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Concept for a distributed baseload electrical power system in the Williston Basin

The geological setting of the Williston Basin with six potential geothermal aquifers having temperatures ranging from 80 ^{o}C to 145 ^{o}C and access to Missouri River water for cooling is conceptually ideal for distributed baseload binary power development. The aquifer systems lie at depths ranging from 2 km to 3.5 km and currently produce oil, gas, and water. Due to extensive exploration and development, significant information on reservoir properties relevant to water production is available. Existing oil field infrastructure in North Dakota includes more than 7000 dry or plugged and abandoned oil and gas wells that potentially could be redeveloped for geothermal use. The successful demonstration of power production using 98 ^{o}C water produced with horizontal open-hole wells drilled into the Lodgepole Formation (Miss.) is a model for similar projects that could be developed throughout the basin. Analysis of the economics of such a system indicates that redeveloping existing wells could provide power at 8.25 ¢/kWh.

The University of North Dakota

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UND Geothermal Laboratory
The University of North Dakota

Concept for Distributed Base load Binary Power

SMU Geothermal Conference No. 9
January 9-11, 2018
Power Plays

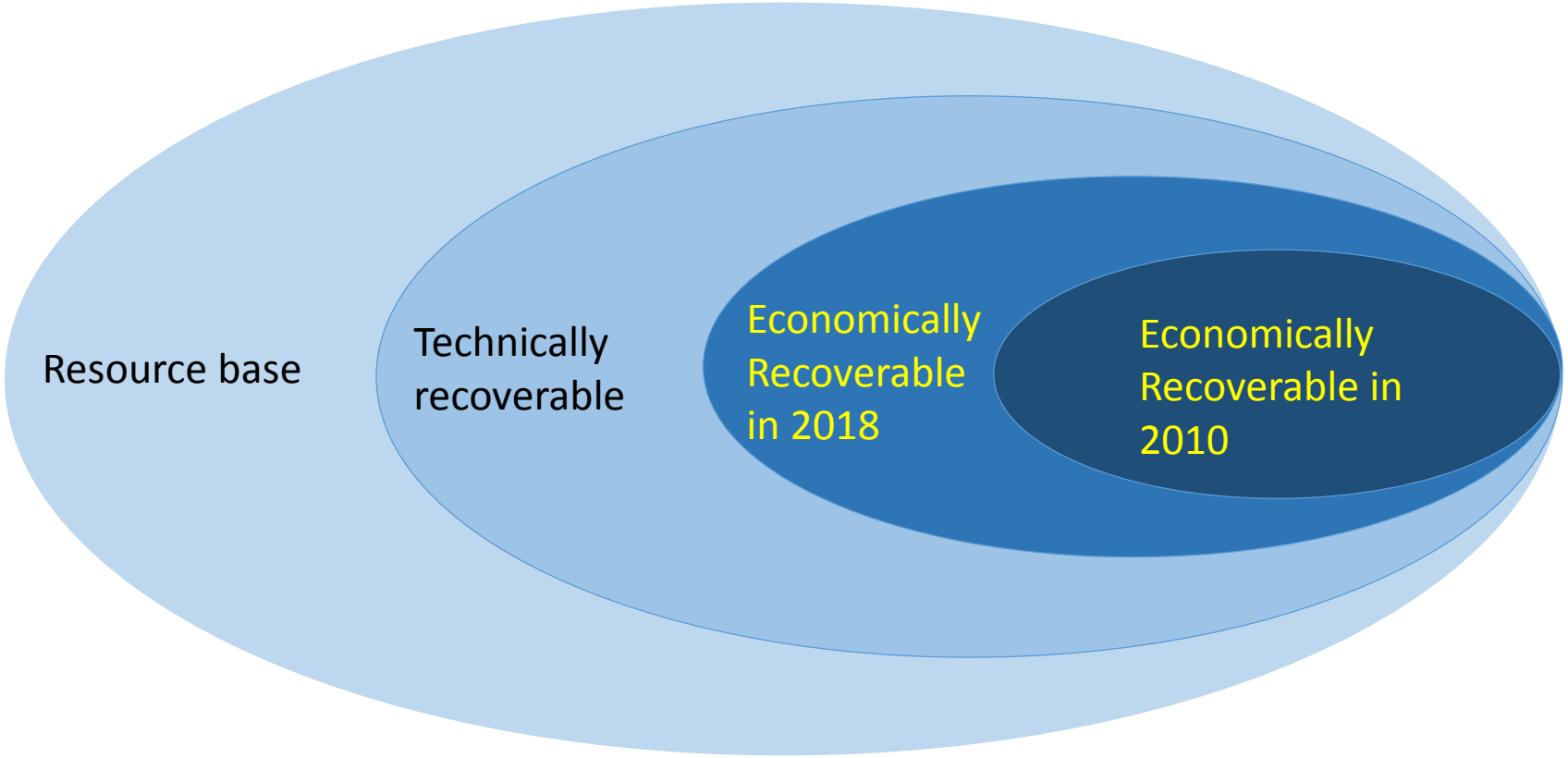
Characteristics of Geothermal Energy in Sedimentary Basins

- Conduction dominated thermal regimes with temperatures already known or easily obtained from various data sources
  - BHT and heat flow data provide understanding of the thermal regime
  - The temperatures are typically less than 150 °C and development requires binary systems
- The resource is widespread
  - Exploration and drilling costs are minimal
  - Risks are small
- The fluids for heat extraction exist throughout sedimentary aquifers
  - Geological data on aquifer properties is readily available
  - Oil and water production data indicate water availability
  - Oil reservoir data and published analyses indicate permeability and porosity

Geothermal Perspective of the Williston Basin

- The temperatures, depths and hydrologic properties of the geothermal resource are well documented (Gosnold et al, 2012, 2015, 2016; Crowell and Gosnold, 2015)
- The accessible energy in six major geothermal aquifers in the Williston Basin is on the order of 2.84×10^{20} J. (Crowell and Gosnold, 2015)
- North Dakota's total annual energy consumption is 5.7×10^{17} J. (EIA, 2016)
- High-volume water production using open-hole laterals has been demonstrated at the UND-CLR binary geothermal power plant (Gosnold, Mann, and Salehfar, 2017; Williams, Neil, and Gosnold, 2016).
- If this the resource were fully developed, it could supply all of North Dakota's energy needs.

