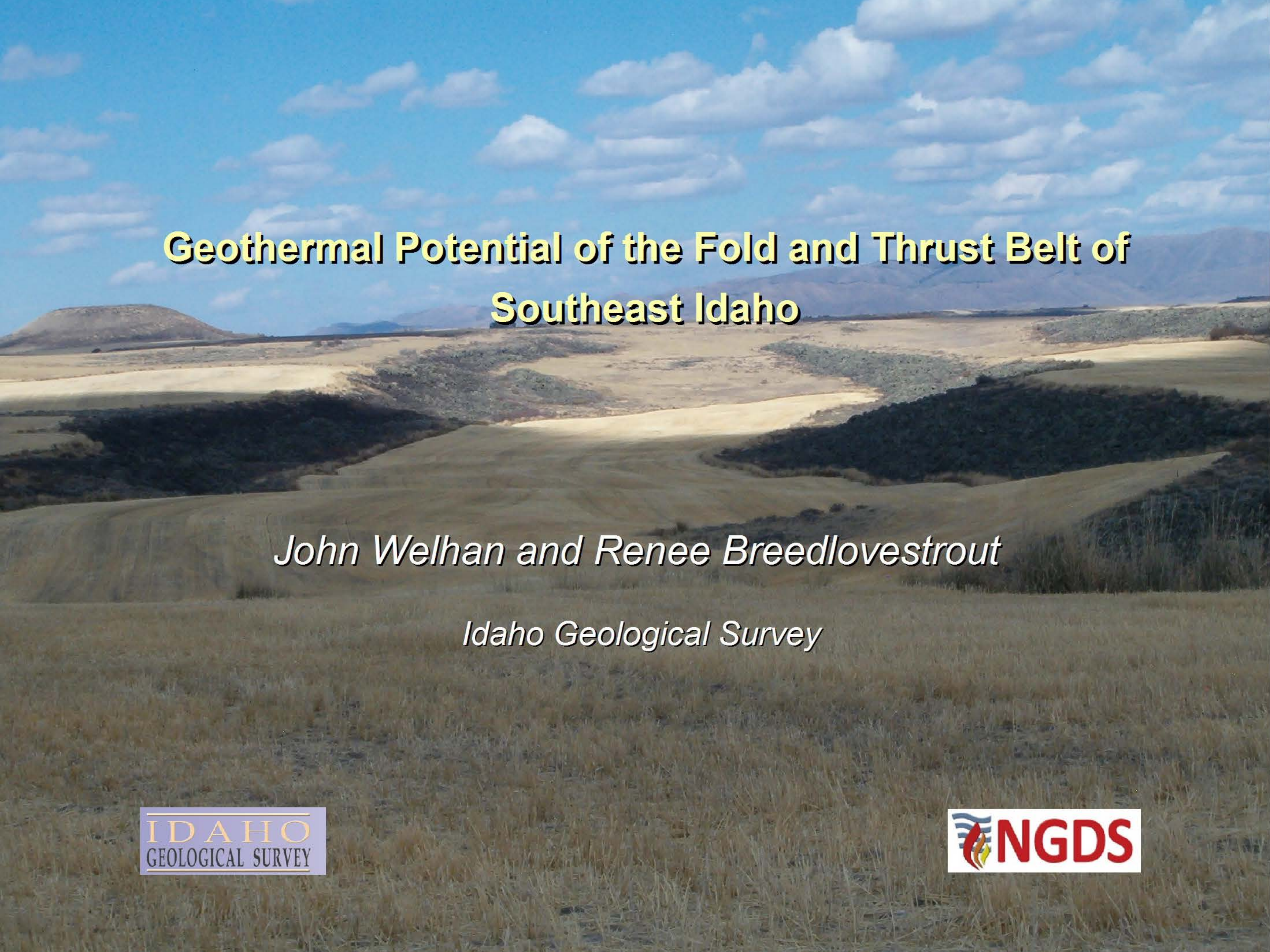


Geothermal Potential of the Fold and Thrust Belt of Southeast Idaho

John Welhan and Renee Breedlovestrout

Idaho Geological Survey

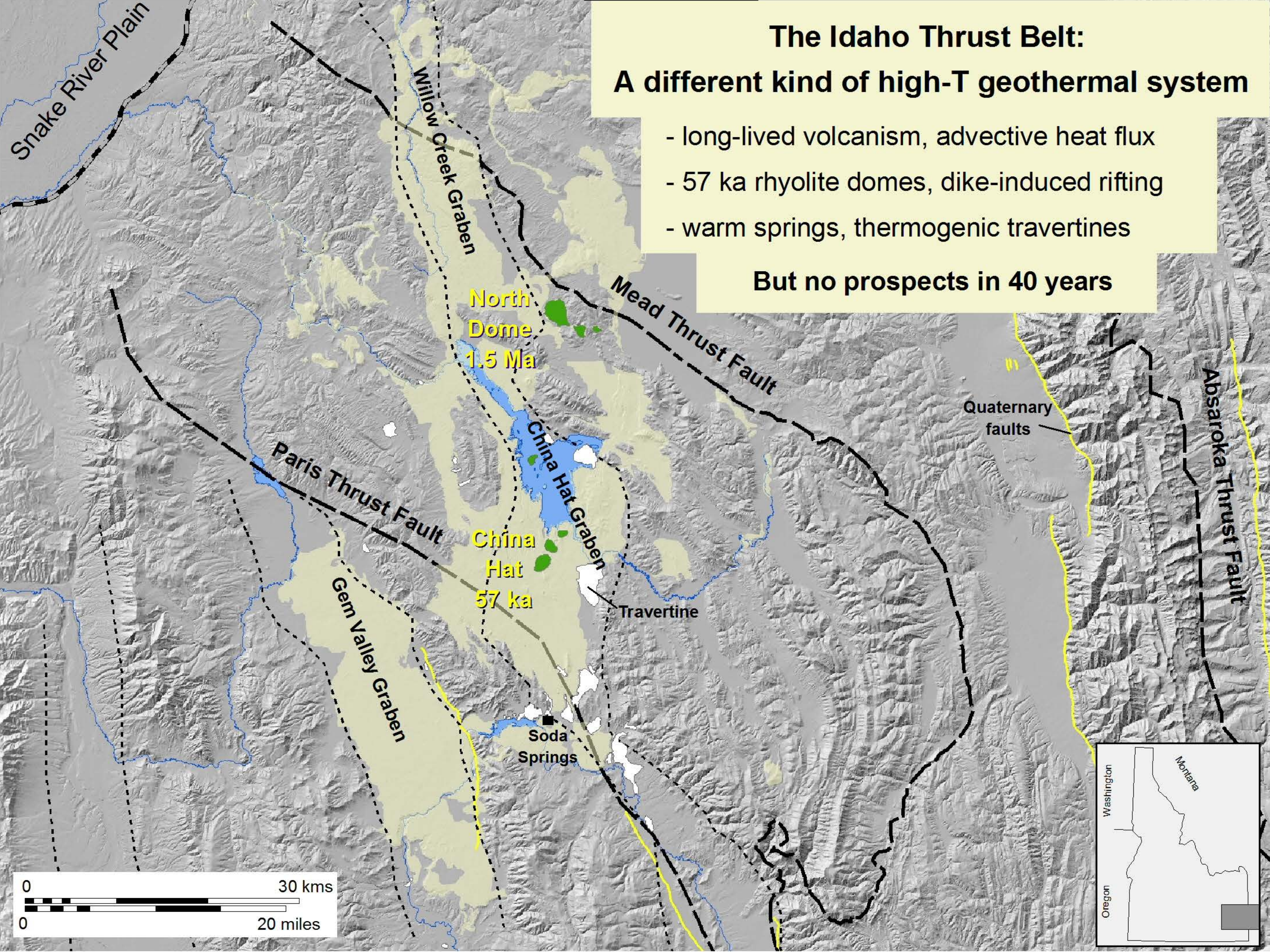
IDAHO GEOLOGICAL SURVEY

NGDS

The Idaho Thrust Belt: A different kind of high-T geothermal system

- long-lived volcanism, advective heat flux
- 57 ka rhyolite domes, dike-induced rifting
- warm springs, thermogenic travertines

But no prospects in 40 years



WHY GET EXCITED?

