Geothermal Resource Characterization of the Slave Point Formation in Clarke Lake Field, Fort Nelson, British Columbia, Canada*

Evan Renaud[1], Nicholas Harris[1], Jonathan Banks[1], and John Weissenberger[1]

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[1]EAS, University of Alberta, Leduc, AB, Canada (erenaud@ualberta.ca)

Abstract

Middle Devonian carbonates of the Slave Point Formation have been host to significant gas reserves (3.57 TCF OGIP in the largest pool) since the discovery of Clarke Lake Field in 1957. The geothermal potential of the field was demonstrated by a 2005 to 2009 experiment in which Petro-Canada Oil and Gas attempted liberating trapped gas by pumping formation water out at rates of 2800 m^3/day to reduce water cut; instead pressure only dropped marginally (100 kPa after one year) due to a strong water drive. High geothermal gradients (> 50 °C/km) and formation water temperatures greater than 110 °C give the field the capability of producing 12 to 74 MW of geothermal energy for the Fort Nelson area. High temperature water, a strong water drive, and porous carbonate rock allow for a viable geothermal resource.

We describe and map depositional and diagenetic facies and relate these to porosity and permeability data to develop a flow model for the formation. In the late Givetian a relative sea level rise drowned the Keg River carbonate platform which allowed small, laterally discontinuous patch reefs of the Slave Point Formation to develop on the flanks of the Horn River Basin. Five depositional facies are associated with a reefal to back reef setting on a carbonate platform and are affected by varying intensities of dolomitization. Pervasive dolomitization of the reef margin occurred by long-distance migration of halite-saturated brines while recrystallized matrix dolomite, replacive and cement saddle dolomites are products of hydrothermal alteration. More porous and permeable zones are related to development of gray matrix dolomite, englarged vugs, and mouldic pores; unaltered limestone facies are considered non-reservoir. Mapping and modeling the spatial variability of dolomitization is a key objective concerning optimization of geothermal well targets.

Development of this geologically based geothermal reservoir model is feasible because of the availability of a large-scale oil and gas well data set. The data include direct permeability/porosity core measurements, well-logs, DSTs, and eighteen core descriptions taken at the BC Oil and Gas Commission core research facility. Over 220 wells in the Clarke Lake area have been used to create stratigraphic cross-sections to interpret the 3D geometry of the reef.

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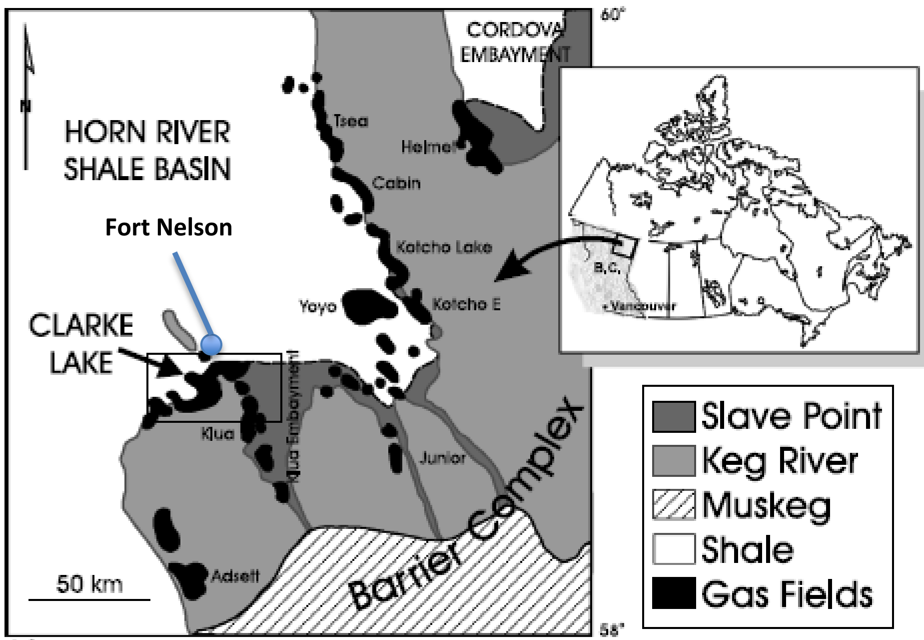
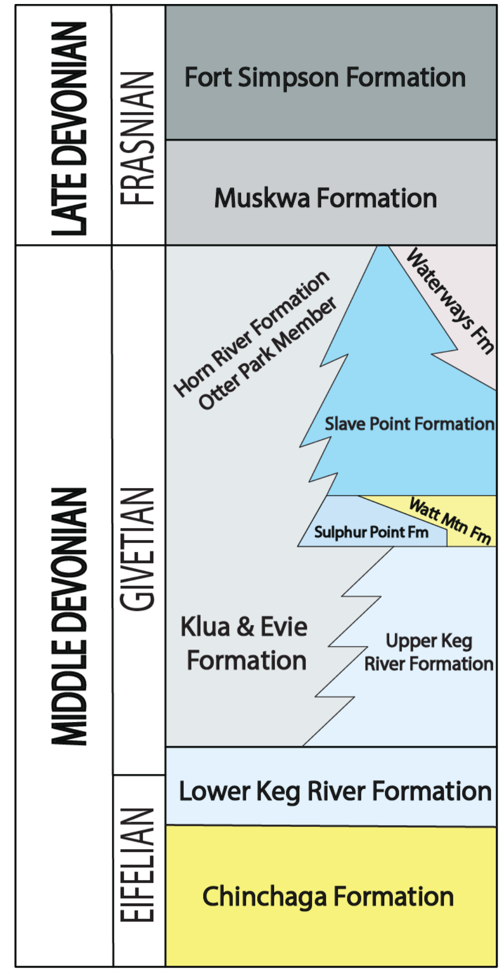
Location & Geological Context



