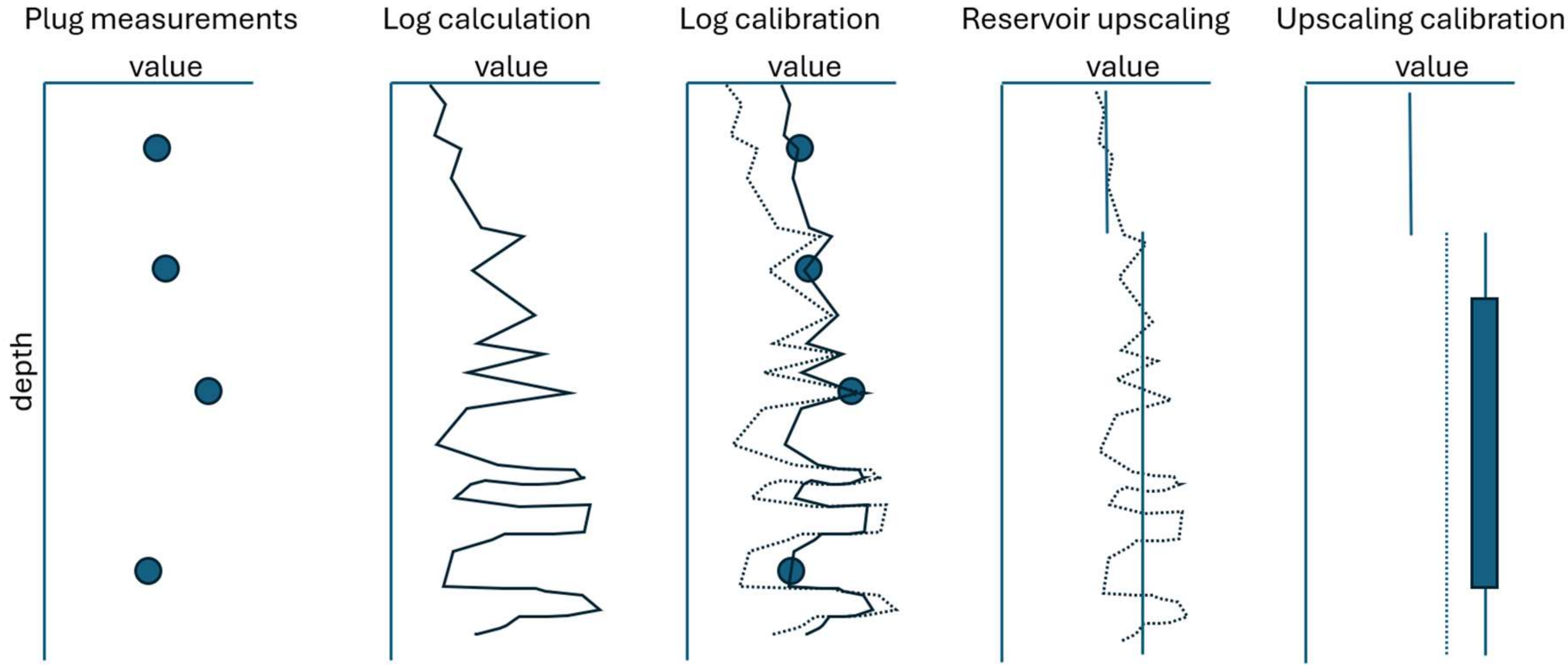
Objective

- Create guidelines to obtain best value and its uncertainty
- Target is input for geomodel applications used in the Dutch geothermal industry.
- The project focused on flow, geomechanical and thermal properties.
- Techniques include
  - Measurements
  - Upscaling
  - Calibration