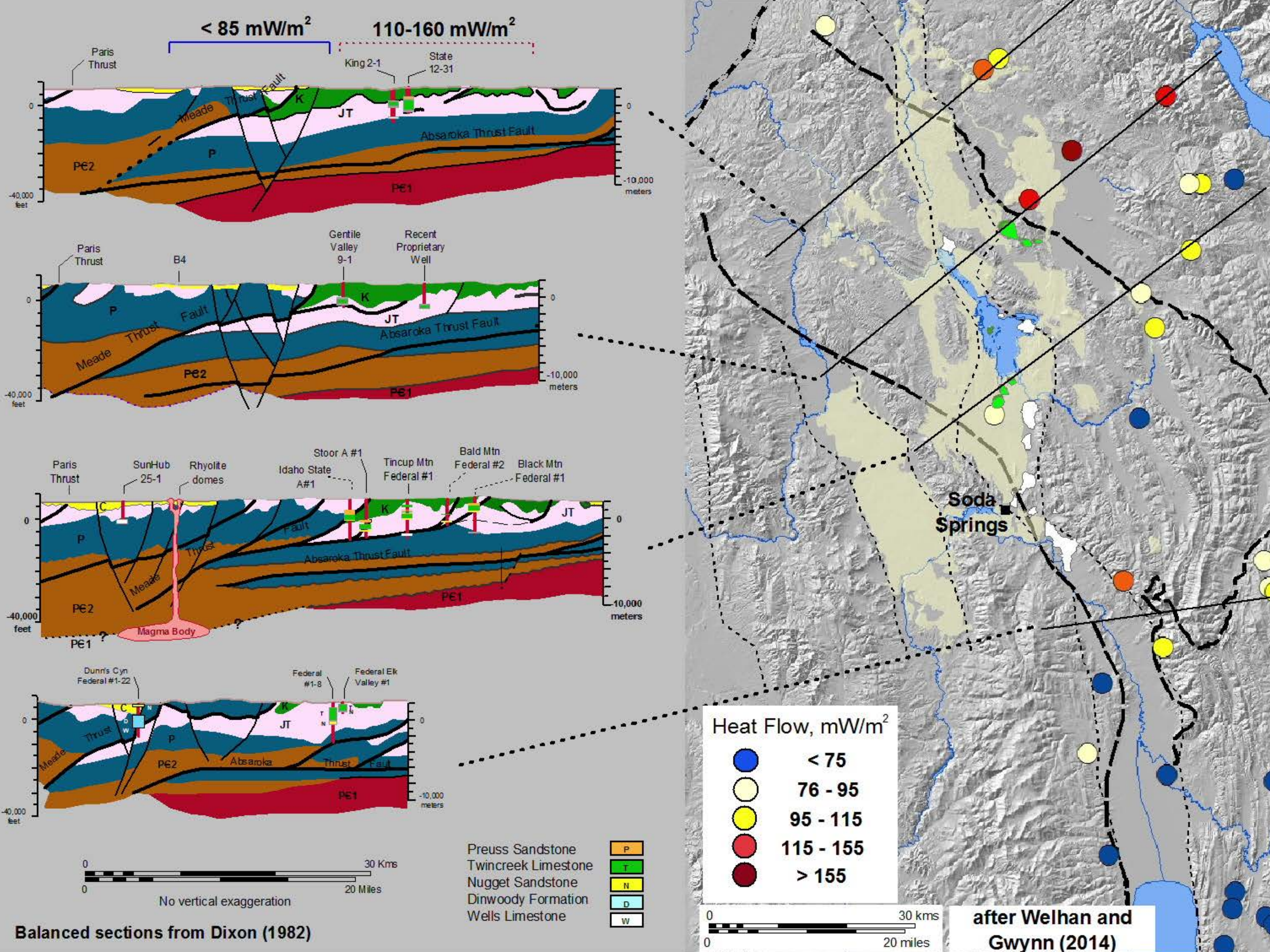
- Hot stratigraphic reservoirs: the next low-hanging fruit
- Economic at T > 150 °C and depths < 4 km

OBJECTIVES

- Summarize the geologic context, conceptual model, and what we know about the thermal resource
- Develop a first-order estimate of its power-generating potential using the "heat-in-place" method, and . . .
- Suggest other economic possibilities for this prospect

The China Hat Rhyolite Magma

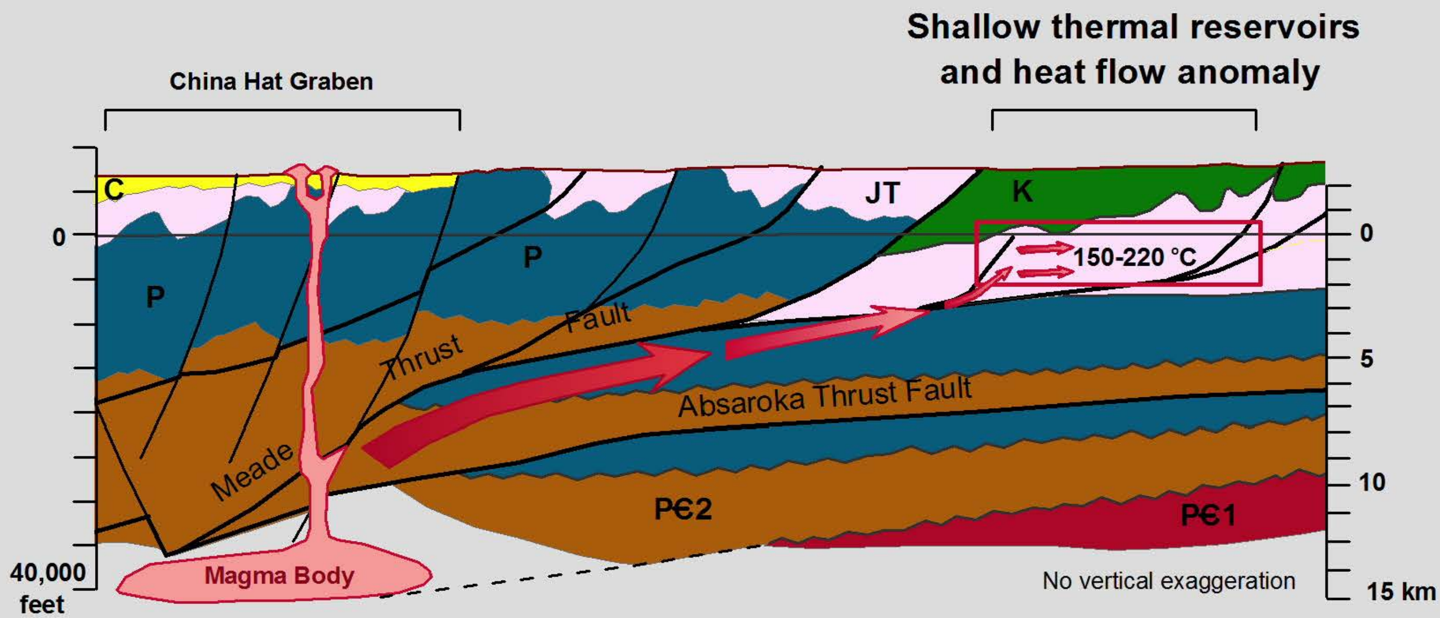
- ✓ An incompatible element-rich topaz rhyolite (U, Th , F, Li)
- ✓ Latest eruption event: 57-70 ka
- ✓ Thermobarometry: 760-810 °C, 12-14 km depth
- ✓ Strong magmatic affinities to eastern Snake River Plain:
  - rhyolite is a product of extreme differentiation
  - mafic parental magma in upper 15-20 km of crust
  - large, un-erupted volume of magma
- ✓ Active, volcanic-scale outgassing (magmatic ^3He, CO_2)



< 85 mW/m²
110-160 mW/m²
Paris Thrust
King 2-1
State 12-31
Meade Thrust Fault
K
JT
Absaroka Thrust Fault
P
PЄ2
PЄ1
-40,000 feet
-10,000 meters
Paris Thrust
B4
Gentile Valley 9-1
Recent Proprietary Well
Paris Thrust
SunHub 25-1
Rhyolite domes
Idaho State A#1
Stoor A #1
Tincup Mtn Federal #1
Bald Mtn Federal #2
Black Mtn Federal #1
Magma Body
Dunn's Cyn Federal #1-22
Federal #1-8
Federal Elk Valley #1
Preuss Sandstone
Twincreek Limestone
Nugget Sandstone
Dinwoody Formation
Wells Limestone
0
30 Kms
20 Miles
No vertical exaggeration
Balanced sections from Dixon (1982)
Soda Springs
Heat Flow, mW/m²
< 75
76 - 95
95 - 115
115 - 155
> 155
30 kms
20 miles
after Welhan and Gwynn (2014)

Conceptual Model

(non-thermohaline heat transport)