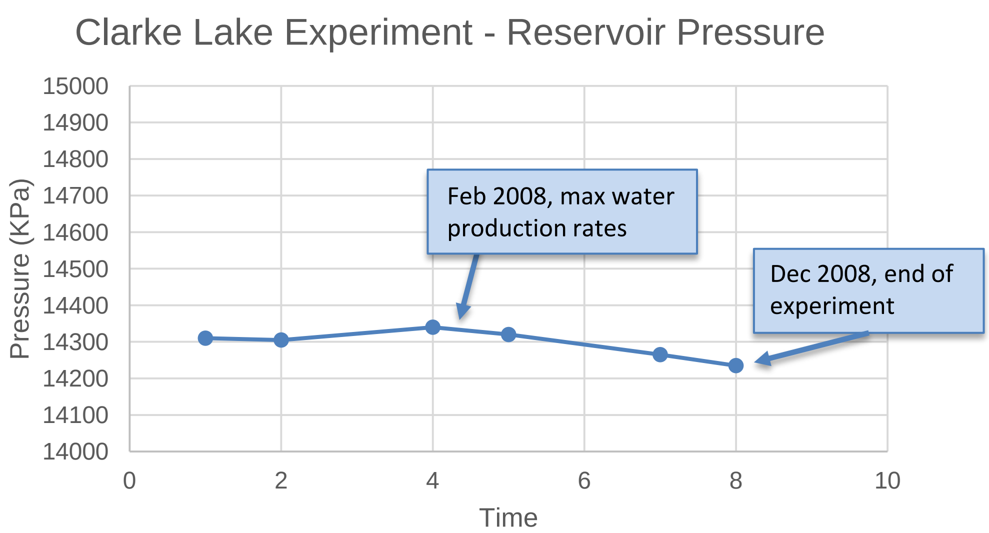
(Lonnee, 2006)

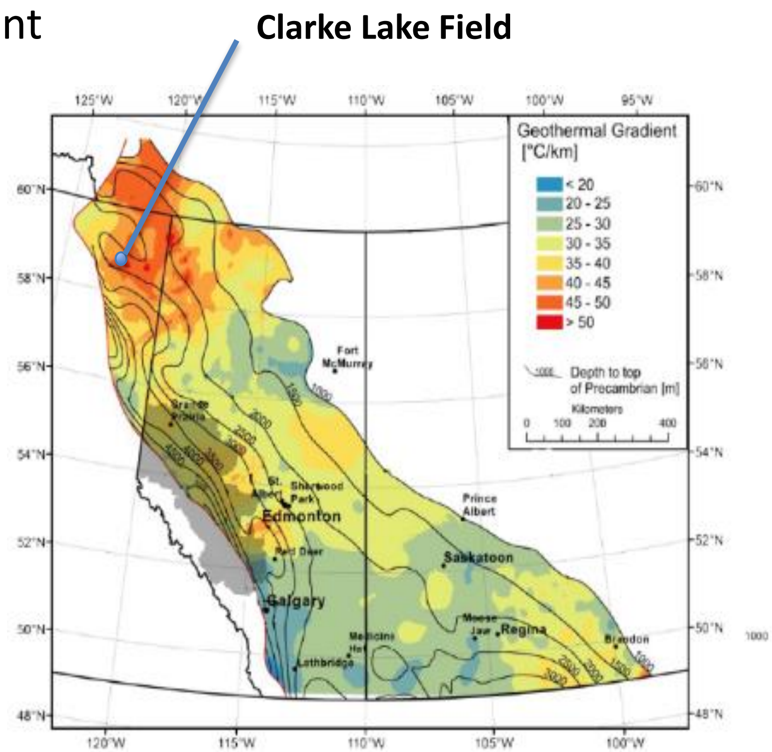
- Field location: ~10km south of Fort Nelson, BC
- Fringing the Horn River Basin
- Main reservoir unit = Slave Point Formation



Field Suitability for Geothermal Energy

- Field shows an anomalous water drive
- Field shows an anomalous geothermal gradient





(Weides and Majorowicz, 2014)

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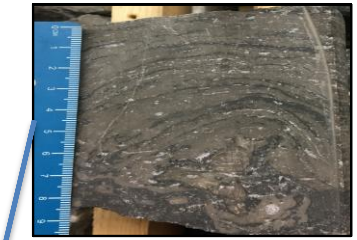
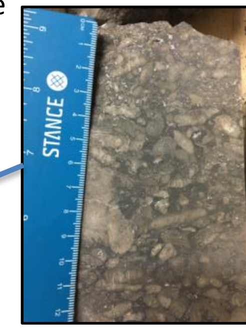
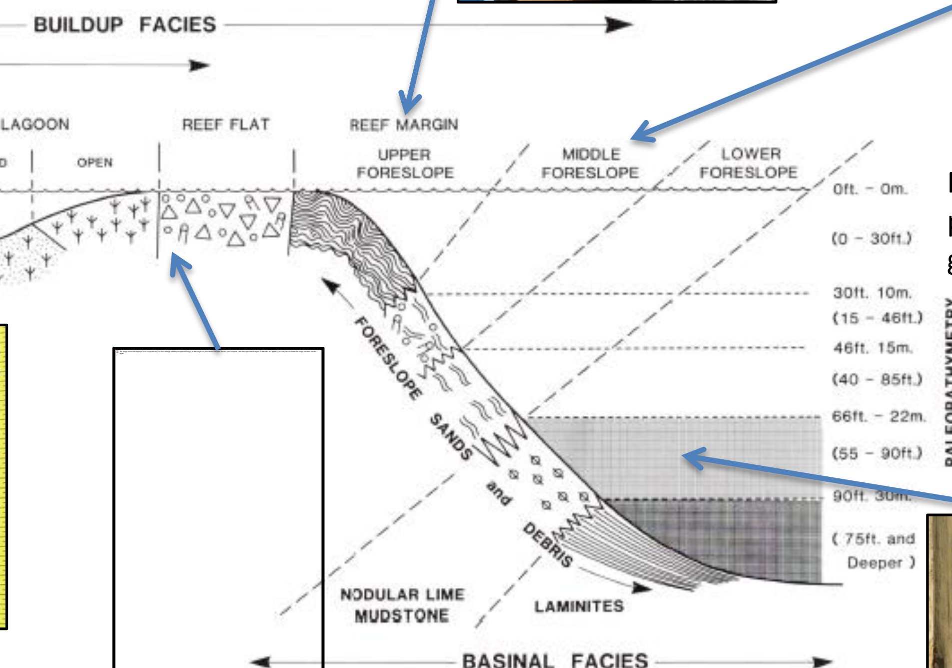
Depositional Facies