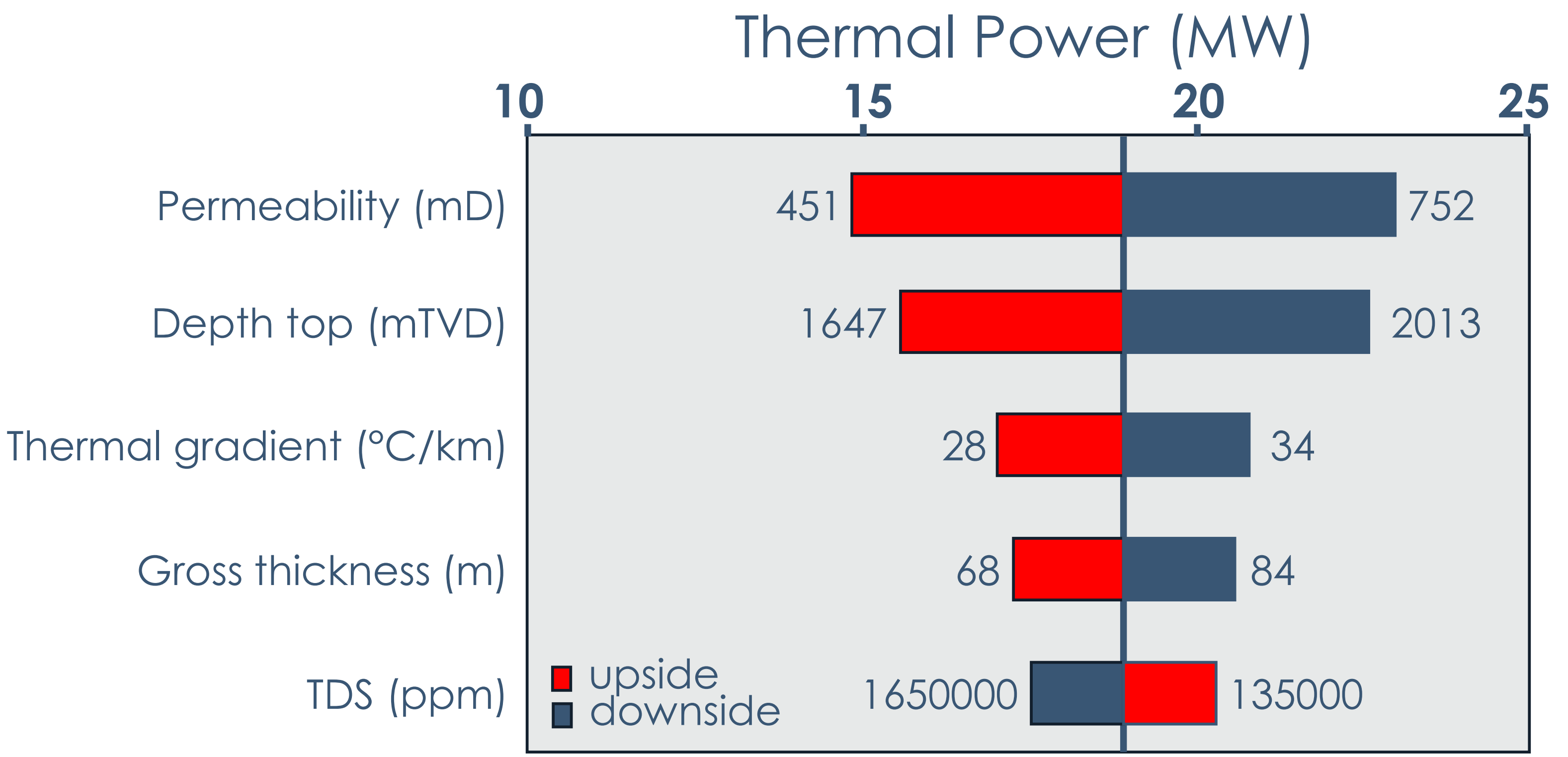


Upscaling Workflow



Parameter	Needed for	Impact on thermal power	Impact on estimating seismic risk	Impact on estimating caprock integrity	Typical uncertainty (pre-drill)
General rock properties					
Depth [mTVD]	SDE++/SDRA	High	Low	Low	Low
Thickness (gross) [m]	SDE++/SDRA	High	Low	Low	Low
Net/Gross [-]	SDE++/SDRA	High	Low	Low	Low/Med
Salinity [ppm]	SDE++/SDRA	Med	Low	Low	Low/Med
Porosity [-]	SDE++/SDRA	Low	Low	Low	Low/Med
Flow properties					
Permeability [mD]	SDE++/SDRA	High	Low	Low	Med/High
Geomechanical					
Compressibility (rock) [1/Pa]	SDRA	Low	High	High	Med/High
Young's modulus [GPa]	SDRA	Low	High	High	Med/High
Poisson ratio [-]	SDRA	Low	Med	Med	Med
Biot coefficient [-]	SDRA	Low	Low	Med	Med
Thermal exp. coeff. [1/K]	SDRA	Low	High	High	High
Friction coefficient [-]	SDRA	Low	High	High	Low/Med
Unconf. compr. Strength (UCS) [MPa]	SDRA	Low	Low	Low	Med/High
Vertical Stress (S_V) [MPa]	SDRA	Low	Low	Low	Low
Min. Hor. Stress (Sh) [MPa]	SDRA	Low	High	High	Med/High
Direction stress field [°]	SDRA	Low	Med	Low	Med/High
Max. Hor. Stress (SH) [MPa]	SDRA	Low	Med	Low	High
Thermal properties					
Heat capacity (rock) [J/kg/K]	SDRA	Low	Low	Low	Low/Med
Thermal conductivity (rock) [W/(m k)]	SDRA	Low	Low	High	Med
Reservoir temperature [°C]	SDE++/SDRA	High	Low	Low	Low