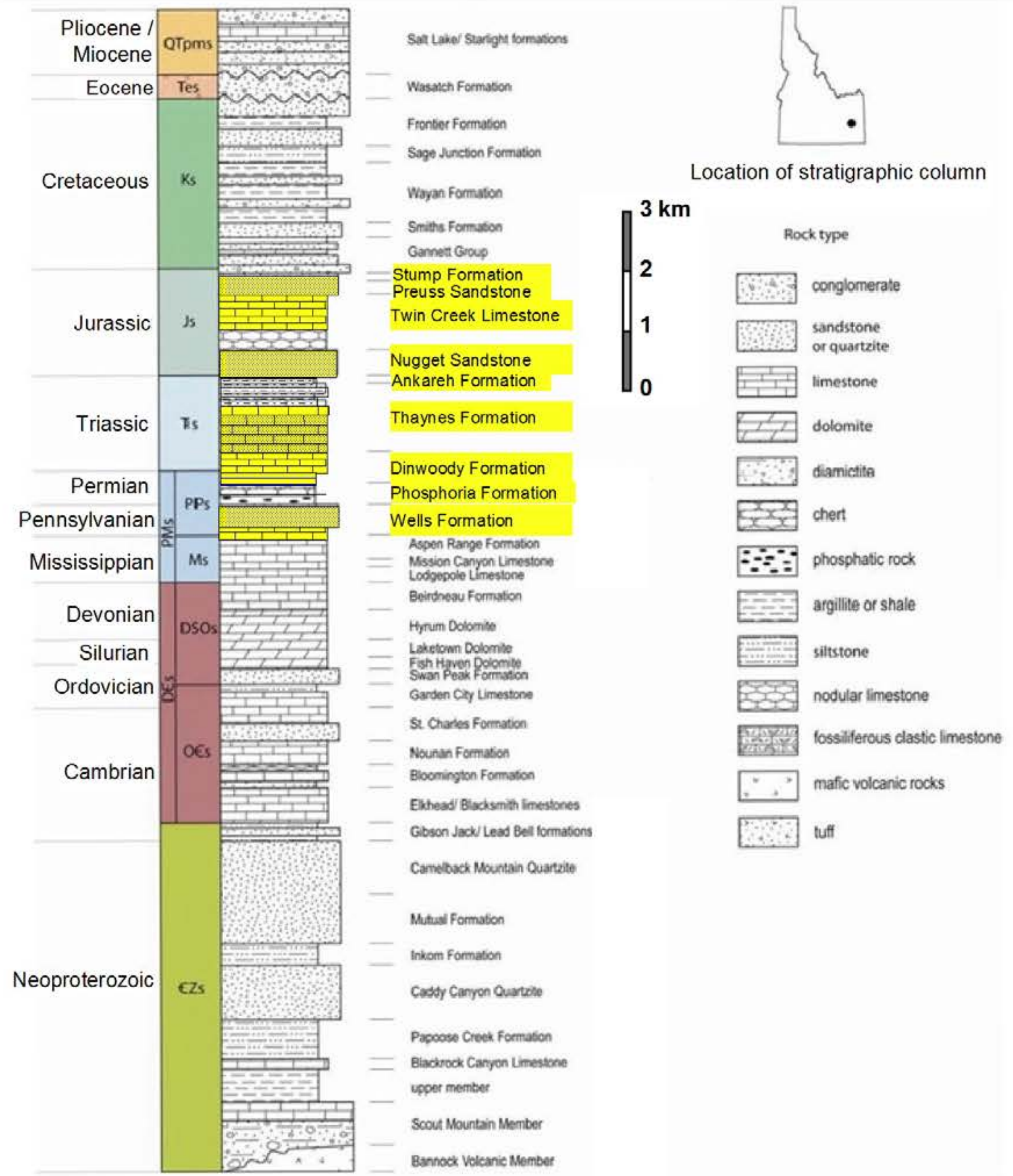
Advective transport of magmatic heat into shallow reservoirs

(crystallization-driven magmatic H_2O flux ~1 M ton / year)*

*** McCurry et al. (2015)**

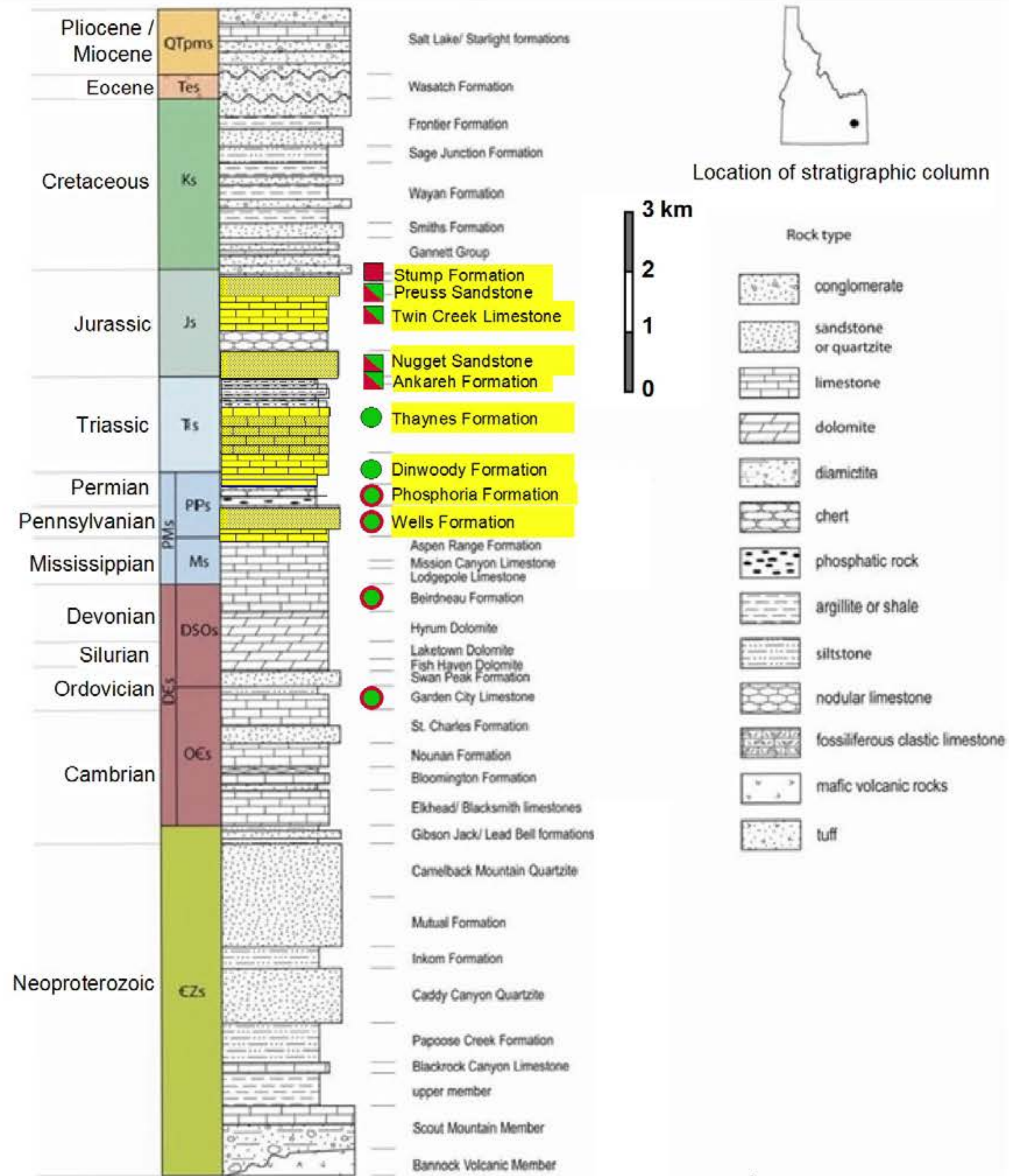
Thermal reservoir rocks in Idaho's thrust belt

Formations known to host economic temperatures



Productive Formations in Utah-Wyoming Thrust Belt *

Oil
Oil & Gas
Gas
Wet Gas

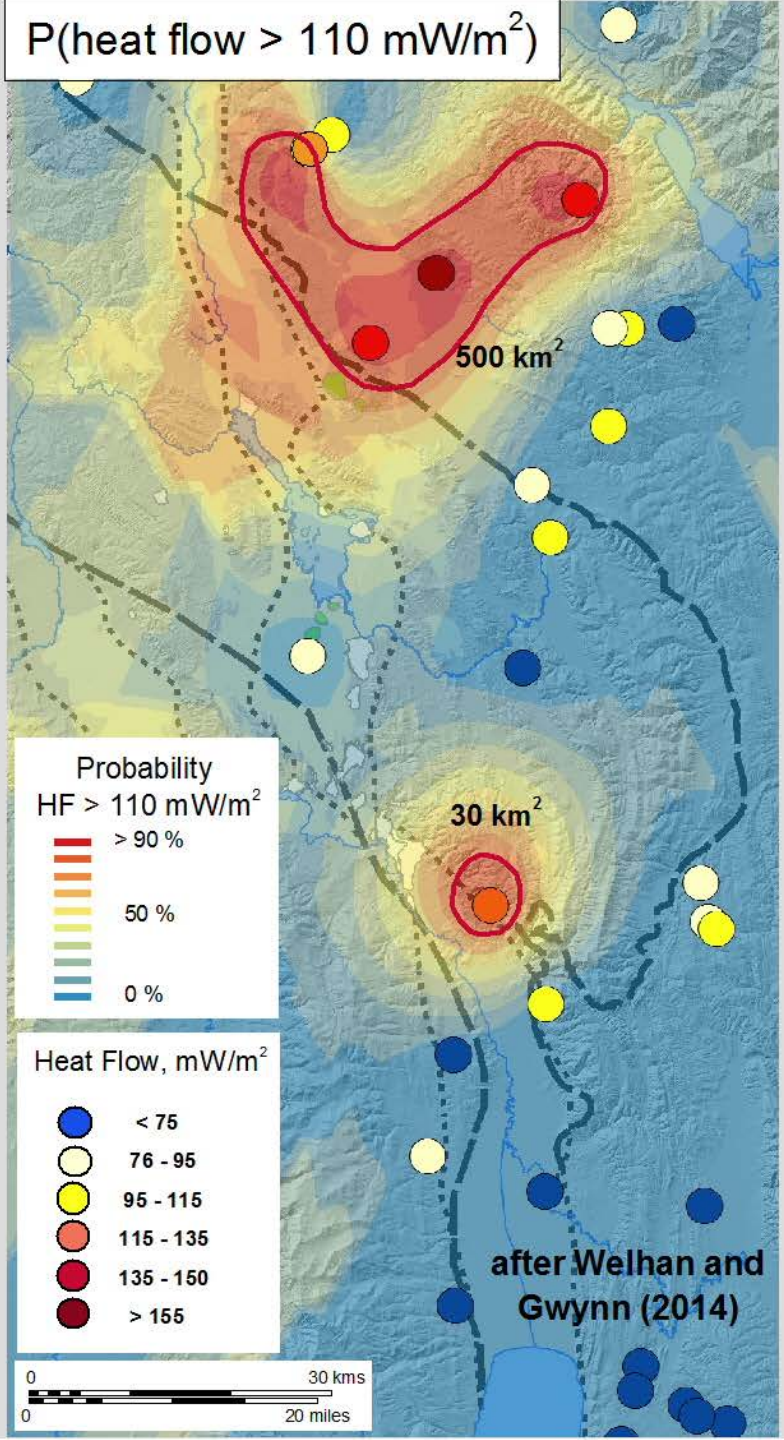


e.g., Nugget Sandstone:

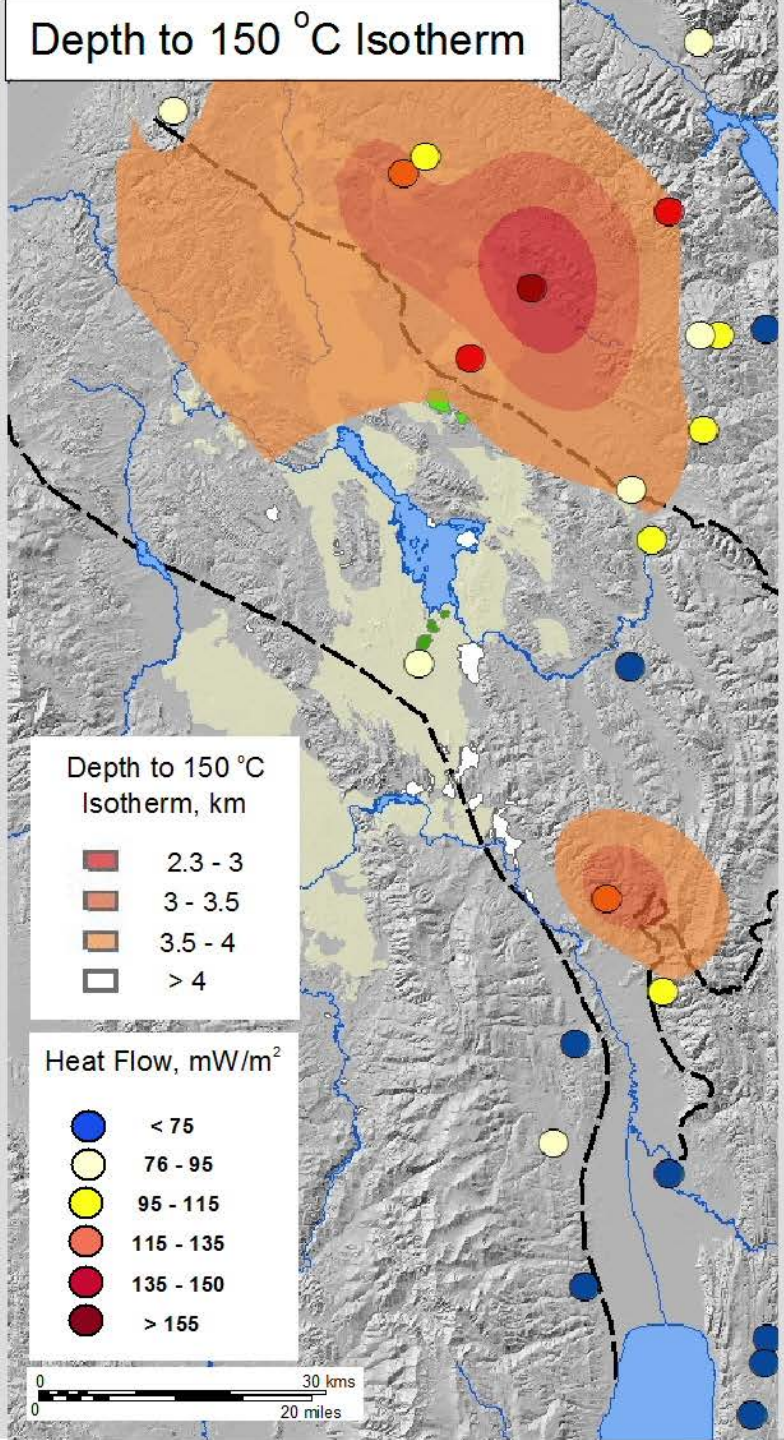
5 to 25% porosity

mD to >1 Darcy

* Powers (1983)



P(heat flow > 110 mW/m2)
500 km2
30 km2
Probability
HF > 110 mW/m2
> 90 %
50 %
0 %
Heat Flow, mW/m2
< 75
76 - 95
95 - 115
115 - 135
135 - 150
> 155
after Welhan and
Gwynn (2014)
0
30 kms
0
20 miles