The economics of geothermal energy improve with technological advance

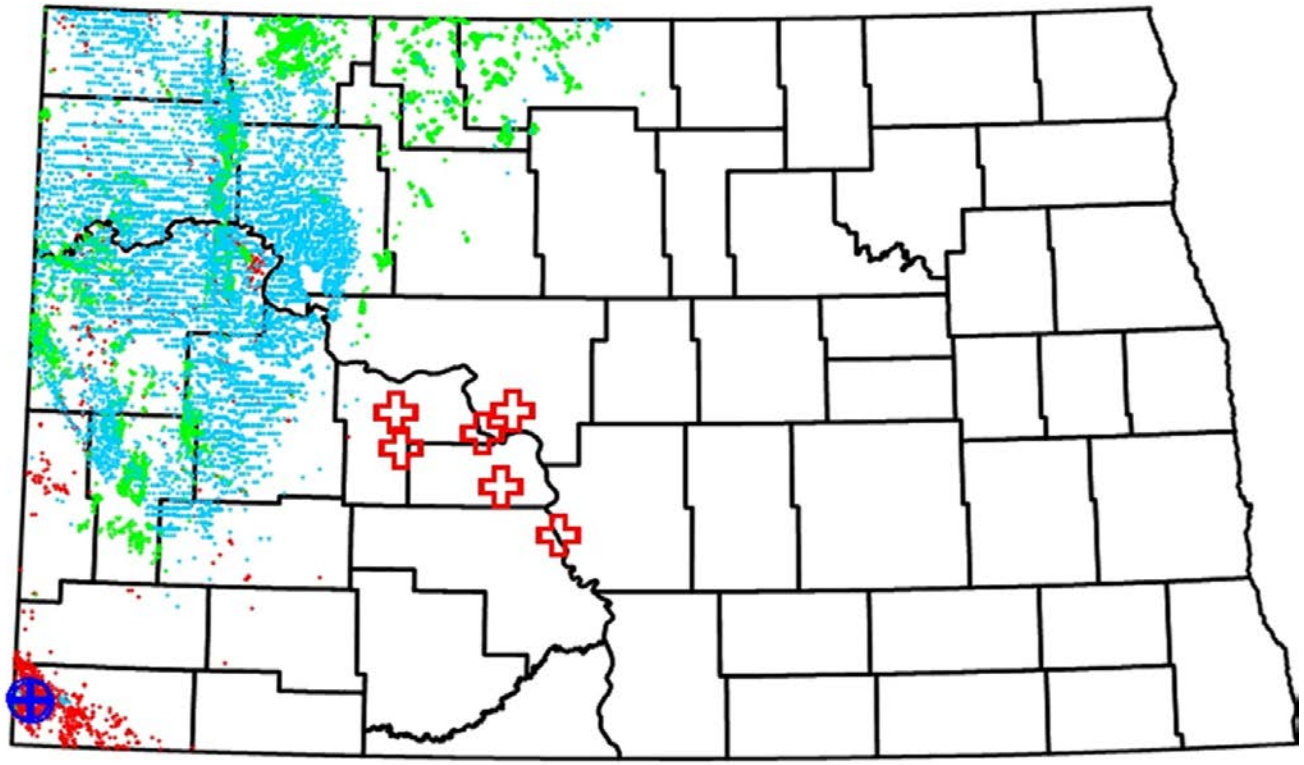


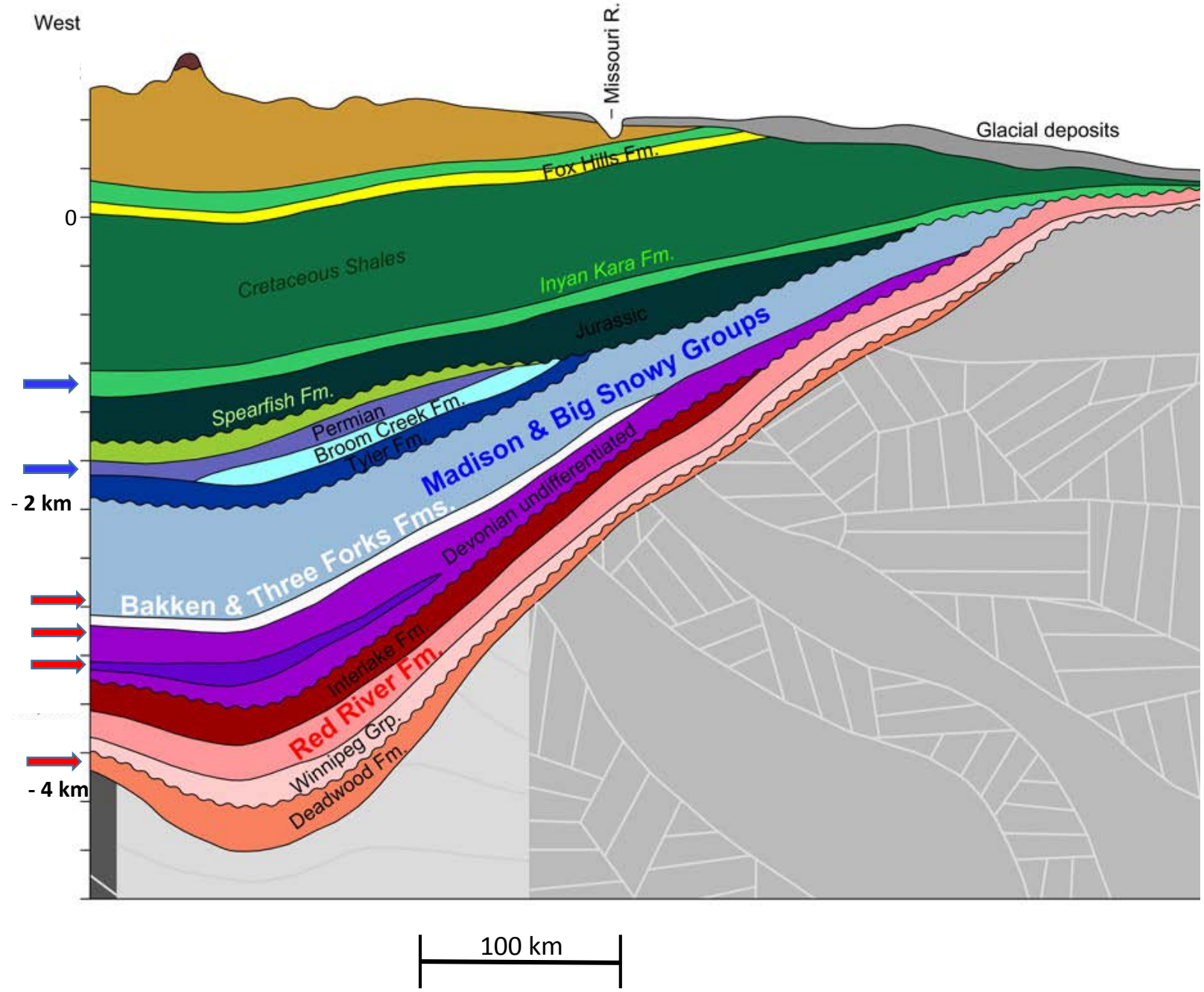
UND Geothermal Activities

- Resource assessment and the National Geothermal Database
  - North Dakota, Minnesota, and Nebraska
- Co-produced fluids and power generation with DOE
  - Wells in the Williston Basin produce low volumes of water
  - Multi-will pads do offer sufficient volumes
- Low-Temperature fluids and power generation
  - The UND-CLR binary geothermal power plant
- Now working on growing geothermal development