Permeability

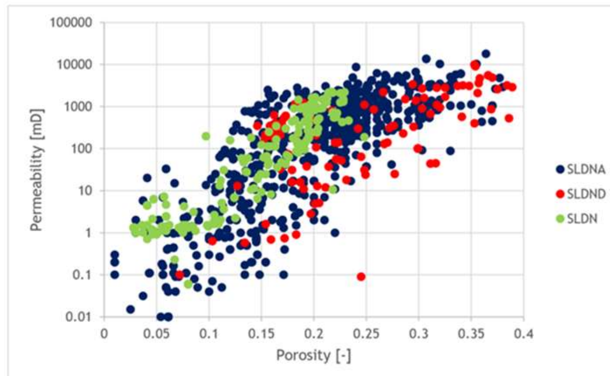


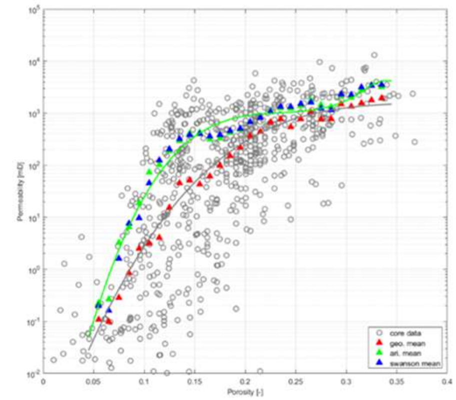
Source: Master Thesis L. Borst

Permeability

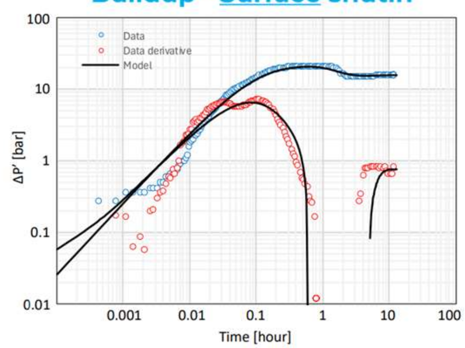
- Permeability and porosity measurements on core plugs
- Create poro-perm equations
- Using porosity log (e.g. NPHI or density-based porosity) to calculate permeability log
- Upscale permeability log to reservoir scale
  - Arithmetic (flow parallel to layering)
  - Harmonic (flow perpendicular to layering)
  - Geometric (no obvious layering)
- Calibrate versus well test

Source: IF Technology (2021)

