

#### Application of Oil and Gas Subsurface Evaluation Methodology to Geothermal: The Value of Data

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Society of Petroleum Engineers Distinguished Lecturer Program www.spe.org/dl



Source: The Scotsman





Source: North Edinburgh News

# We're the Society of **PETROLEUM** Engineers **WHY SHOULD WE CARE ABOUT GEOTHERMAL?**

### The Future of Energy?





- 195 countries ratified the Paris agreement
- Restrict global temperature increase to below 2 °C
- Will require significant reduction in carbon production, reduction in hydrocarbon use
- Will require significant increase in renewables use







- Wind
- Solar
- Hydro
- Biomass
- Geothermal

#### What is Geothermal Energy?



Geothermal energy is heat within the earth. The word geothermal comes from the Greek words geo (earth) and therme (heat). Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings, and to generate electricity

(from https://www.eia.gov/energyexplained/geothermal/)

### Geothermal Energy Applications



	Туре	Approx. Depth	Temperature	Applications	Examples
Increasing	Heat Pump	< 150m	< 40 °C	Small scale (domestic) heating and cooling	Worldwide
	Low Temperature	< 2500m	40-100 °C	District Heating, Agriculture (greenhouse heating)	Netherlands, France, Germany
Depth	Mid Temperature	< 4000m	100-150 °C	Industrial uses (Food processing, industrial drying)	East Africa, New Zealand
_	High temperature	> 4000m	> 150 °C	Power Generation	Iceland, California, Turkey







#### Geothermal Systems





Direct use – direct use of hot water produced from formation Hydrothermal and enhanced - uses a 'doublet'

- Cold water injected into formations by injection well, heated and produced from producer well
- Commonly passed through heat exchanger to heat working fluid

#### **Closed loop system**

 Separates formation fluids from surface equipment

#### Comparing to Other Renewables



#### Pros

Potentially available everywhere

Can provide constant baseload

Practically zero emissions

Little reliance on variable environmental factors (sun, wind)

Small footprint when installed

Potential long project life (30+ years)

### Comparing to Other Renewables



Pros	Cons
Potentially available everywhere	Currently capital intensive – sometimes challenging economics
Can provide constant baseload	Lack of public understanding, Social acceptance
Practically zero emissions	Potential environmental effects - seismicity
Little reliance on variable environmental factors (sun, wind)	Lack of required infrastructure (e.g. heat grids), or challenges to integrate with existing infrastructure
Small footprint when installed	"Young" compared to other renewables (e.g. wind, solar, hydro) – less expertise to realise projects, still much to research
Potential long project life (30+ years)	

### **Global Installed Renewables Capacity**



#### Installed Renewables Capacity (GW)



#### Installed Geothermal Capacity (GW)



# Geothermal, though currently small compared to other renewables, is growing rapidly

Source: https://www.statista.com/statistics/267233/renewable-energy-capacity-worldwide-by-country/

### Installed Geothermal Capacity by Country





Source: https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2020-installed-power-generation-capacity-mwe/



#### THE ECONOMICS OF GEOTHERMAL

### Project Realization Cost/Risk vs Time





Source: https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/FINAL\_Geothermal%20Handbook\_TR002-12 Reduced.pdf

### Projects have similar risk/cost/return vs. time to hydrocarbon exploration

- Initial relatively low cost but high risk exploration stage
- Appraisal stage with increasing costs
- Development and construction stage with rapidly increasing costs
- Project start up with reducing costs and returns finally beginning
- Long operating phase, with low costs and steady returns

How can we reduce risk, cost and realisation time?

### Unsubsidized Levellized cost per KWh



#### 250 200 150 100 50 Solar Thermal Tower 0 Gas Combined Cycle Geothermal wind peaking nuclear

#### Levellized cost per KWh (US\$)

### Once installed, geothermal energy is competitive with other energy sources

- However risks in geothermal development are greater than other renewables
- Return on investment can be longer

## How can we reduce these risks and improve returns?



# How Do Oil and Gas and Geothermal Compare?



Similar Objectives to Oil and Gas?

# The safe, economic extraction of a subsurface energy source with the minimum of adverse effects on the environment

#### Comparing the Two Industries



#### **Oil and Gas**

Established extensive worldwide industry

Mix of major operators and independents, well established supporting industries

Over 150 years of knowledge

Well established methodologies, best practices, regulation, procedures for safely and economically utilising resources

### Comparing the Two Industries



Oil and Gas	Geothermal
Established extensive worldwide industry	Long established, global footprint, significant growth in last few years, but still small compared to oil and gas
Mix of major operators and independents, well established supporting industries	Relatively small industry, few major operators, little experienced supporting industry
Over 150 years of knowledge	Knowledge base growing, but still gaps (subsurface, operational, HSE etc)
Well established methodologies, best practices, regulation, procedures for safely and economically utilising resources	Fewer accepted methodologies, best practices, regulation, procedures for safely and economically utilising resources.