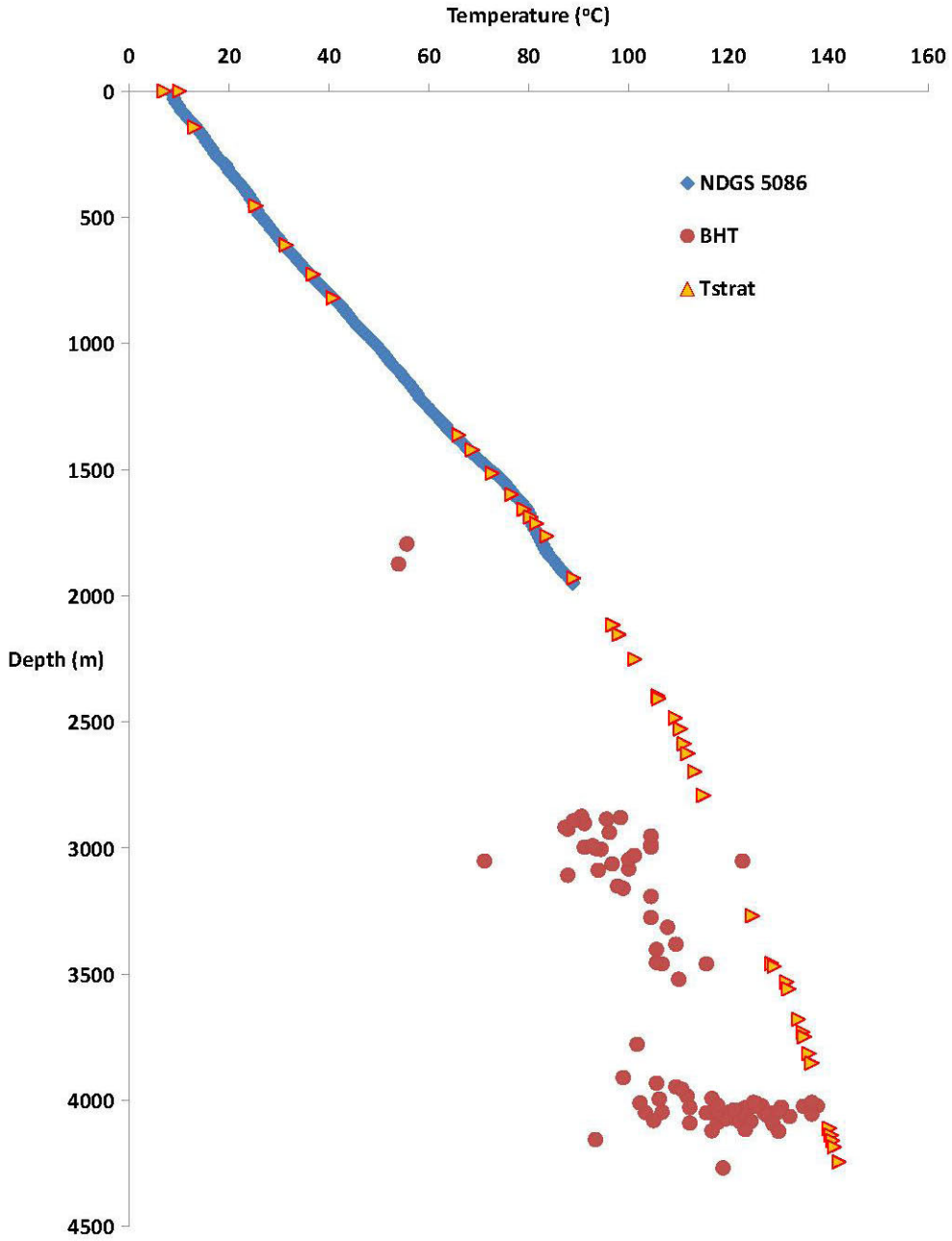
A great opportunity for distributed power

- 2,600 MW additional power needed to produce Bakken and Three Forks by 2032
- Existing power for ND-MT is from 6 coal or gas-fired power plants on Missouri River.
- Current supply for the boom is from diesel, propane & produced gas at 5 X grid power cost