Facies 2A: Massive stromatoporoid boundstone



Facies 2B: *Stachyode* packstone to grainstone



(Wendte, 1992)

Facies 1C: Laminated mudstone

Facies 1B: *Amphipora* wackestone

Facies 1A: *Stachyode* - *Amphipora* wackestone to packstone

Facies 3A & 3B: Crinoid wackestone and mudstone

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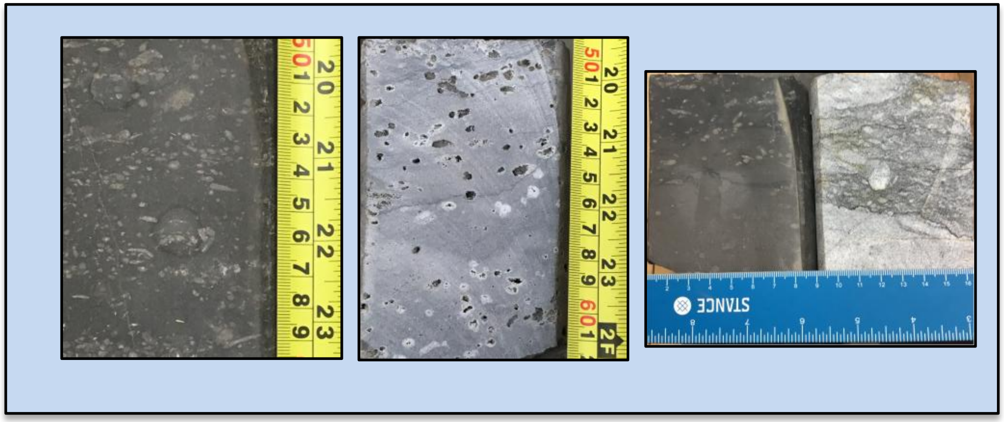
Dolomitic Overprint

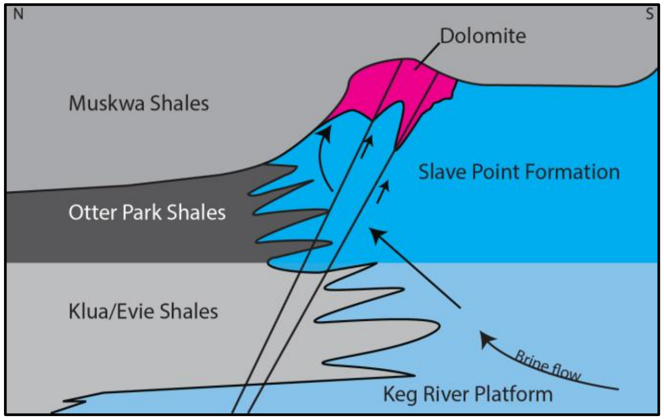
- Parent limestone has been dolomitized destroying depositional character to certain degrees
- Two brines responsible:

  1) Halite brine > gray matrix dolomite (GMD)

  2) Hybrid brine > recrystallization of GMD, oversized vugs and saddle dolomite (SD) as a cement and replacement product

Facies Association 4





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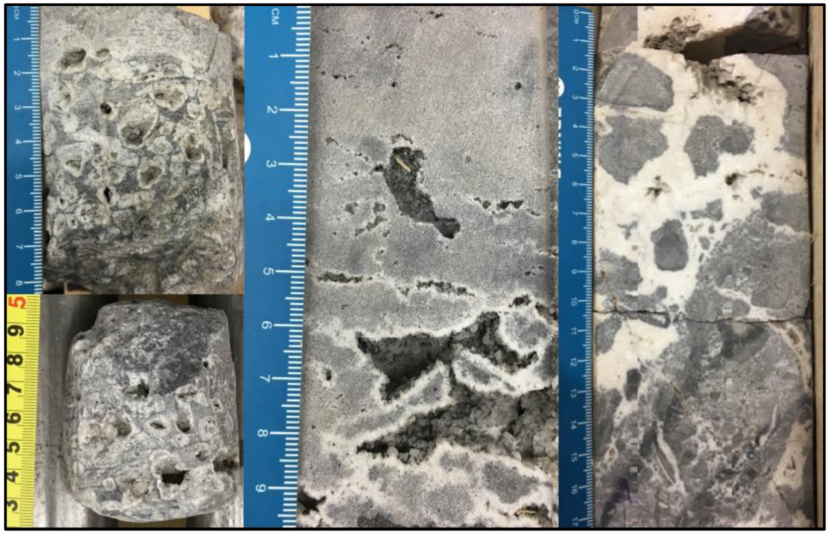
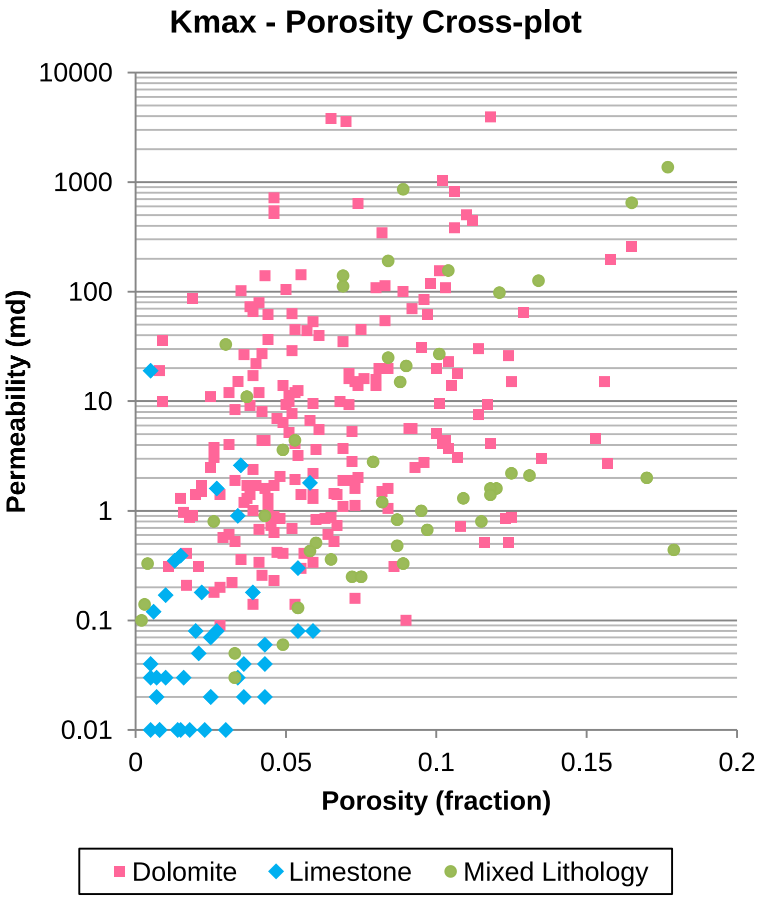
Diagenetic Control on Reservoir Quality