### **Can Oil and Gas Contribute?**

### What's Important for Oil and Gas?



#### What's Important?

Where are the hydrocarbons

How much is there

Are they producible

What will it cost

#### What Controls These?

Reservoir structure, thickness and aerial extent

Porosity

Hydrocarbon Saturation

Permeability

**Recovery factor** 







#### Property

Temperature

Permeability

Effective porosity

Fractures



Property	What do we want?
Temperature	Higher is better
Permeability	Higher is better
Effective porosity	Higher is better
Fractures	More open fractures is better



Property	What do we want?	Why?
Temperature	Higher is better	More heat produced
Permeability	Higher is better	Greater flow, more heat production
Effective porosity	Higher is better	More surface area, more heat transfer
Fractures	More open fractures is better	More surface area, better permeability, greater flow, more heat



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#### Is there anything else?

Property	Why?
Lithology and geochemistry	Different lithologies behave differently with injection = scaling potential, pore plugging
Formation water	Dissolved solids, scale (radioactive?) and corrosion
Formation and reservoir structure	Is the well in the optimal position? Better location = better flow = more heat. Is the injected water going where you think it is?
Geomechanical properties	Rock strength, fracture strength. Subsidence and seismicity, wellbore stability



#### Is there more?

- What don't we know?
- What must we learn?



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#### How Well Do We Know The Subsurface for Geothermal?



What information is commonly recorded in a geothermal well? Subsurface acquisition – Logging (Wireline/LWD)

- Seen as 'expensive', often limited Gamma Ray, occasionally resistivity, identify formation tops for stopping
- Porosity, permeability, thermal properties often inferred from other data not measured

Well Tests

- Bulk measurement of flow
- Doesn't say where flow is coming from

#### **Implications?**

• High local uncertainty on formation properties

### Information from Public Data



#### **An example – the Dutch NLOG Subsurface Database**

- Record of all subsurface information in The Netherlands
  - Many countries have similar national data repositories
- All data older than five years in public domain
- Very comprehensive database



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### Information from Public Data



#### **BUT key information for geothermal is limited**

- Data concentrated in oil and gas areas
- Data in geothermal plays (green) is rather old (1900's to 1980's) and limited
- Geothermal prospects are 'dry' for oil and gas. Little recent exploration or data.
- Lots of uncertainty

# Many other countries face similar challenges





#### Showing the Value of Data – A Case Study

# The Implications Of Limited Subsurface Knowledge

#### A Case Study

- Fractured carbonate geothermal well 113m open hole completed interval
- Assumed majority of interval will flow
- Nuclear Magnetic Resonance (NMR) and acoustic logs run for porosity determination
- Porosities up to 15%, NMR derived Coates permeability up to 200mD



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#### The Implications Of Limited Subsurface Knowledge

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Min	Min	Productive	Net/Gross
Moveable	Permeability	Interval	
Porosity (%)	(mD)	(m)	
5	2	36.5	0.323



### Where's The Flow Coming From?



#### But does it all flow?

- Production logs (spinners, pressure, temperature) run for flow identification
- Significant flow over only one interval
- Why?



### Why Is Only This Interval Flowing?





### What Are The Implications?



#### How can lack of subsurface knowledge affect a project?

- Poorer performance than expected
- Lower economic return Less attractive to investors
- Lack of geochemical knowledge? Corrosion, Scaling?
- Unexpected solids production? Pump Wear?
- Reactivation of faults? Seismicity?
- What else?



#### How Can Subsurface Knowledge Benefit Geothermal?

#### **Increasing Energy Production - The Base Case**



39

#### **DoubletCalc – energy production estimation**

- TNO example DoubletCalc scenario
- Base case 0.8 net to gross
- What if we steered well to improve net-togross by 5%?