Age		Generalized Stratigraphy	Hydrostratigraphy
Quaternary / Tertiary		Ft. Union, White River, & Coleharbor Groups	Upper Aquifer
		Fox Hills Fm. & Hell Creek Fm.	
Cretaceous	U	Pierre Shale	Cretaceous Aquitard System
	U	Colorado Group (includes Niobrara & Belle Fourche)	
	L	Newcastle Fm.	Dakota Aquifer
	L	Scull Creek Fm.	
	L	Inyan Kara Fm.	
Jurassic	U	Swift Fm.	Jurassic, Triassic, Permian Aquitard System
	M	Rierdon Fm.	
	M	Piper Fm.	
Triassic		Spearfish Fm.	
Permian	U	Minnekahta Fm.	
	L	Opeche Fm.	
Pennsylvanian		Minnelusa Group (Broom Creek Fm., Amsden Fm., Tyler Fm.)	Pennsylvanian Aquifer
Mississippian	U	Big Snowy Group	Mississippian Aquitard
	U	Madison Group: Charles Fm.	
	L	Madison Group: Mission Canyon Fm.	Madison Aquifer
	L	Madison Group: Lodgepole Fm.	
		Bakken Fm.	Bakken/Three Forks Aquitard
		Three Forks Fm.	
Devonian	U	Jefferson Group (Duperow Fm. & Birdbear Fm.)	Minor Devonian Aquifer
	U	Manitoba Group (Dawson Bay Fm. & Souris River Fm.)	
	M	Prairie Fm.	Prairie Aquiclude
	M	Winnipegosis Fm.	Winnipegosis Aquifer
Silurian		Ashern Fm.	Basal Aquitard
		Interlake Fm.	
Ordovician	U	Red River Fm.	Basal Aquifer
	M	Winnipeg Group	
	L	Deadwood Fm.	
Cambrian	U	Deadwood Fm.	
	M	Deadwood Fm.	
Precambrian		Superior Province & Trans-Hudson Orogenic Belt	Lower Boundary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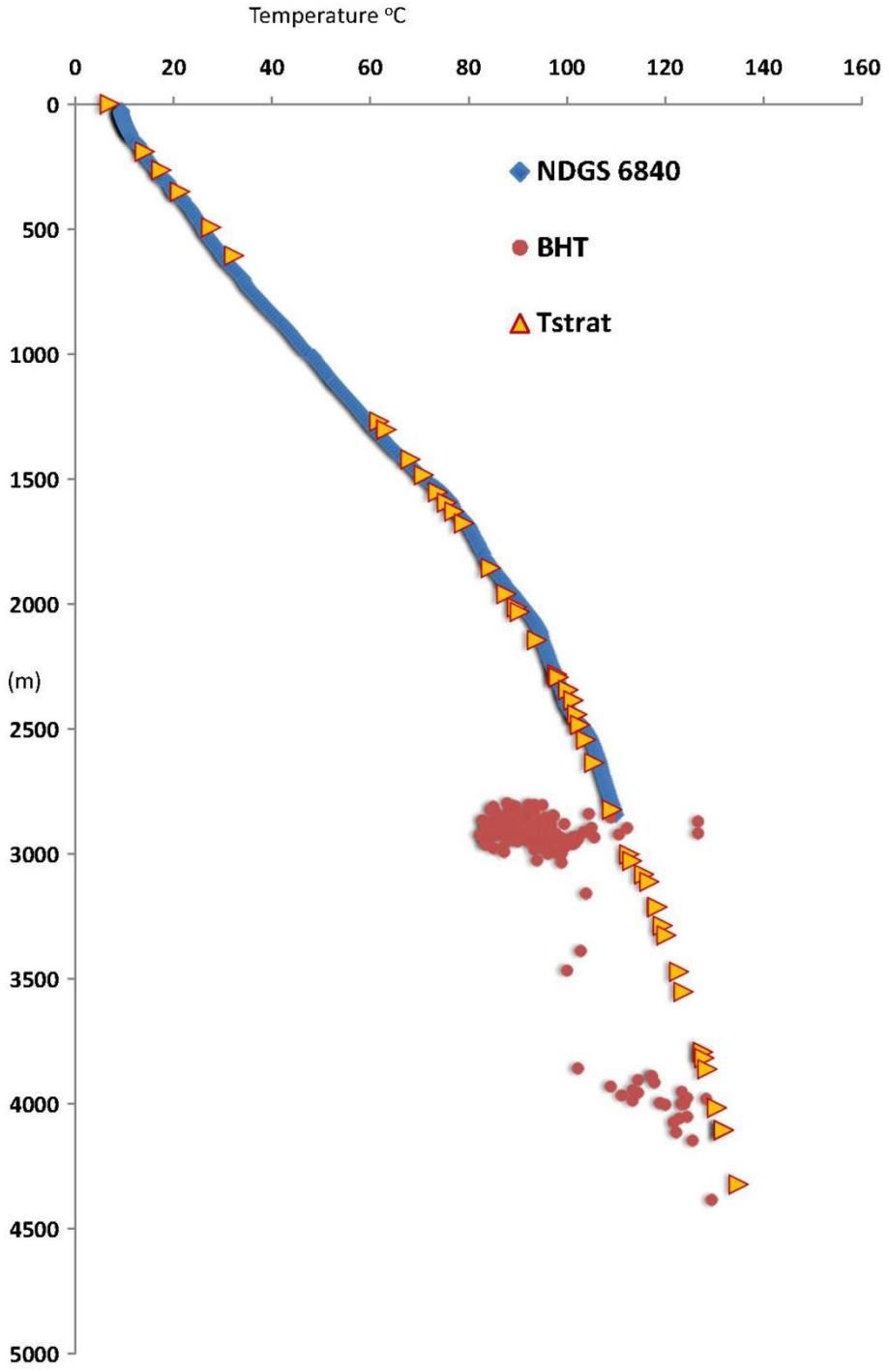
4500
Depth (m)
NDGS 5086
BHT
Tstrat