- High porosity and permeablity rocks are dictated by presence of dolomite
- Parent limestone rock is considered non-reservoir
- Mixed lithology samples show relatively high permeability





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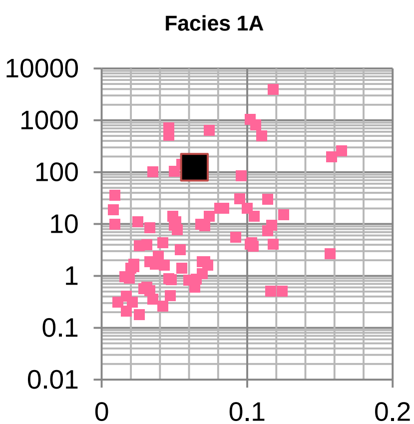
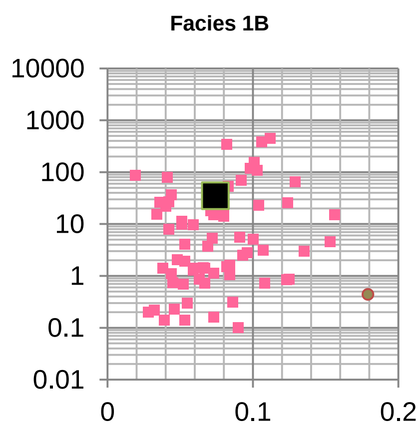
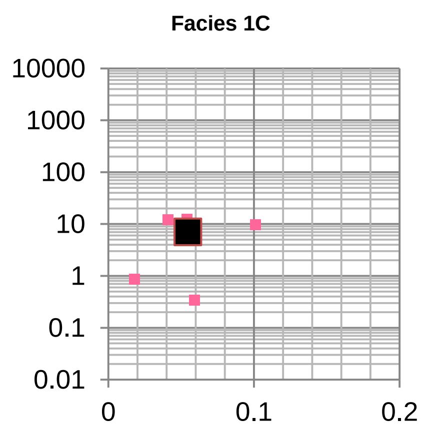
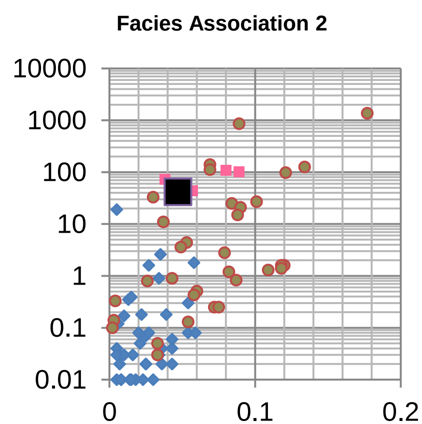
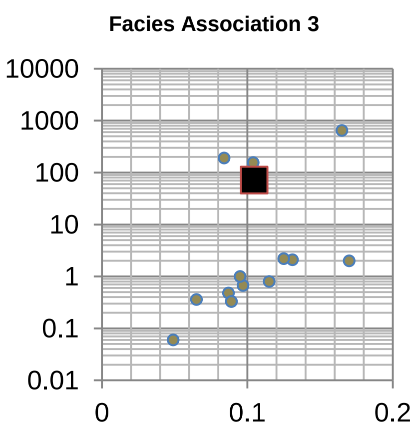
Reservoir Quality by Facies