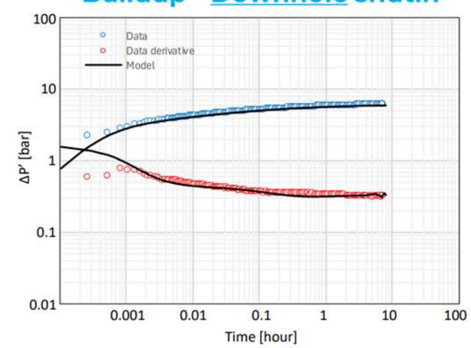




Buildup - Surface shutin



Buildup - Downhole shutin



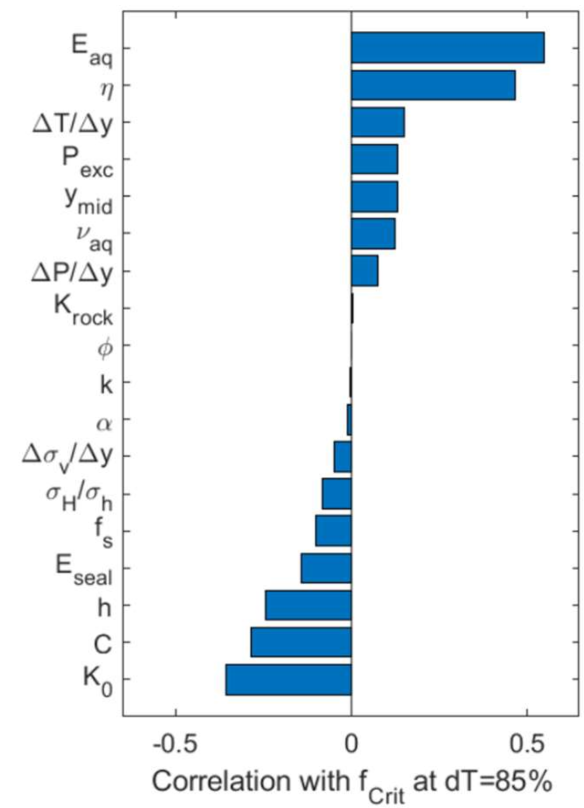
Source: P. Bruinen EAGE GET 2024

Young’s modulus (I)

Young’s modulus (E) has large effect on stress changes due to temperature changes

$$\frac{\Delta\sigma_h}{\Delta T} = \frac{E}{1-\nu}\beta$$

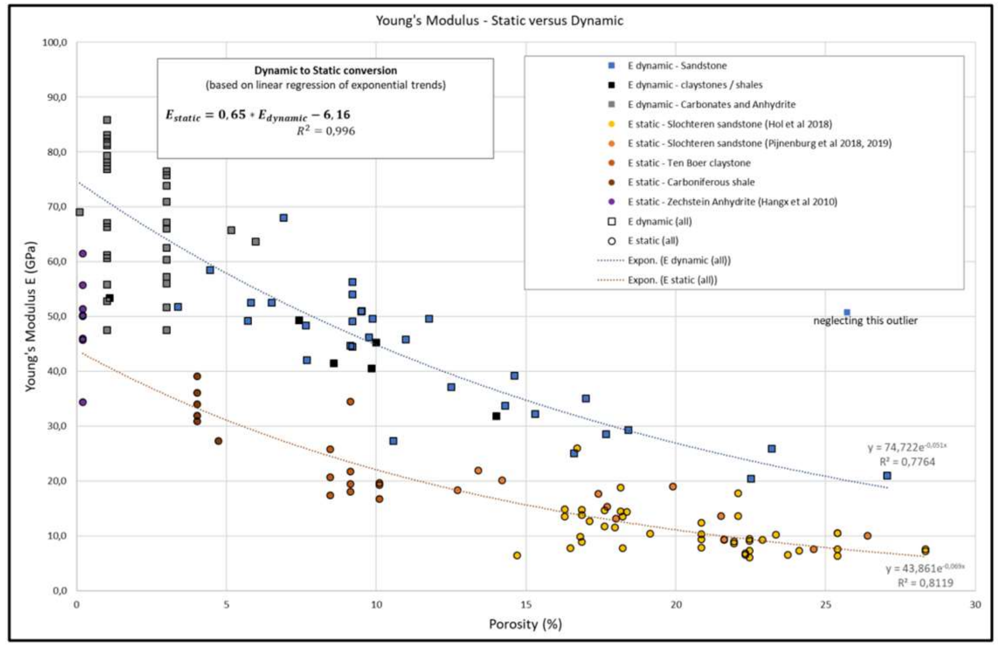
Important both for SDRA and caprock integrity



Source: WarmingUp project

Young's modulus (II)