Temperature °C
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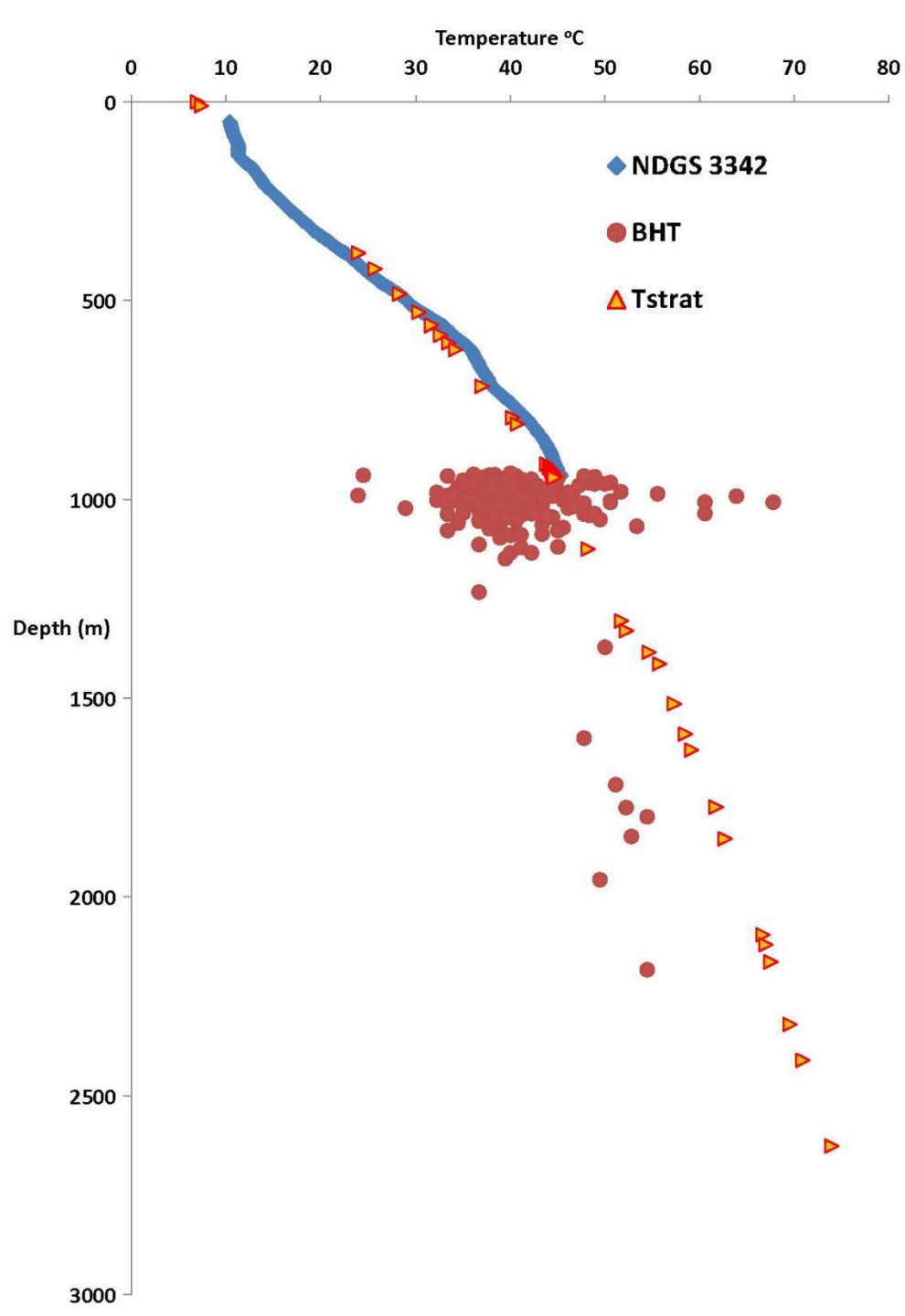
(m)
NDGS 6840
BHT
Tstrat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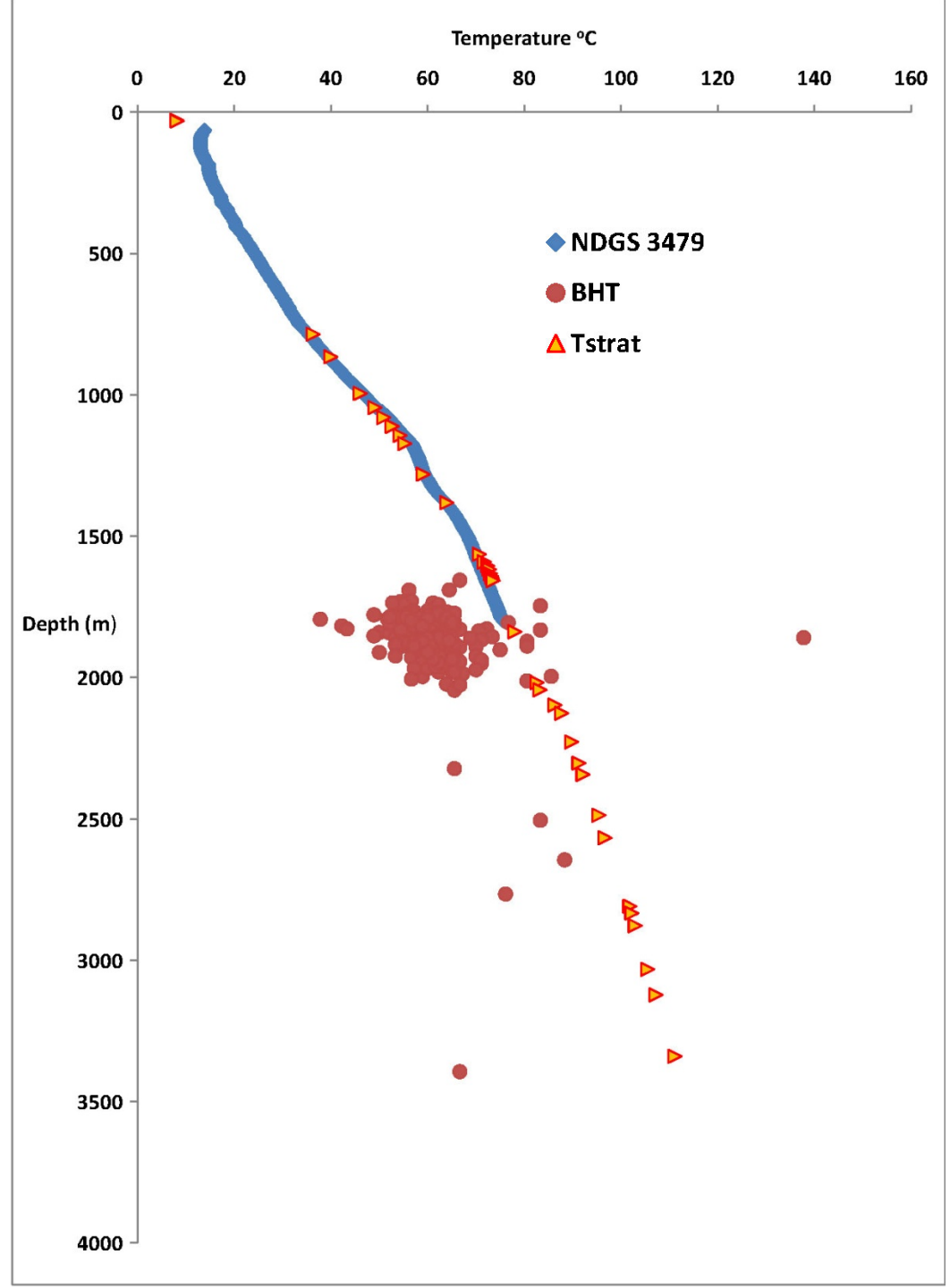
Depth (m)
NDGS 3342
BHT
Tstrat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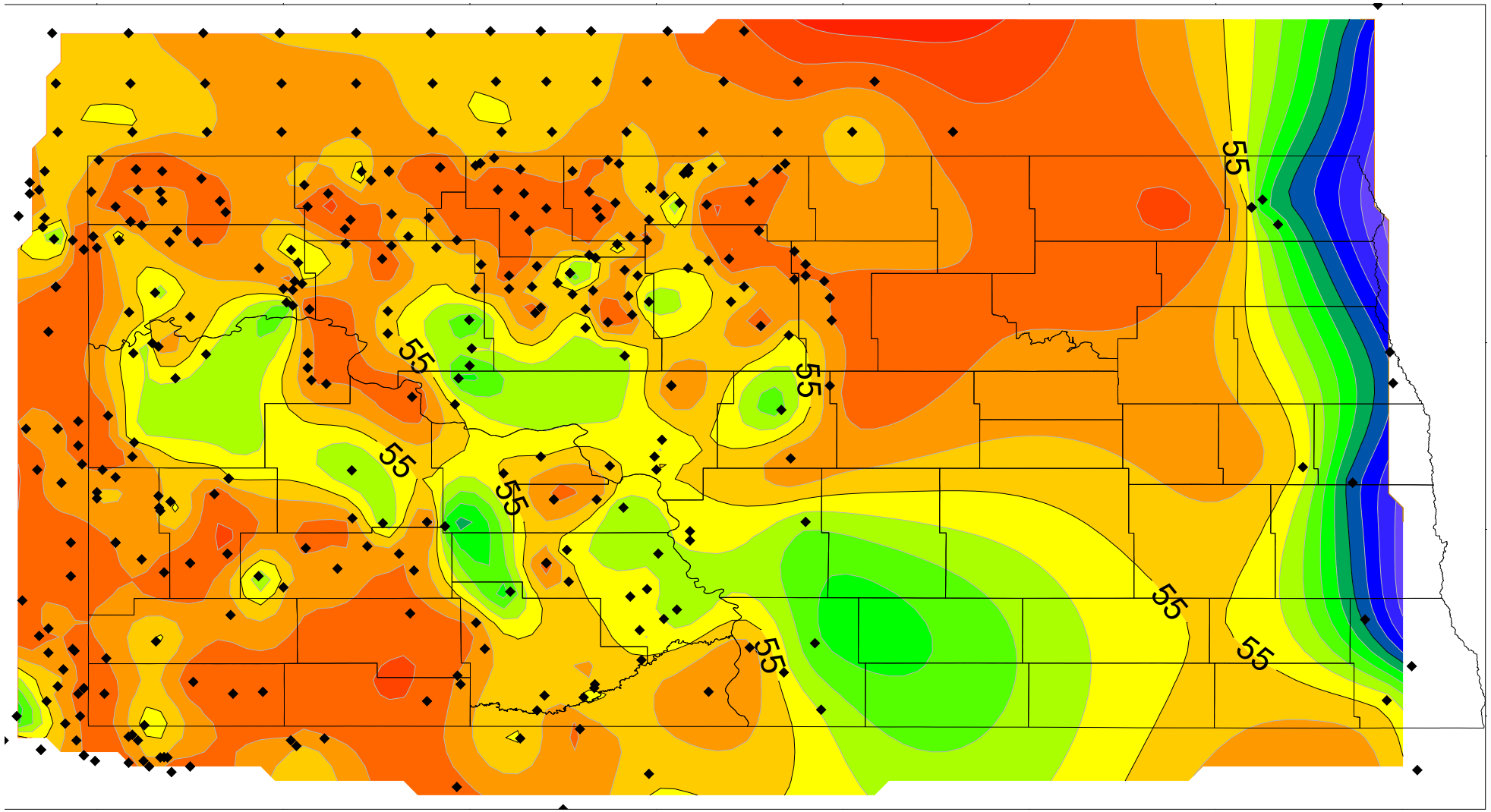
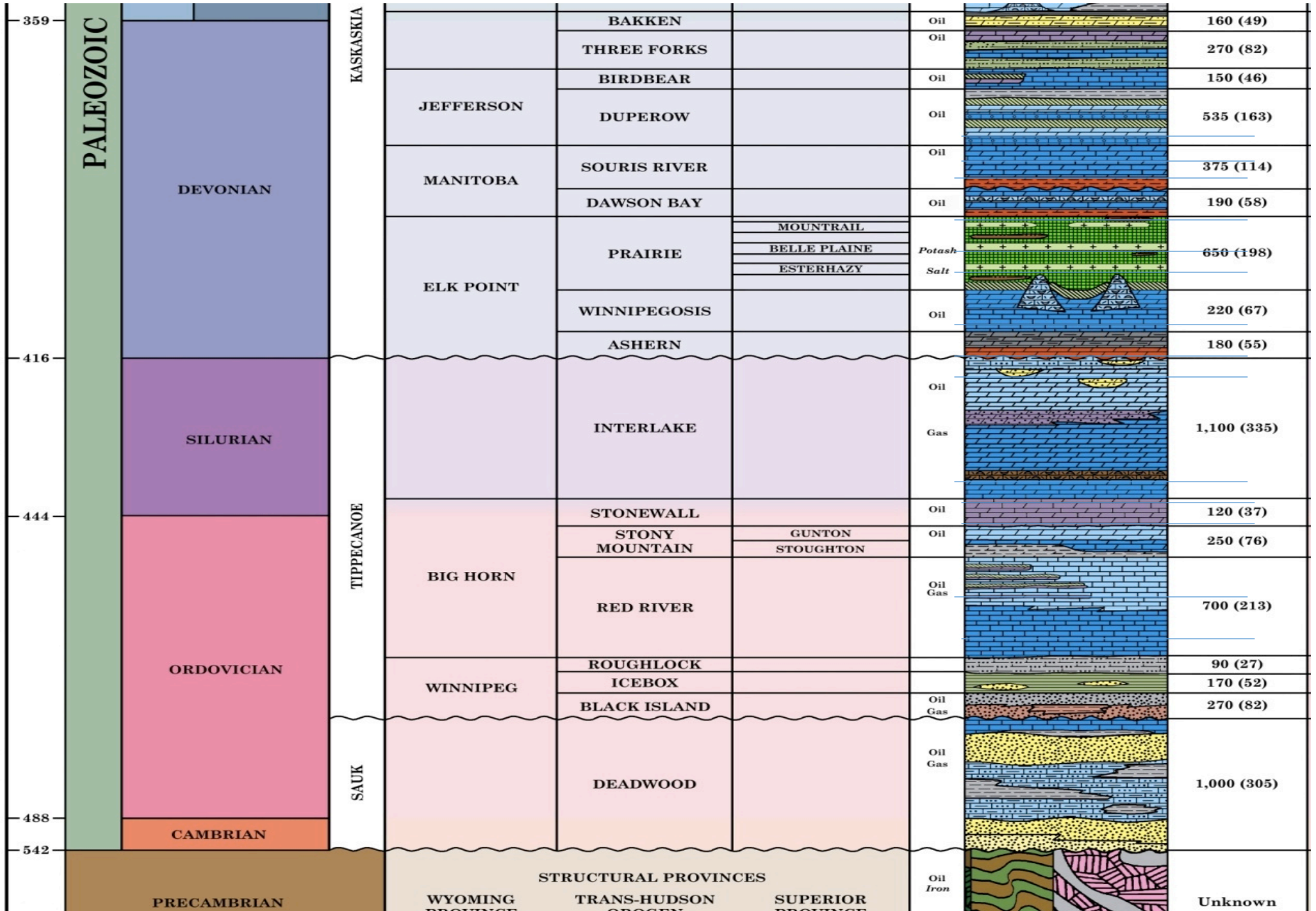
Depth (m)
NDGS 3479
BHT
Tstrat