Doublet Calculator 1.4.3								
umber of simulation runs (-) 1000 Calculate ! Open Scenario Save Scenario						Ex	it Program	
file: C:\Users\bradtom\Documents\Geothermal\doubletcalc\DoubletCalc_143_03022016\example.xml Geotechnical input								
r propertie	S							
		min	median	max	Property			value
eability (mD)		150	250	500	aquifer kh/kv ratio (-)			1
gross (-)		0.75	0.80	0.85	surface temp	erature (°C)		10
thickness (m	)	95	105	115	geothermal g	pradient (°C/m)	)	0.031
producer (m 1	IVD)	2255.0	2505	2756.0	[ mid aquifer	temperature p	roducer (°C)]	0
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pipe segment sections p (m AH)	pipe segment depth p (m TVD)	pipe inner diameter p (inch)	pipe roughness p (milli-inch)	Segment	pipe segment sections i (m AH)	pipe segment depth i (m TVD)	pipe inner diameter i (inch)	pipe roughness i (milli-inch)
500	500	5	1.2	1	50	50	5	1.2
1054	1054	12.375	1.2	2	1054	1054	12.375	1.2
1930	1833	8.625	1.2	3	1930	1833	8.625	1.2
2678	2505	6.625	1.2	4	2645	2468	6.625	1.2
				5				
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https://www.nlog.nl/en/nieuws/doubletc alc-2d-v10

#### **Increasing Energy Production – Steering A Well**

- Sand-shale sequence
- Well steered using porosity logs
  - e.g. deep azimuthal resistivity, azimuthal density, Nuclear Magnetic Resonance
- Stay in most productive (porous/permeable) zone.
- Improve net/gross



## 5% net to gross increase = >440kw (5.3%) power increase at P50





At wholesale electricity price of €0.1/kWh, almost €400,000 additional revenue per year! 41

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#### Not Just Net-to-Gross



#### 5% increase in permeability gives further 300kW output

wo Doublet Calculator 1.4.3 Result Table           probabilistic plots         fingerprinting           export base case details		
Geotechnics (Input)	Geotechnics (Output)	100%
aquifer permeability (mD)         158.0         263.0         525.0           aquifer netto gross (-)         0.8         0.85         0.95           aquifer gross thickness (m)         95.0         105.0         115.0           aquifer top at producer (m TVD)         2255.0         2505.0         2756.0	Carlo cases (stochastic inputs)         P90         P50         P10           aquife kH net (Dm)         18 21         24.0         36.97           mass ow (kg/s)         38 49         47.66         62.09           pump volume flow (m <sup>5</sup> h)         130.9         162.4         211.6           required pump power (kW)         238.3         295.8         385.4	90% P90: 7.03 80% 70%
Property	min median max	₹ <sup>60%</sup> 8.33→9.07 MW
aquifer permeability (mD)	150.0 250.0 500.0	P50: 9.07
mid aquifer net to gross (-)	1 8 0 85 0 9 temperature at heat exchanger (°C) 82 74 86.73 90.96	
Property	min median max	30%
aquifer permeability (mD)	158.0 263.0 525.0	10% P10: 12.09
aquifer net to gross (-)	0.8 0.85 0.95	0%
skin broduce (*)            skin due to penetration angle p (-)            pipe segment sections p (m AH)         500.0,1054.0,1930.0,2678.0           pipe segment depth p (m TVD)         5000.01054.0,1833.0,2505.0           pipe incer diameter o (inch)	aquifer pressure at producer (bar)     255 08       aquifer pressure at injector (bar)     251.18       pressure difference at producer (bar)     13.38	5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 14.5 15.5 geothermal power (MW)
pipe roughness p (milli-inch)         12,12,12,12,12           outer diameter injector (inch)         6.13           skin injector (-)         0.0	aquifer temperature at producer * (*C)     89 28       temperature at heat exchanger (*C)     86.72       pressure at heat exchanger (bar)     15.95	$+7/0kM - \epsilon 650,000  oxtra revenue per vea$
skin due to penetration angle i (-)         -0.97           pipe segment sections i (m AH)         50.0,1054.0,1930.0,2645.0           pipe segment depth i (m TVD)         50.0,1054.0,1833.0,2468.0	* @ mid aquifer depth	$\tau$ 40kw – $\epsilon$ 050,000 extra revenue per yea

### Conclusions



- Geothermal is a viable economic environmentally friendly energy source
- Current application of subsurface evaluation to geothermal is often limited
- Well established oil and gas evaluation principles equally applicable to geothermal
- Subsurface data acquisition often seen as unnecessary expense that should be minimised
- Additional direct measurement of certain key properties would be very beneficial
  - May only become apparent many years in the future
  - Acquisition later in life of well may be impractical or impossible, and expensive
- Potential to increase heat production and cost savings through efficiency and optimisation of prospects

#### A Final Conclusion



- As SPE members, we know the subsurface
- We as an industry have the knowledge to help make geothermal energy technically and economically viable



#### Acknowledgements

- SPE
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