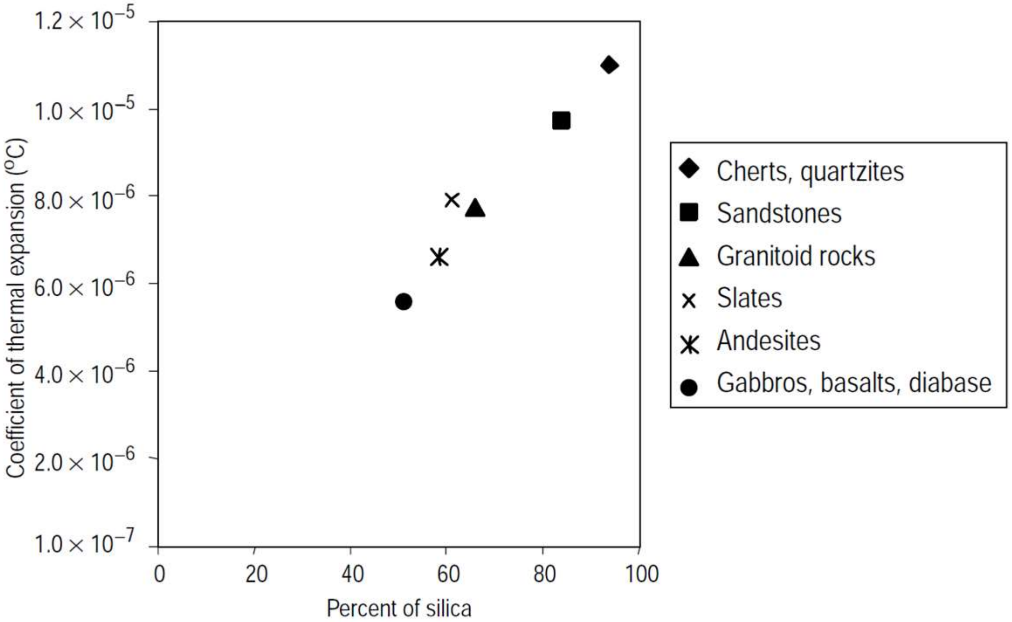
- Static E is measured on core plugs
- Dynamic E can be calculated from sonic logs (using V_p and V_s)
- Static E log is calculated using an E_{dyn} to E_{stat} conversion
- E_{stat} log is upscaled using:
  - Arithmetic (Voigt)
  - Harmonic (Reuss)
  - Average Voigt & Reuss (Hill)
- No real calibration possible for upscaled property



Example E_{dyn} to E_{stat} from DHAIS study (2021) (TNO)

Thermal expansion coefficient

- Good correlation between mineralogy and thermal expansion coefficient
  - Use cuttings to estimate mineralogy
  - Use mineralogy to estimate thermal expansion coefficient
- Us Harmonic and Arithmetic upscaling for upper and lower bound
- No calibration for upscaling possible



Source: Reservoir Geomechanics, Mark Zoback, 2007.

Summary Properbase

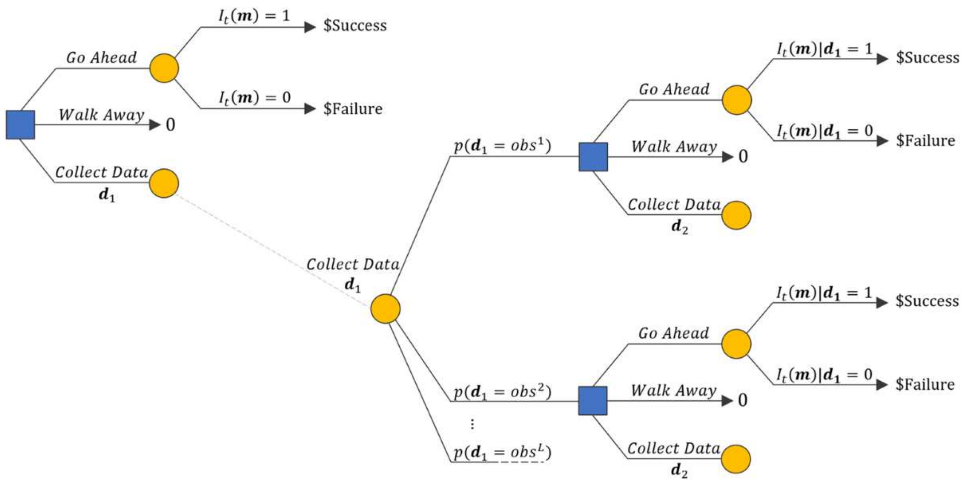
- Most parameters can be measured on core with low uncertainty
- Many parameters can be estimated using logs with low or medium uncertainty
- Most parameters can be upscaled to reservoir scale with medium uncertainty
- Only a few parameters can be calibrated versus well tests

	Core measurement	Log measurement & calibration	Upscaling to reservoir scale	Calibration of Upscaling
density				
porosity				
permeability				
Young's modulus				
Poisson's ratio				
compressibility				
Biot coefficient				
thermal expansion coefficient		(from cuttings)		
specific heat capacity		(from cuttings)		
thermal conductivity				
thermal diffusivity				