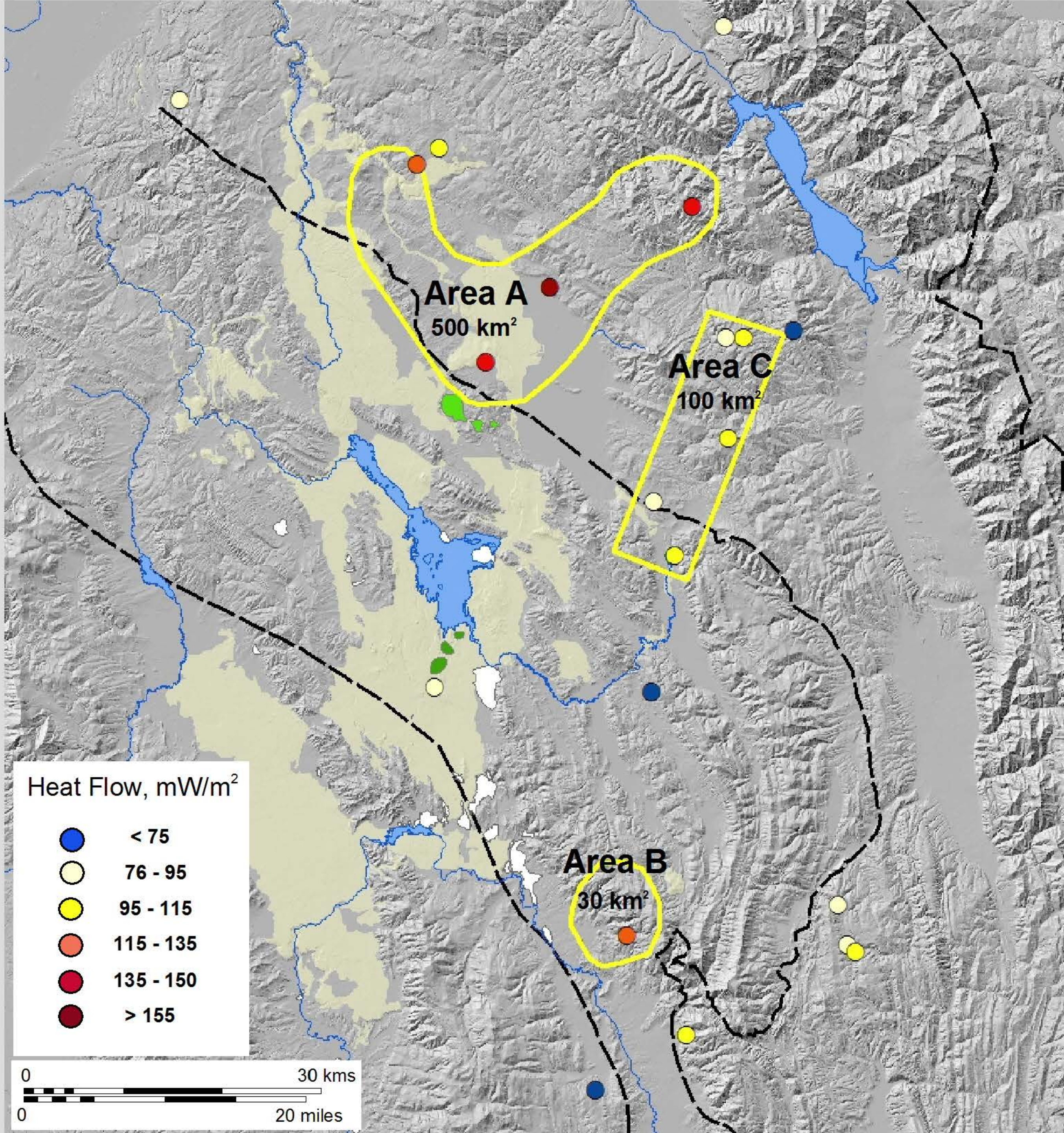


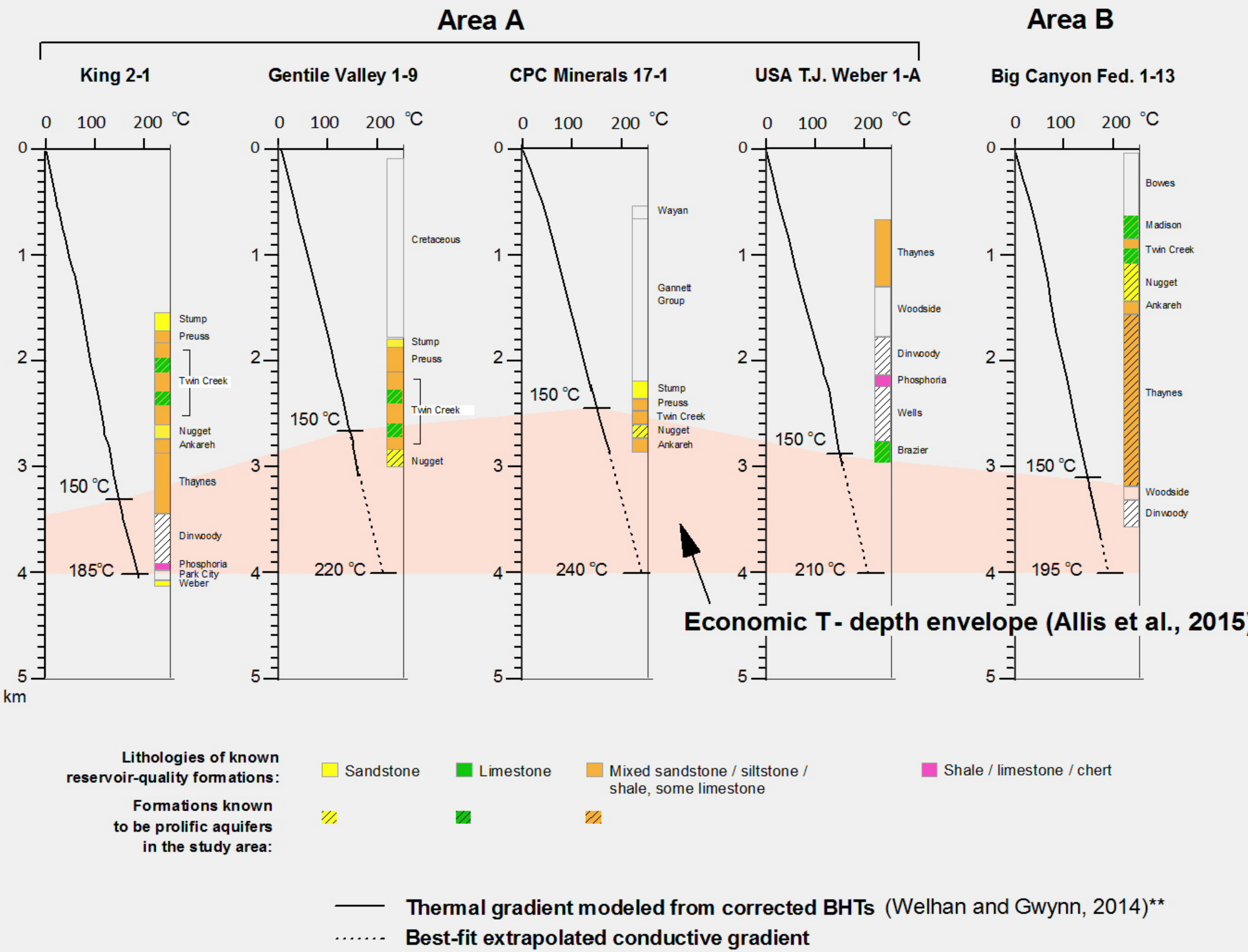
Depth to 150 °C Isotherm
Depth to 150 °C
Isotherm, km
2.3 - 3
3 - 3.5
3.5 - 4
> 4
Heat Flow, mW/m2
< 75
76 - 95
95 - 115
115 - 135
135 - 150
> 155
0
30 kms
0
20 miles

Areas Considered for Power Generation Potential

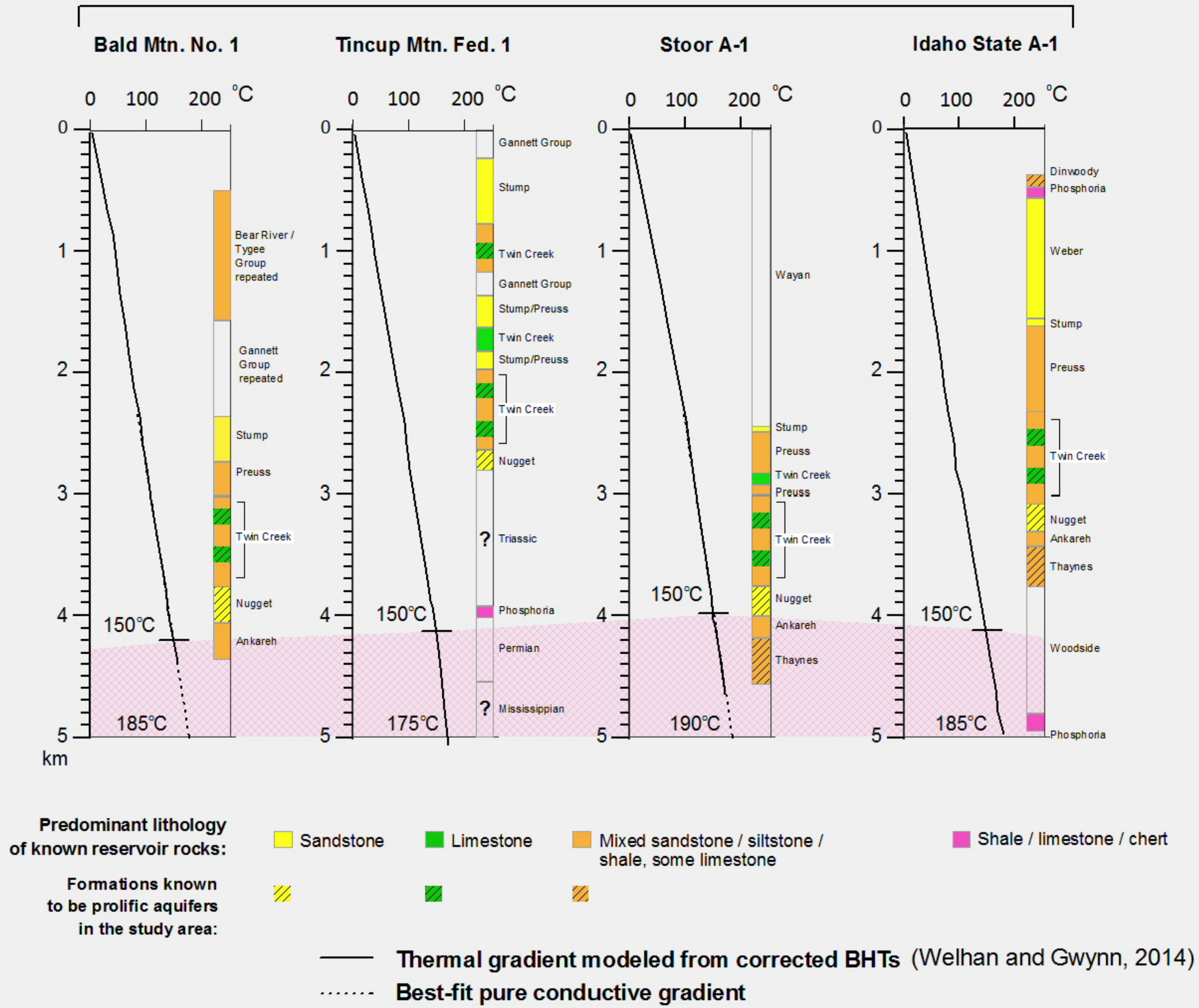
Areas A, B: Primary and secondary thermal anomalies, respectively

Area C: Deeper, thermal reservoirs with mineral co-production potential




Area A
Area B
King 2-1
Gentile Valley 1-9
CPC Minerals 17-1
USA T.J. Weber 1-A
Big Canyon Fed. 1-13
0 100 200 °C
km
Stump
Preuss
Twin Creek
Nugget
Ankareh
Thaynes
Dinwoody
Phosphoria
Park City
Weber
Cretaceous
Wayan
Gannett Group
Woodside
Wells
Brazier
Bowes
Madison
150 °C
185°C
220 °C
240 °C
210 °C
195 °C
Economic T- depth envelope (Allis et al., 2015)
Lithologies of known reservoir-quality formations:
Sandstone
Limestone
Mixed sandstone / siltstone / shale, some limestone
Shale / limestone / chert
Formations known to be prolific aquifers in the study area:
Thermal gradient modeled from corrected BHTs (Welhan and Gwynn, 2014)**
Best-fit extrapolated conductive gradient