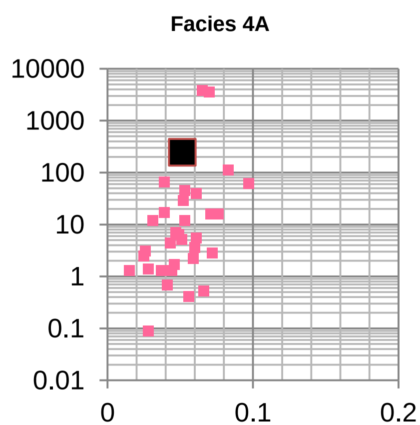


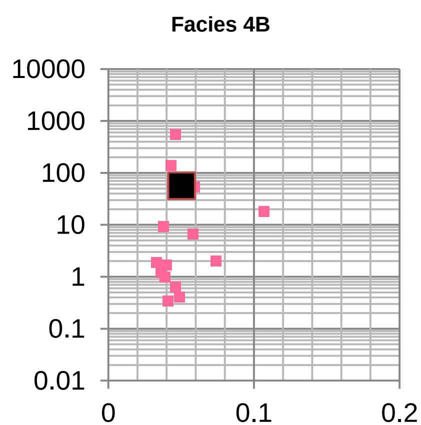












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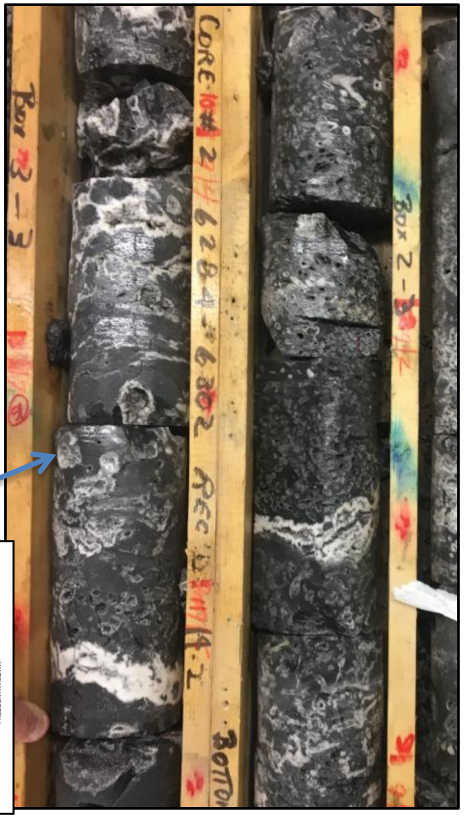
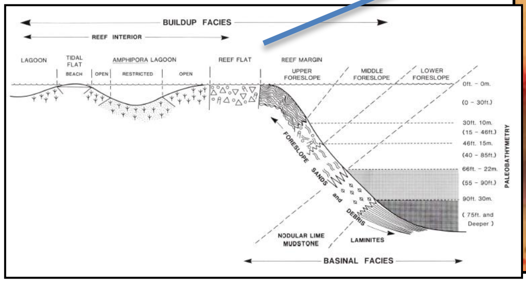
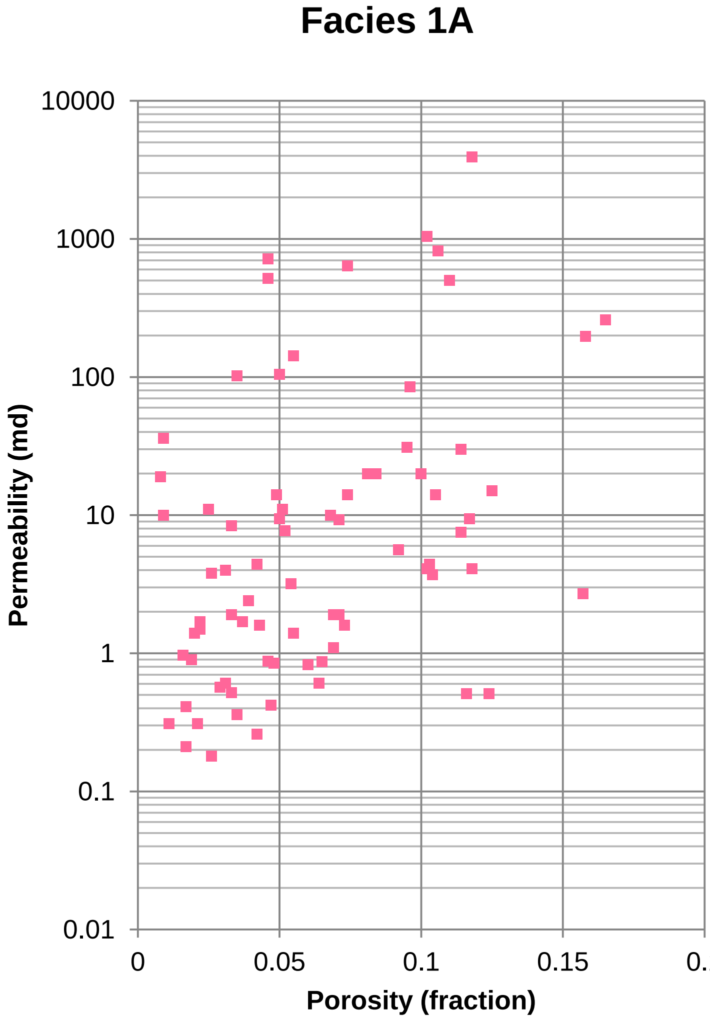
Facies 1A Reservoir Quality

- Facies 1A was found to display the best reservoir potential
- Dissolution of stromatoporoids allowed for significant mouldic porosity to develop
- Dolomitized sections of facies 1A do not always display this mouldic porosity