ND Heat Flow based on combination of BHT and 34 equilibrium temperature logs in holes 1.0 to 2.6 km deep





Wm k^{-1}

1.1	±	0.20
3.10	±	0.73
3.19	±	0.51
2.92	±	0.48
2.75	±	0.6
2.99	±	0.7
3.1	±	0.24
3.77	±	0.67
3.89	±	0.01
3.79	±	0.67
3.28	±	0.94
4.07	±	0.39
3.46	±	1.02

System	Rock Units	Lithology	Max. Thickness	Depth	Conductivity	°C
Quaternary	Cole harbor +	Clay, silt, sand, gravel	510	0	1.4	6
Tertiary	White River	Siltstone, clay, sand	75	53	1.3	8
	Golden Valley	Clay, siltstone, lignite	65	98	1.1	10
	Fort Union	Silt, clay, sand	600	518	1.2	33
	Hell Creek	Sand	200	658	1.7	40
	Fox Hills	Silt, shale, sandstone	120	742	1.2	43
Cretaceous	Pierre	Shale	700	1232	1.1	68
	Niobrara	Shale	75	1285	1.1	71
	Carlisle	Shale	120	1369	1.1	75
	Greenhorn	Shale, shaly limestone	45	1400	1.4	77
	Bell Fourche	Shale	105	1474	1.1	80
	Mowry	Shale	55	1512	1.1	82
	Newcastle	Sandstone, shale	45	1544	1.6	84
	Skull Creek	Shale	40	1572	1.2	85
	Inyan Kara	Sandstone	135	1666	1.6	90

North Dakota nd.gov Official Portal for North Dakota State Government

Related Links

- Premium Services
- Code Definitions
- Digital & Image Logs
- Map This Well
- Get Well File