Area C



Bald Mtn. No. 1
Tincup Mtn. Fed. 1
Stoor A-1
Idaho State A-1
0
100
200
°C
0
1
2
3
4
5
km
Bear River / Tygee Group repeated
Gannett Group repeated
Stump
Preuss
Twin Creek
Nugget
Ankareh
150°C
185°C
Gannett Group
Stump
Twin Creek
Gannett Group
Stump/Preuss
Twin Creek
Stump/Preuss
Twin Creek
Nugget
? Triassic
Phosphoria
Permian
? Mississippian
150°C
175°C
Wayan
Stump
Preuss
Twin Creek
Preuss
Twin Creek
Nugget
Ankareh
Thaynes
150°C
190°C
Dinwoody
Phosphoria
Weber
Stump
Preuss
Twin Creek
Nugget
Ankareh
Thaynes
Woodside
Phosphoria
150°C
185°C
Predominant lithology of known reservoir rocks:
Sandstone
Limestone
Mixed sandstone / siltstone / shale, some limestone
Shale / limestone / chert
Formations known to be prolific aquifers in the study area:
Thermal gradient modeled from corrected BHTs (Welhan and Gwynn, 2014)
Best-fit pure conductive gradient

Summary of Inferred Reservoir Conditions

	Area A	Area B	Area C
Depth, km to 150 °C isotherm	2.8 ± 0.5	3.1 ± 0.5	4.1 ± 0.1
$T_{Maximum}$, °C	215 ± 15 at 4 km	195 ± 15 at 4 km	185 ± 15 at 5 km
$T_{Average}$, °C	185 ± 15 at 2.5 - 4 km	170 ± 15 at 2.5 - 4 km	170 ± 10 at 4 - 5 km
Resource thickness, m	400 ± 300 at 2.5 - 4 km	>400 at 2.5 - 4 km	400 ± 300 at 4 - 5 km

Heat-in-Place Energy Assessment

Stored Reservoir Thermal Energy:

$$E_R = C_R * V_R * (T_R - T_O)$$

Electric Power Generation Capacity (30 year life):

$$P_E = n * R * E_R / (F * t)$$

Thermal Recovery and Energy-Conversion Factors:

$R = E_X / E_R = 0.02 - 0.1$ * (0.08 - 0.2) +

$n = E_E / E_X = 0.05 - 0.12$ ** (average of 52 flashed-steam plants)

$= 0.05 - 0.08$ ** (range of 31 binary plants, $T_R = 150 - 220$ °C)

(0.3 - 0.4) +

+ **Williams et al. (2008); GeoFRAT** *** Sanyal et al. (2002)** **** Moon and Zarouk (2012)**

Constraints on Monte Carlo Power Estimates

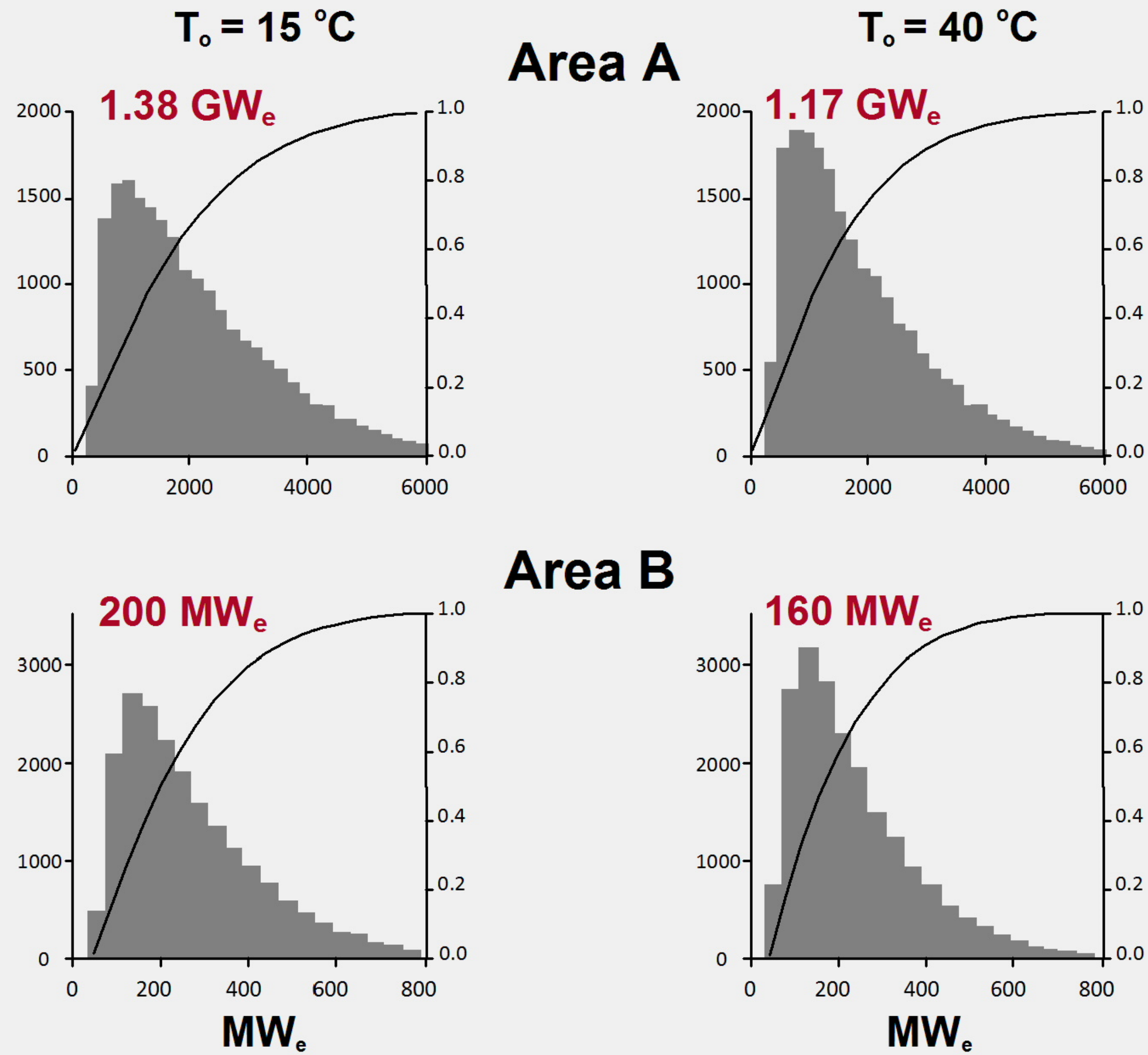
		T_R, °C *	V_R, km^3	Power conversion	Recovery factor
Area A	Min	170	20	0.05	0.02
	Max	200	350	0.12	0.10
Area B	Min	150	8	0.05	0.02
	Max	195	21	0.12	0.10
Area C	Min	150	10	0.05	0.02
	Max	170	70	0.08**	0.10

* Average T between the 150 °C isotherm and 4 km (Areas A, B) or 5 km (Area C) depth

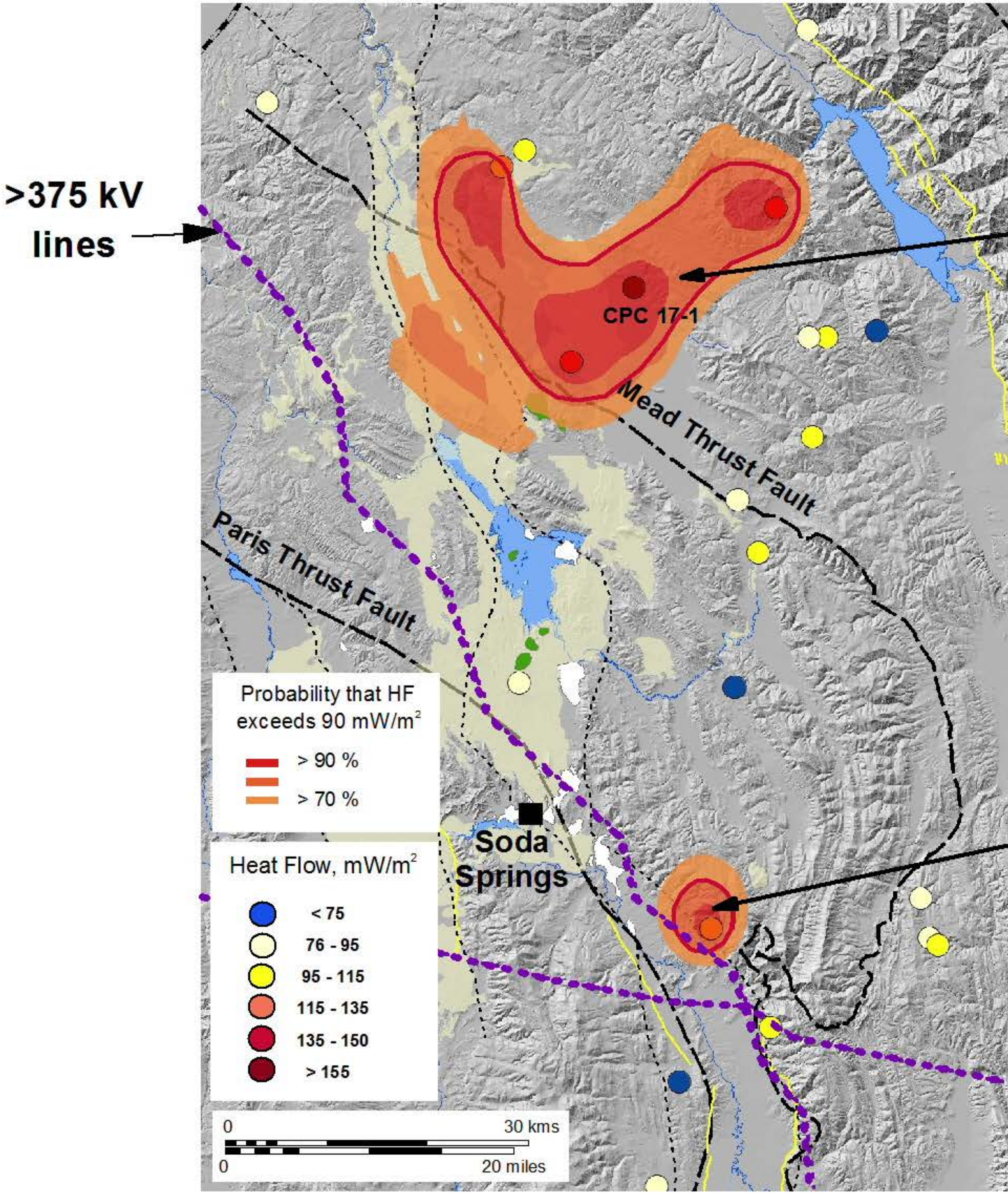
** For binary-cycle power conversion of lower temperature and possibly high-salinity fluid