Mean kmax (md): 124md
Mean porosity: 6.4%

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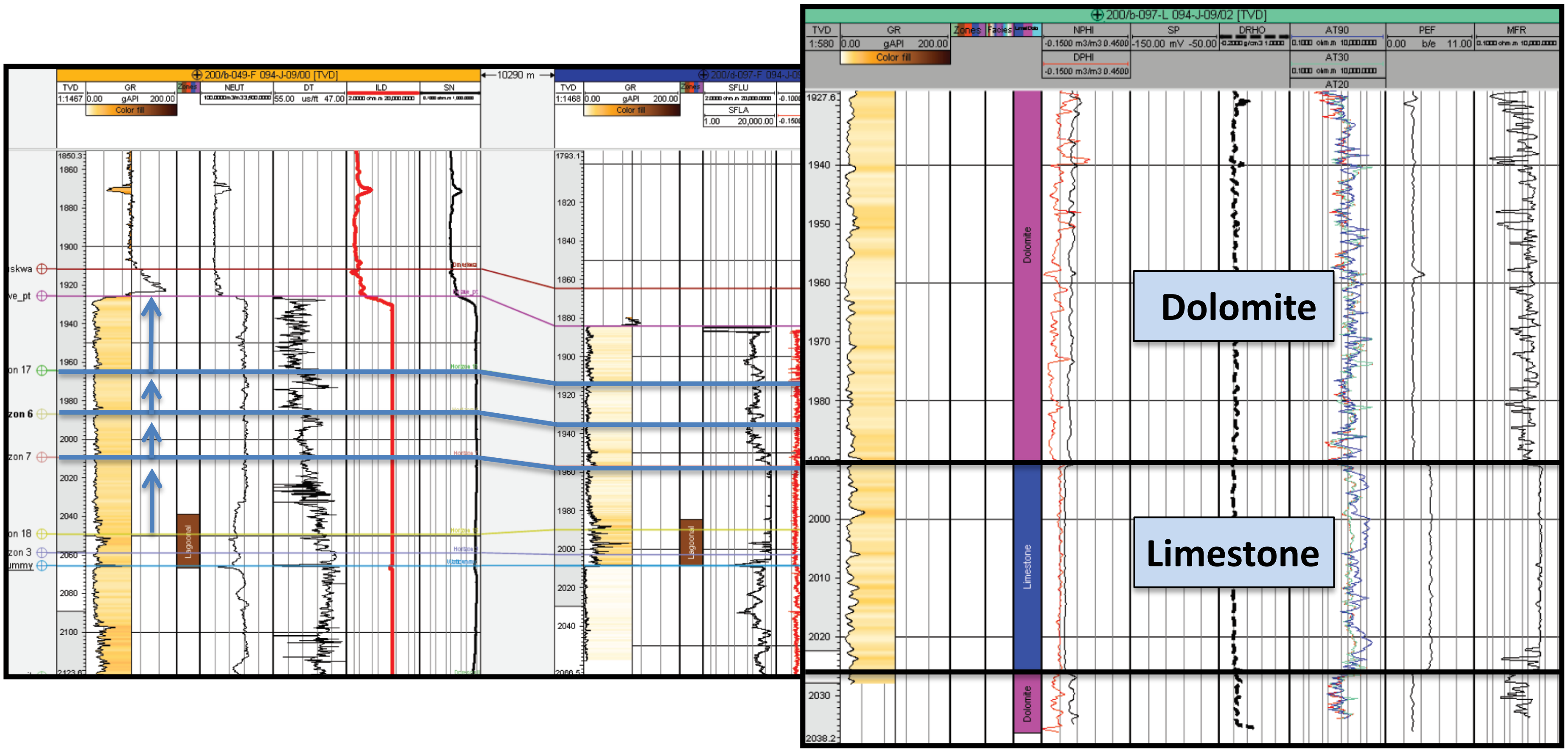
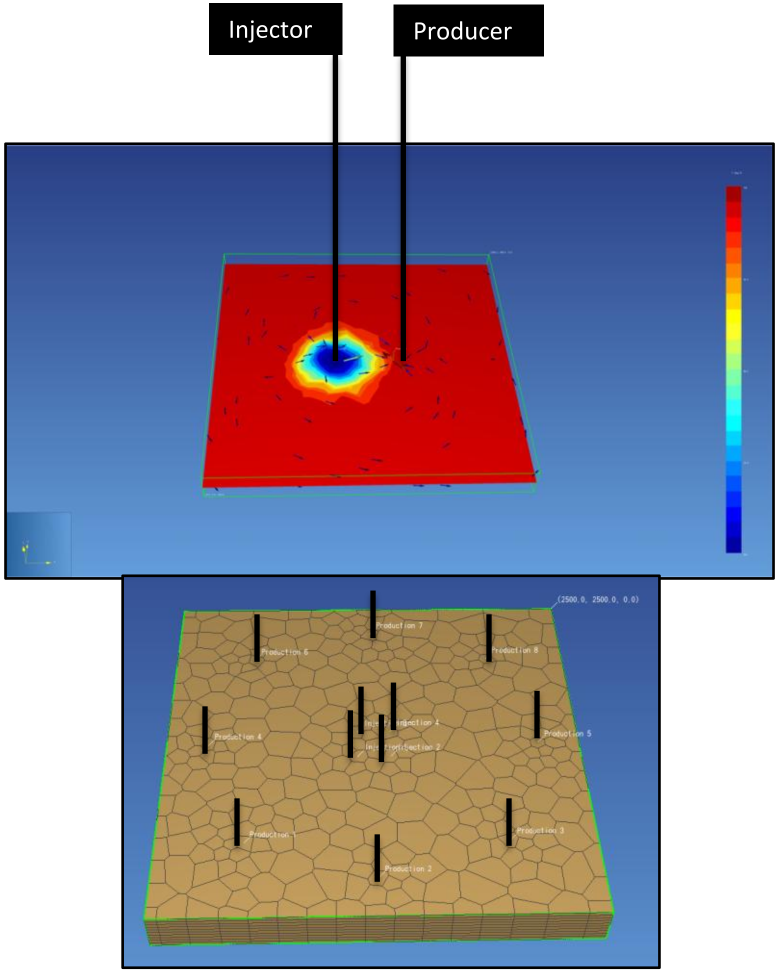
Flow Unit Correlation



Flow Simulations using PetraSim

- Simulation inputs: reasonable range of porosity and permeability for facies 1A
- 10 cases involved well doublets
- 4 cases involved 4 injector wells and 8 producer wells
- Ten of fourteen simulations were successful in sustaining a 25-year geothermal projects



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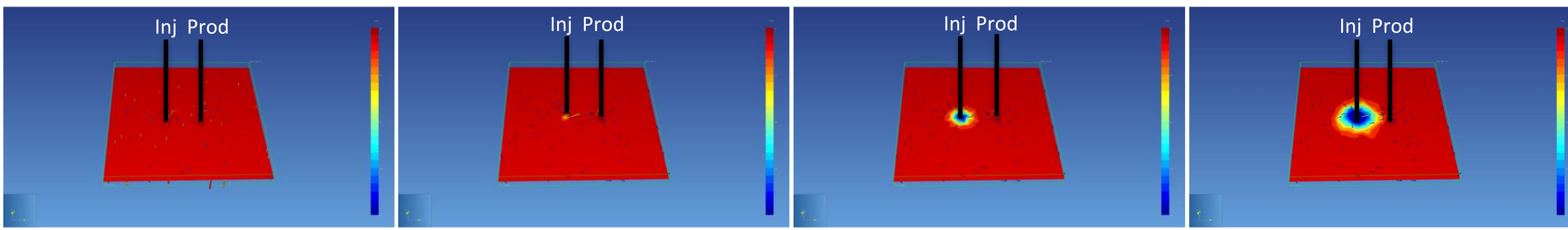
Max Kmax and Porosity Simulation

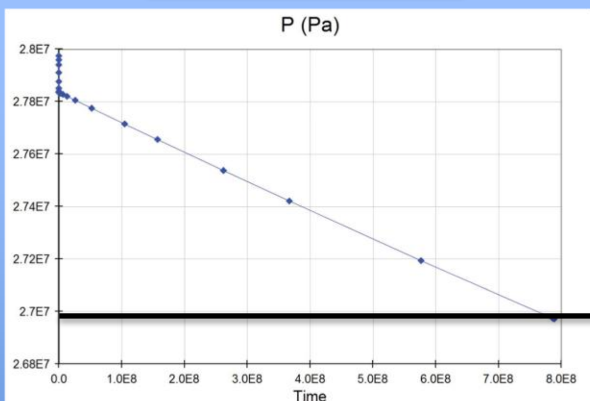
Time = 1500 seconds	Time = 6.5535e6 seconds	Time = 1.57286e8 seconds	Time = 7.88924e8 seconds
	~76 days	~5 years	25 years