Parameter	Wireline log and/or logging while drilling										Core	Rock and fluid samples			Well test			Desk study	Impact on geothermal project			
	RHOB	NPHI	NMR	Vp	Vs	GR	Caliper	4 arm Caliper	RES	Image log	Lab tests	XRD cuttings	Fluid samples	Temperature samples	Well test	(X)LOT/FIT	Interference/ Spinner test	Literature / offset data	Thermal power	seismic risk	caprock integrity	Pre-drill uncertainty
Depth top reservoir	YC	YC		YC		Y	Y			Y		Y					YC	P	Low	Low	Low	Low
Thickness (gross)	YC	YC		YC		Y	Y			Y		Y					YC	P	High	Low	Low	Low
Net/Gross	YC	YC		YC		YC			E								Y	P	High	Low	Low	Low/Med
Porosity	YC	YC	Y	YC		I	I		E		Y		I		P		P	P	Low	Low	Low	Low/Med
Permeability	P	P	YC	P		I	I		E		Y				Y		YC	E	High	Low	Low	M/H
Salinity							P		P				Y	I	Y			P	Med	Low	Low	Low/Med
Reservoir temperature														Y	Y			P	High	Low	Low	Low
Direction stress field								Y		Y								E	Low	Med	Low	M/H
Vertical Stress (SV)	Y			P	P													P	Low	Low	Low	Low
Max. Horizontal Stress (SH)							I	I		I						P		E	Low	Med	Low	High
Min. Horizontal Stress (Sh)	P			P	P											Y		E	Low	High	High	Med/ High
Heat capacity (rock)							P				Y	YC						P	Low	Low	Low	Low
Thermal conductivity (rock)							P				Y	YC						P	Low	Low	High	Low
Compressibility (rock)	P	P		P	P						Y				P			E	Low	Low	Low	M/H
Young's modulus	P	P		P	P						Y				P			E	Low	High	High	M/H
Poisson ratio				P	P						Y							E	Low	Med	Med	Med
Biot coefficient	P	P		P							Y				P			E	Low	Low	Med	Med
Thermal expansion coefficent											Y	YC						E	Low	High	High	High
Friction coefficient											Y							E	Low	High	High	Med

Value of Information

- Value of Information (VoI) is describing the potential worth of a project with and without the extra information
- If worth difference is higher than the cost of the information, then it is worthwhile to obtain the information
- VoI is very project specific
- Some information are "standard", others might be useful to measure. Especially if the development is larger (e.g. multi doublets)

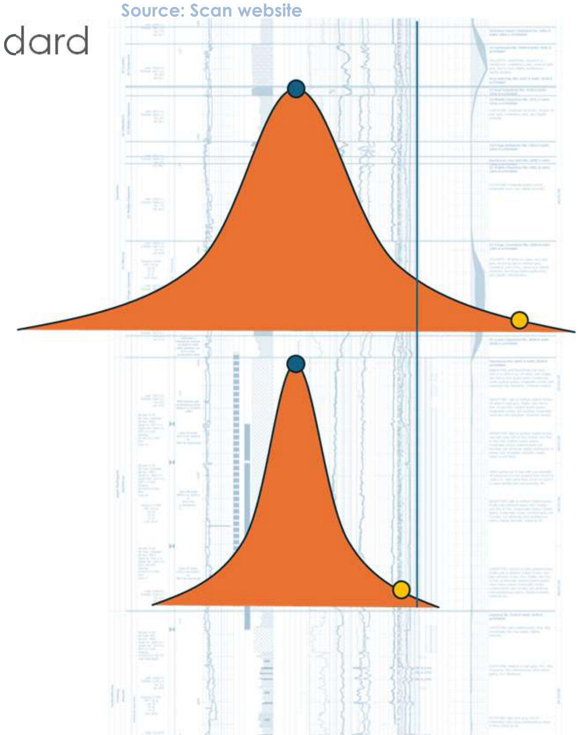


Data gathering for geothermal projects

Measurements within a standard drilling campaign:

- ☐ Gamma-ray,
- ☐ Litholog,
- ☐ ROP,
- ☐ Caliper,
- ☐ cuttings,
- ☐ wash-out well test,
- ☐ fluid samples and
- ☐ temperature samples.

Source: Scan website



Proposed additional measurements:

- ☐ XRD analysis of cuttings (€)
- ☐ Well logs:
  - Di-pole sonic log (Vp & Vs) (€€),
  - Density log (€€),
  - 4 arm-caliper log (€€)
- ☐ Well-test and/or interference test (€€/€€€)
- ☐ (X)LOT well test (€€).
- ☐ Core (€€€€)
  - can be very useful, especially in developments with multiple wells.

And now?

The presented property upscaling guideline for the geothermal industry is currently under review by external specialists

The guideline will become public available

Feedback on the guideline is welcome

Please remember: no guideline can replace critical thinking from domain specialists