Predicted Power Generating Capacity

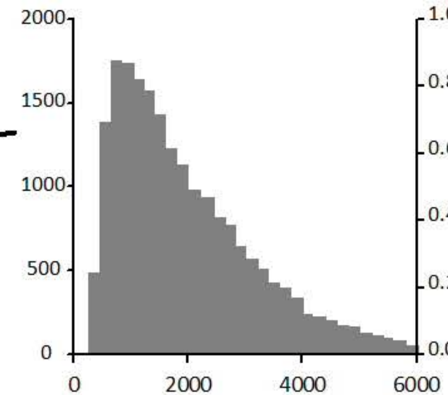
(20,000 realizations)



GeoFRAT estimate for Area A (10,000 realizations): **2.0 GW$_e$**



1270 MW$_e$



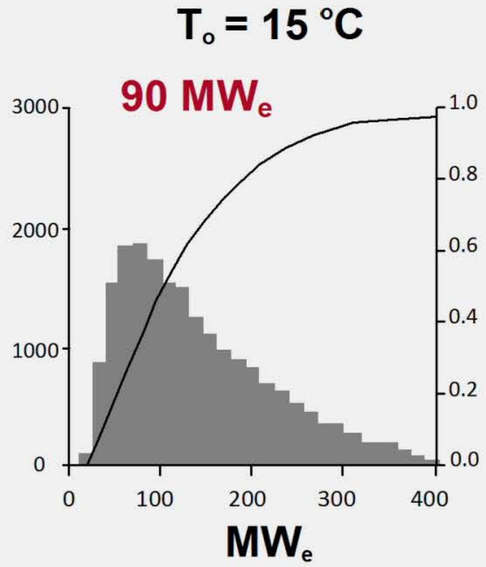
Area A	(T_o = 15 - 40 °C)
Median	1270 MW$_e$
25th	688
10th percentile	370

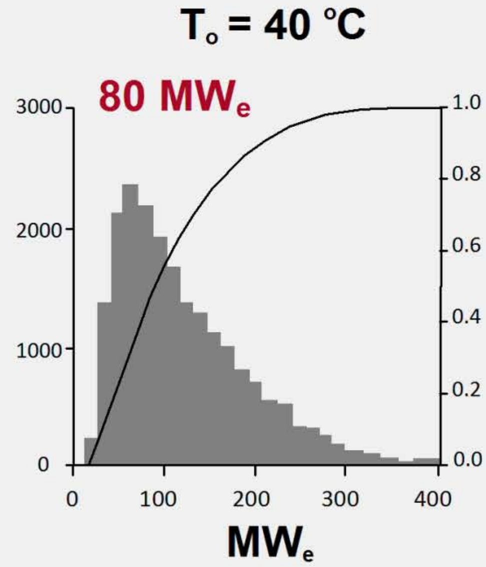
180 MW$_e$

Area B	(T_o = 15 - 40 °C)
Median	180 MW$_e$
25th	109
10th percentile	68

Area C

Predicted Power Generating Capacity
(20,000 realizations)

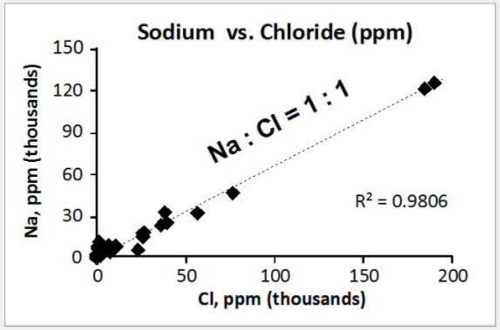




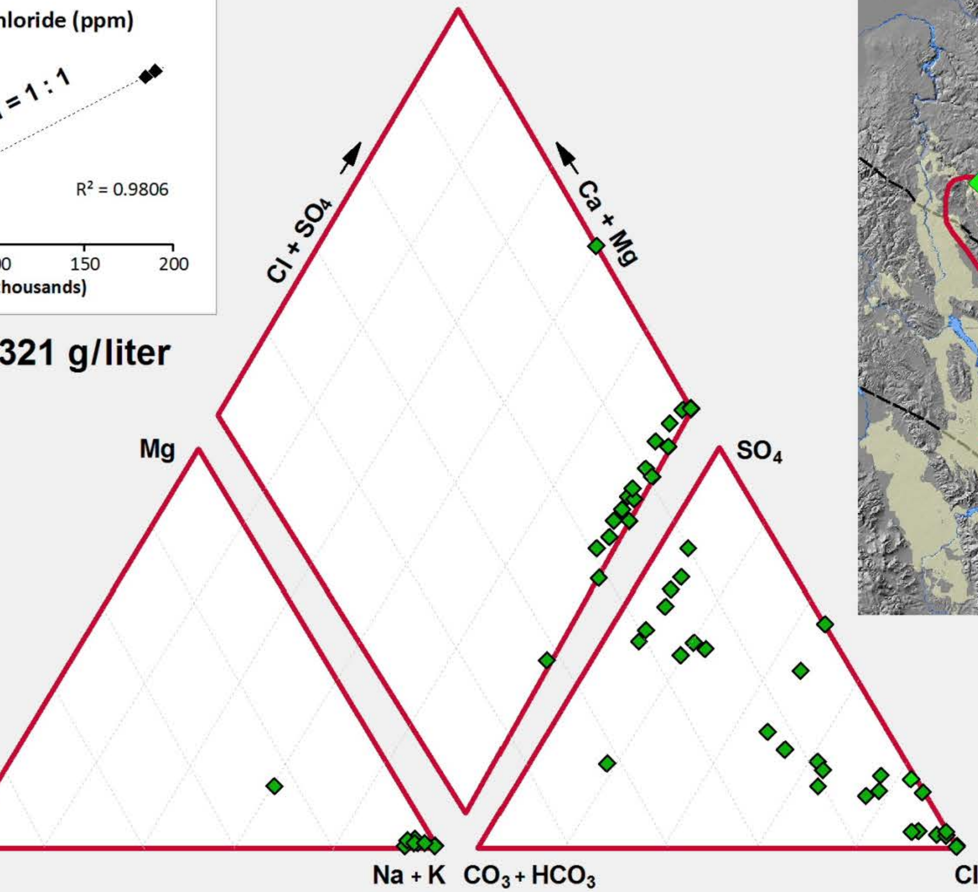
Area C is likely not an economic power resource:

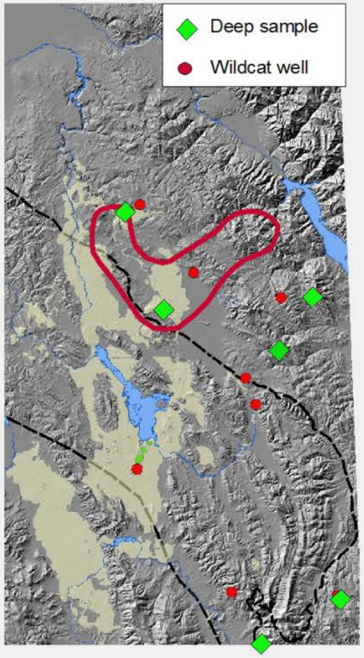
It lies outside the 4 km temperature - depth envelope,

and it has high-salinity fluids (>300,000 ppm) . . .