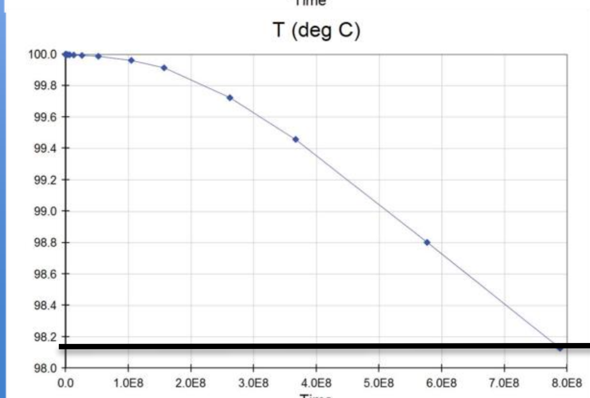
Time

Pressure & Temperature Trends

Producer Well

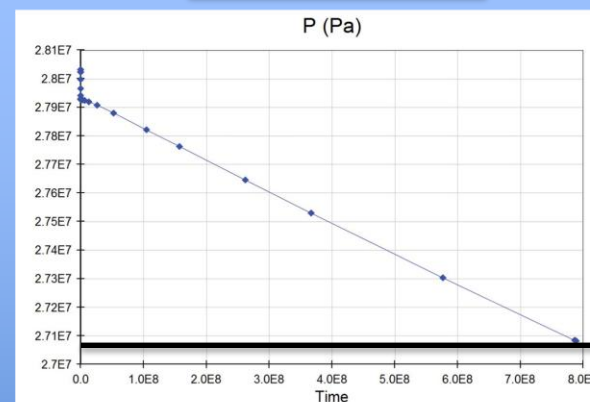


27210 kPa = 765 kPa change after 25 years

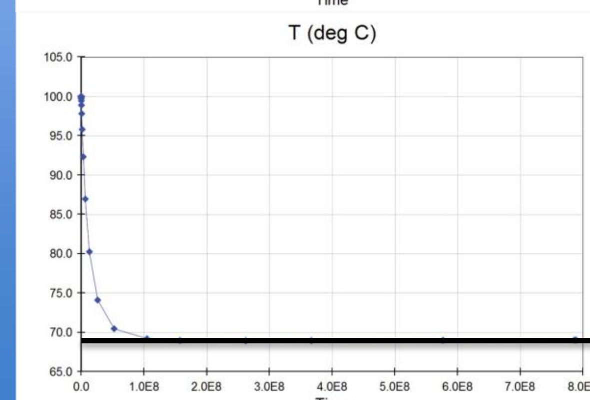


98.1°C after 25 years

Injector Well



27321 kPa = 704 kPa change after 25 years



Stabilized at ~69°C after 3 years into simulation

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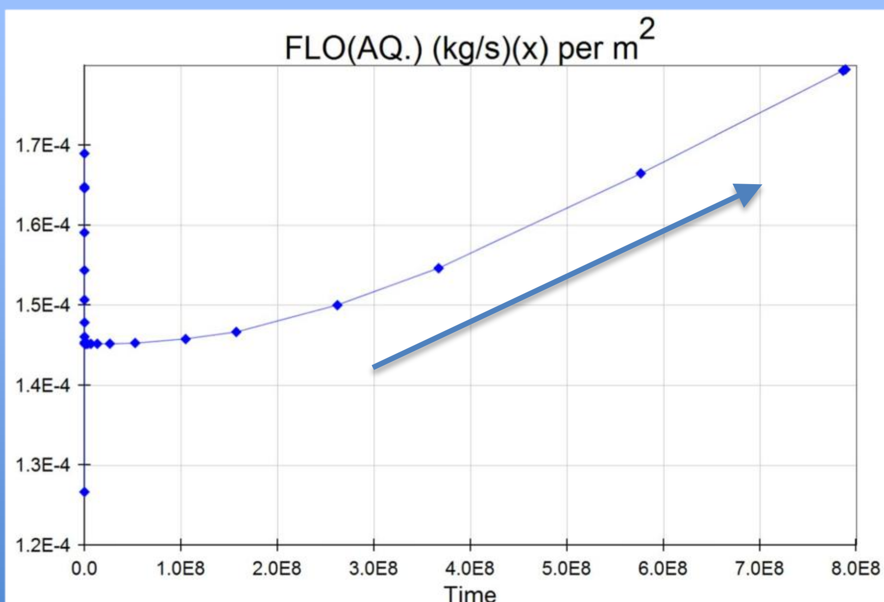
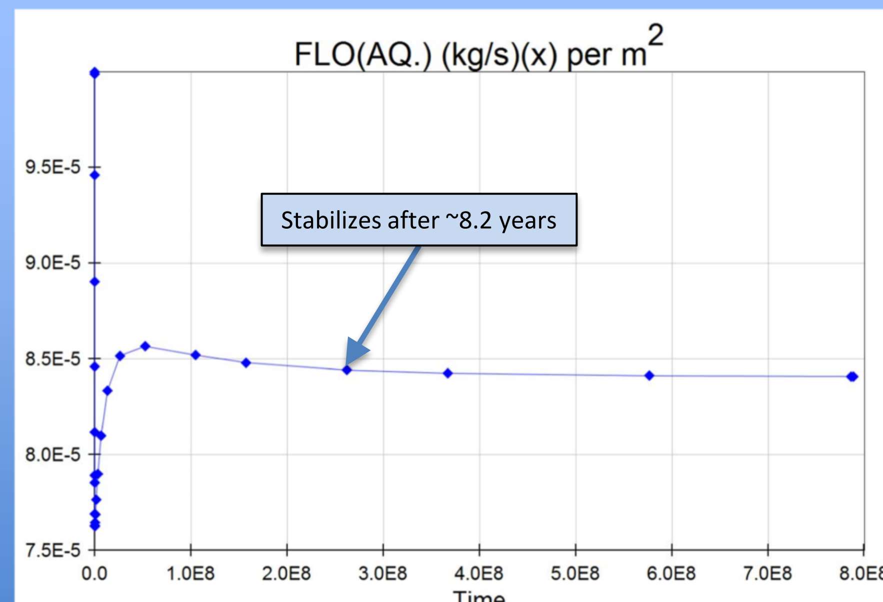
Formation Water Flow Rates

Producer Well



Injector Well



- **Linear increase in flow at producer well associated with a pressure differential at injector well**
- **Flow at injector stabilizes at ~8.4E-5 (kg/s)(x) per m^2**