Well File Last Modified:
3/16/2013 10:22:10 AM

Get Well Scout Ticket Data

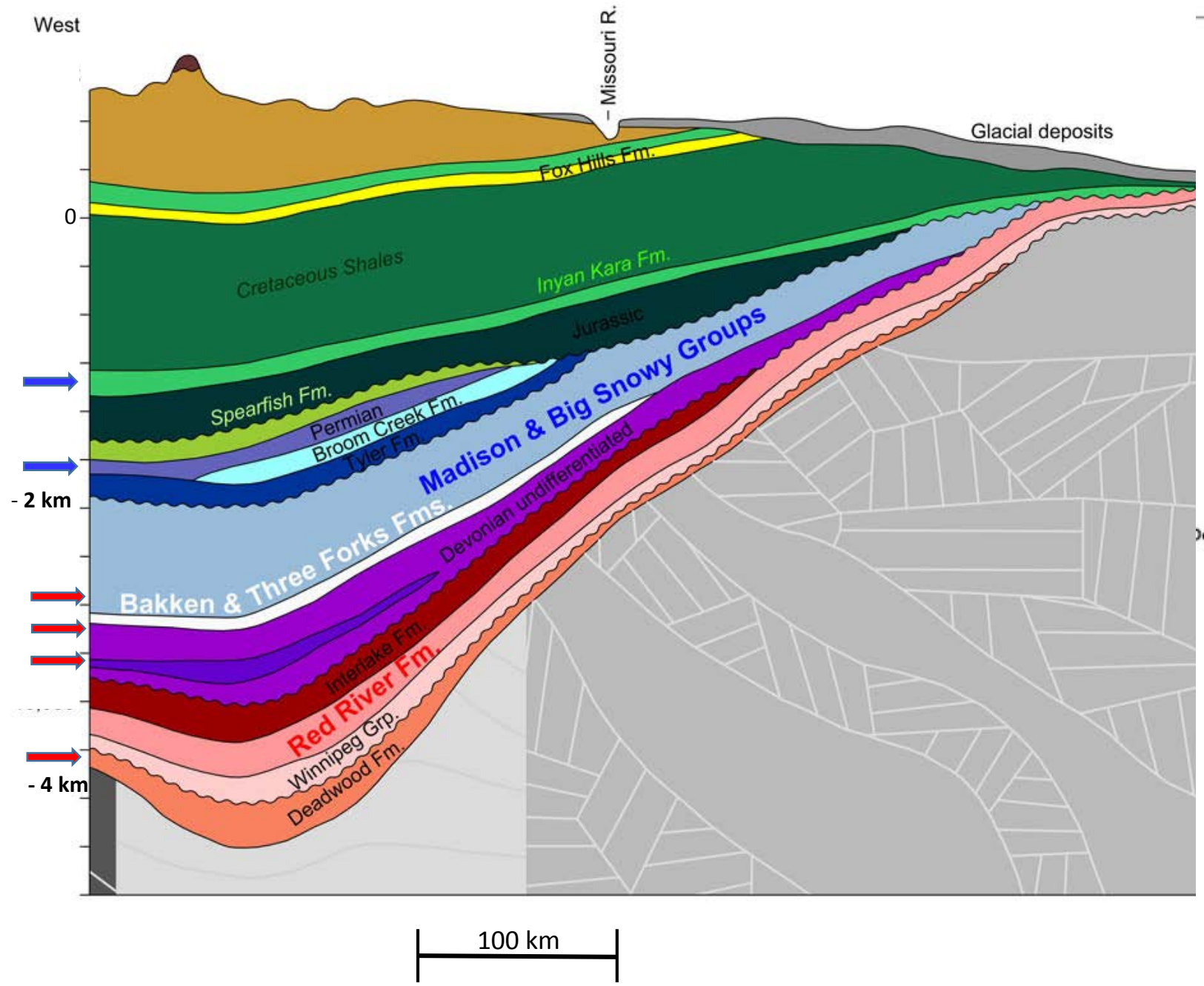
Enter File Number: 0
Or Enter API Number: 0