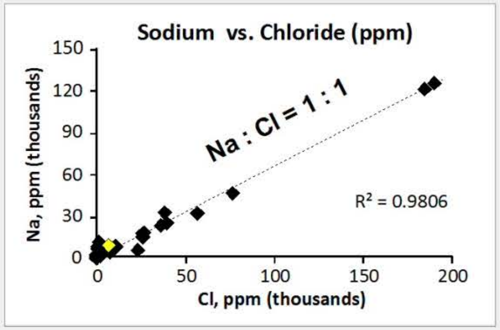
Max TDS = 321 g/liter



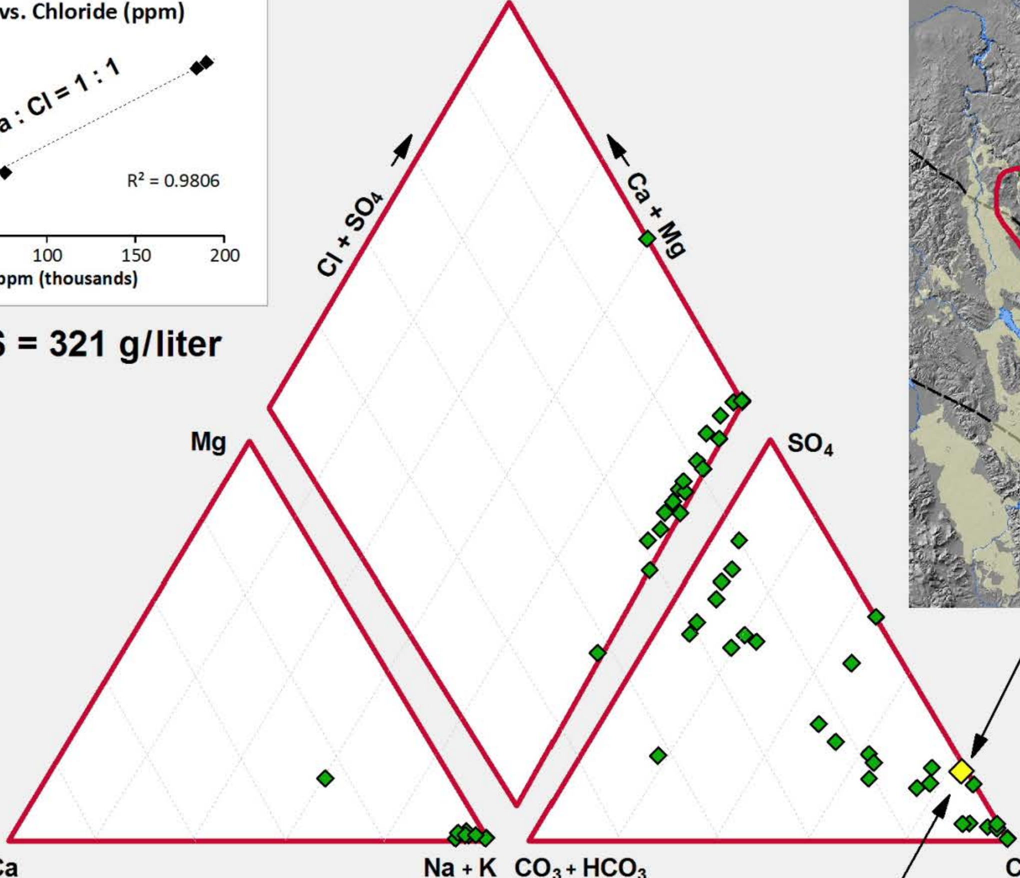


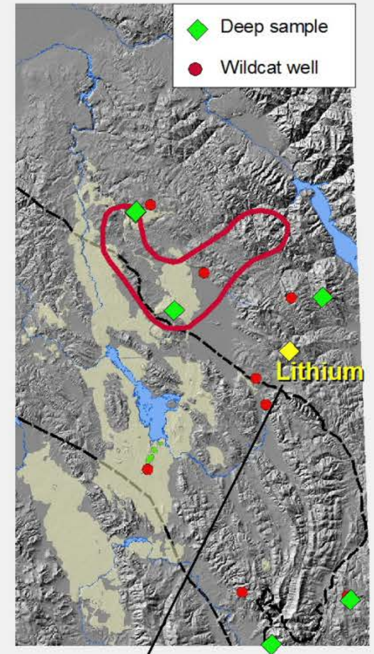
Fluid Chemistry From Drill Stem Test Samples:

Dissolution of NaCl (Preuss salt beds) $\pm$ $CaSO_4$



Max TDS = 321 g/liter





Salton Sea: Li = 205 ± 160 (2σ) mg/l

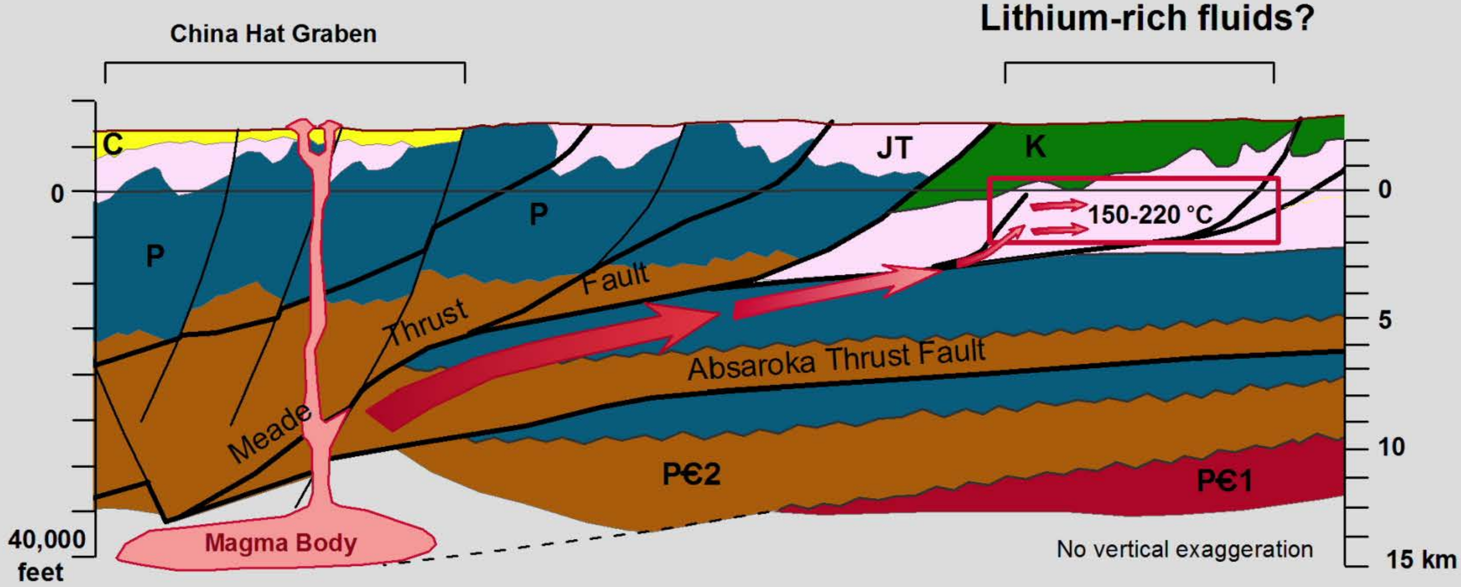
Li/Cl ~ 150x seawater

Li = 113 mg/l (diluted?)

Li/Cl > 1200x seawater

Conceptual Model

(non-thermohaline heat transport)



Crystallization-driven magmatic CO_2 flux estimate matches observed surface flux,

<u>so estimated lithium hydrothermal output ~ 100 tons/day</u>*

Do These Thermal Reservoirs Have Mineral Co-production Potential ?

*** McCurry et al. (2015)**

Conclusions and Recommendations

Favorable Factors

- potentially very large thermal resource at 150 - 240 °C
- thermal replenishment via advective transport of magmatic heat?
- Area A is within 30 km of existing HVT lines; Area B, within 5 km
- lithium co-production potential (?)

Significant Unknowns

- reservoir thickness, poropermeabilities, compartmentalization ?
- how sensitive are economics to drilling depth & rock properties ? *
- how sensitive are levelized costs to T_R, reservoir productivity ? *

*** Sanyal and Butler (2009)**

Raw NGDS data available at geothermaldata.org
and this analysis and data synthesis will be on-line shortly:

"Geologic Conceptual Models and Economic Potential of a Hidden High-Temperature Geothermal Resource in the Idaho Thrust Belt"

Idaho Geological Survey Technical Report (in review)

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Questions?

Previously Published Reports:

Welhan (2014)
Proc. 41st Workshop on Geothermal Reservoir Engineering, Stanford
https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2016/Welhan.pdf

Welhan et al. (2014)
Proc. 39th Workshop on Geothermal Reservoir Engineering, Stanford
https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2014/Welhan.pdf

Welhan and Gwynn (2014)
Geothermal Resources Council Transactions, v. 38, p. 1055-1066

Welhan et al. (2013)
Geothermal Resources Council Trans., v.37, p. 365-374

Welhan et al. (2013)
AAPG Search and Discovery #80329, AAPG Rocky Mountain Section Meeting
http://www.searchanddiscovery.com/pdfz/documents/2013/80329welhan/ndx_welhan.pdf.html