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Geothermal Power Potential

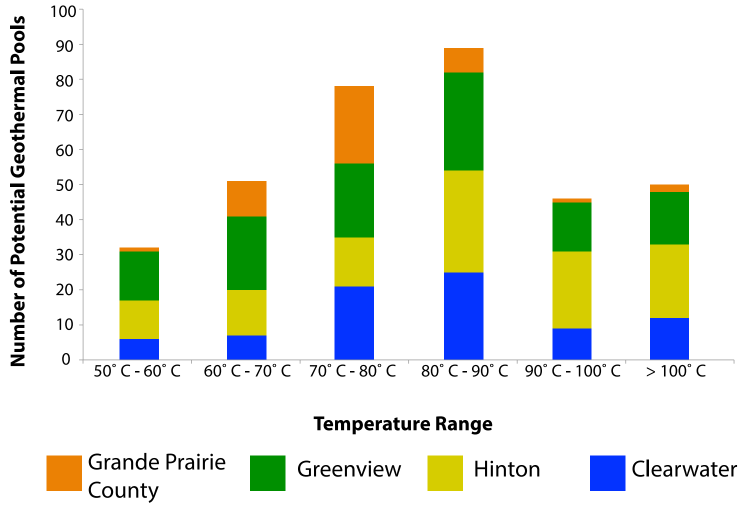
kWe = mass flow rate * fluid heat capacity * dT * engine efficiency

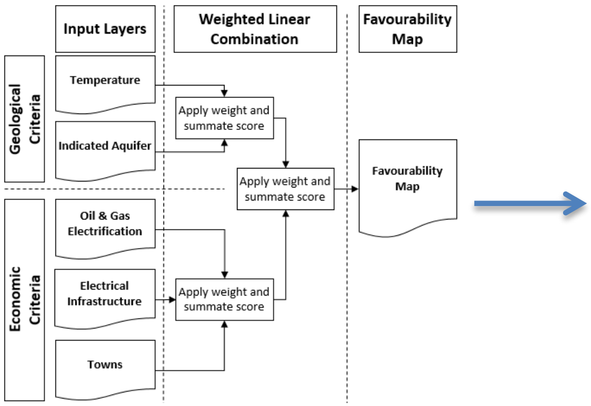
- Doublet configuration:

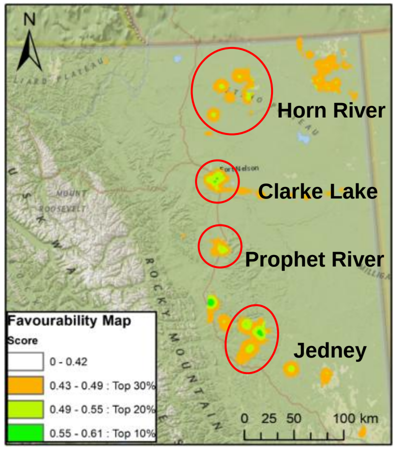
Electrical power: **300 kWe**
Total thermal power: **10000 kWt**

- Four injector and eight producer configuration:

Electrical power: **2400 kWe**
Total thermal power: **80000 kWt**







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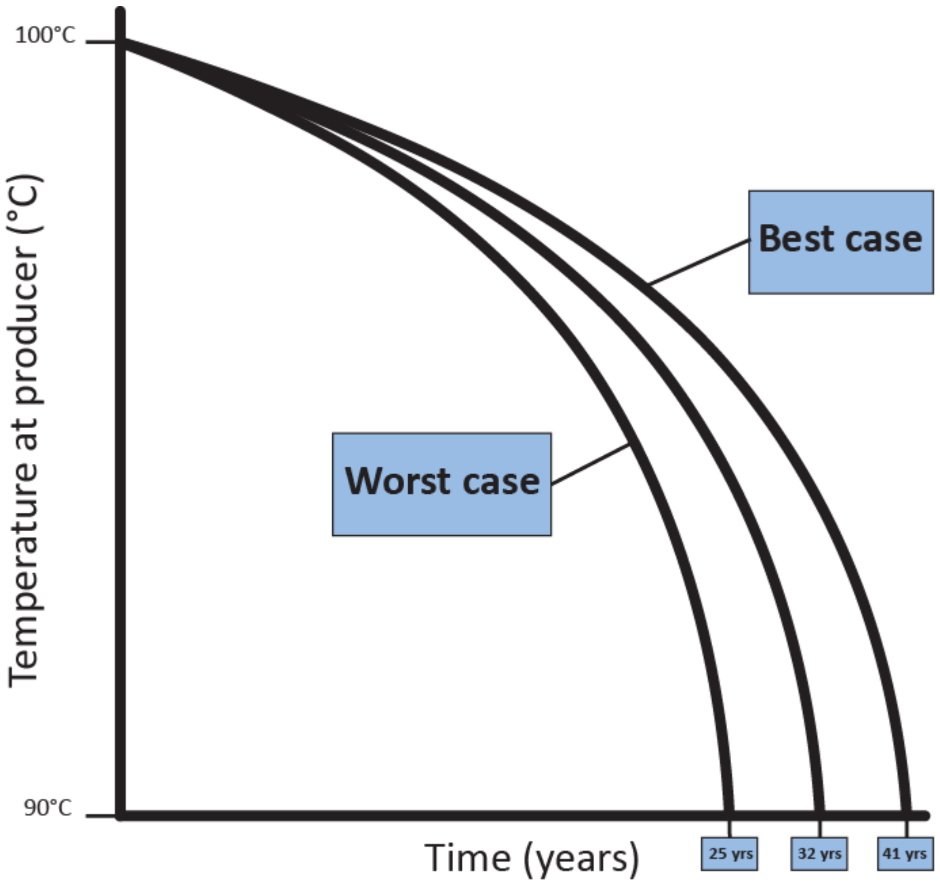
Future Simulation Work

- Apply a stochastic model to reservoir cells

  - Provide a risk analysis of break through time by assessing different stochastic realizations

- Apply simulations to other facies

  - Assess reservoir viability of other dolomitized units



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Conclusions

- Slave Point Formation can be mapped based on diagenetic and depositional character
- Hydrothermal dolomite has created significant secondary porosity
- Preliminary simulations show we are able to sustain 25-year geothermal projects
- Goal is to delineate where facies 1A displays these enhanced petrophysical characteristics

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