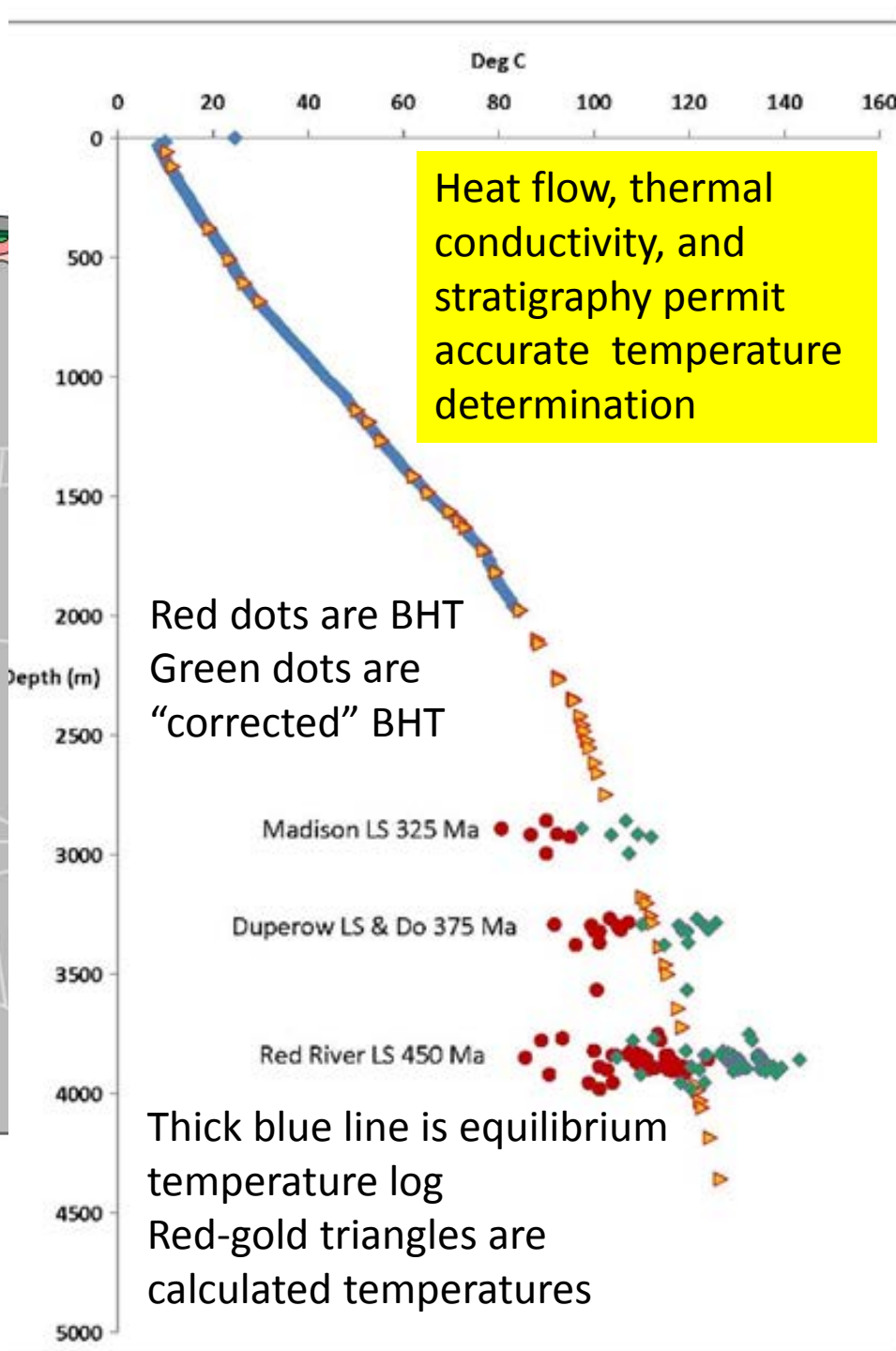
Get Scout Ticket Data

NDIC File No: **4957** API No: **33-025-00038-00-00** County: **DUNN**
Well Type: **OG** Well Status: **DRY** Status Date: **11/10/1970** Wellbore type: **VERTICAL**
Location: **NWNW 8-147-93** Footages: **660 FNL 760 FWL** Latitude: **47.571839** Longitude: **-102.563462**
Current Operator: **MIAMI OIL PRODUCERS, INC.**
Original Operator: **MIAMI OIL PRODUCERS, INC.**
Current Well Name: **ESTATE OF HAIRY ROBE 1**
Original Well Name: **ESTATE OF HAIRY ROBE #1**
Elevation(s): **2212 KB** Total Depth: **13780** Field: **MOCCASIN CREEK**
Spud Date(s): **9/6/1970**

Digital or Image Log(s) available: **BCS** 8MB, **DIL** 8.2MB
Formation Tops
K-P 1920 K-GH 4290 K-M 4730 K-IK 5037 J-S 5483 J-R 5930
T-S 6453 PM-MK 6748 PM-OP 6786 PM-EBA 7174 PN-T 7723 M-KL 8166
M-MD 8320 M-MDR 8777 M-MDLS 8844 M-MDFA 9016 M-MDLP 9602 MD-B 10459
D-TF 10537 D-BB 10766 D-DP 10850 D-SR 11205 D-DB 11475 D-PE 11590
D-W 11723 S-I 12014 S-CL 12567 O-G 13211 O-ST 13275 O-RR 13362
Casing String(s): **10.75" 1150'**
Completion Data
Pool: **RED RIVER** Comp Dt: **11/10/1970** Status: **DRY** Status Dt: **11/10/1970**

Strat	Age	Elapsed Time	**52 mW m^{-2}**	λ (W/m/K)	Depth from surface (m)
Surface	0	542	7		0
Brule Fm	23	519	10.0	1.2	38
Chadron Fm	34	508	11.3	1	64
Golden Valley Fm	42	500	15.8	1.1	139
Tongue R. Fm	59	484	29.1	1.1	383
Slope Fm.	62	480	31.9	1.1	433
Cannonball Fm.	63	479	34.5	1.1	481
Ludlow Fm	65	478	37.5	1.1	537
Hell Creek Fm	66	477	40.9	1.1	599
Fox hills Fm	71	471	45.0	1.2	674
Pierre Fm	75	467	40.8	1.1	589
Niobrara Fm	91	451	65.7	1.3	1046
Carlille Fm	93	449	66.7	1.2	1069
Greenhorn Fm	98	445	76.1	1.2	1256
Belle Fourche Fm	98	444	76.9	1.2	1272
Mowry Fm	100	442	78.8	1.2	1310
Newcastle Fm	110	432	80.4	1.3	1341
Skull Creek Fm	120	422	80.7	1.2	1348
Inyan Kara Fm	128	414	88.6	1.6	1507


West
Missouri R.
Glacial deposits
Fox Hills Fm.
Cretaceous Shales
Inyan Kara Fm.
Jurassic
Spearfish Fm.
Permian
Broom Creek Fm.
Tyler Fm.
Madison & Big Snowy Groups
Devonian undifferentiated
Bakken & Three Forks Fms.
Interlake Fm.
Red River Fm.
Winnipeg Grp.
Deadwood Fm.
0
- 2 km
- 4 km
100 km


Deg C
0
20
40
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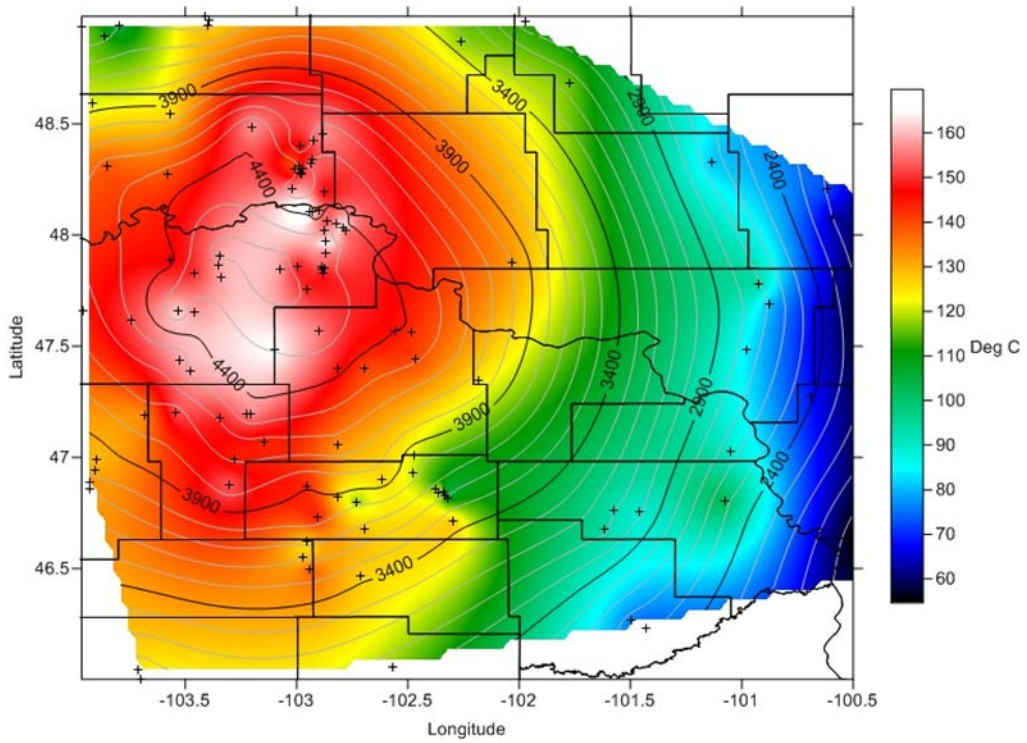
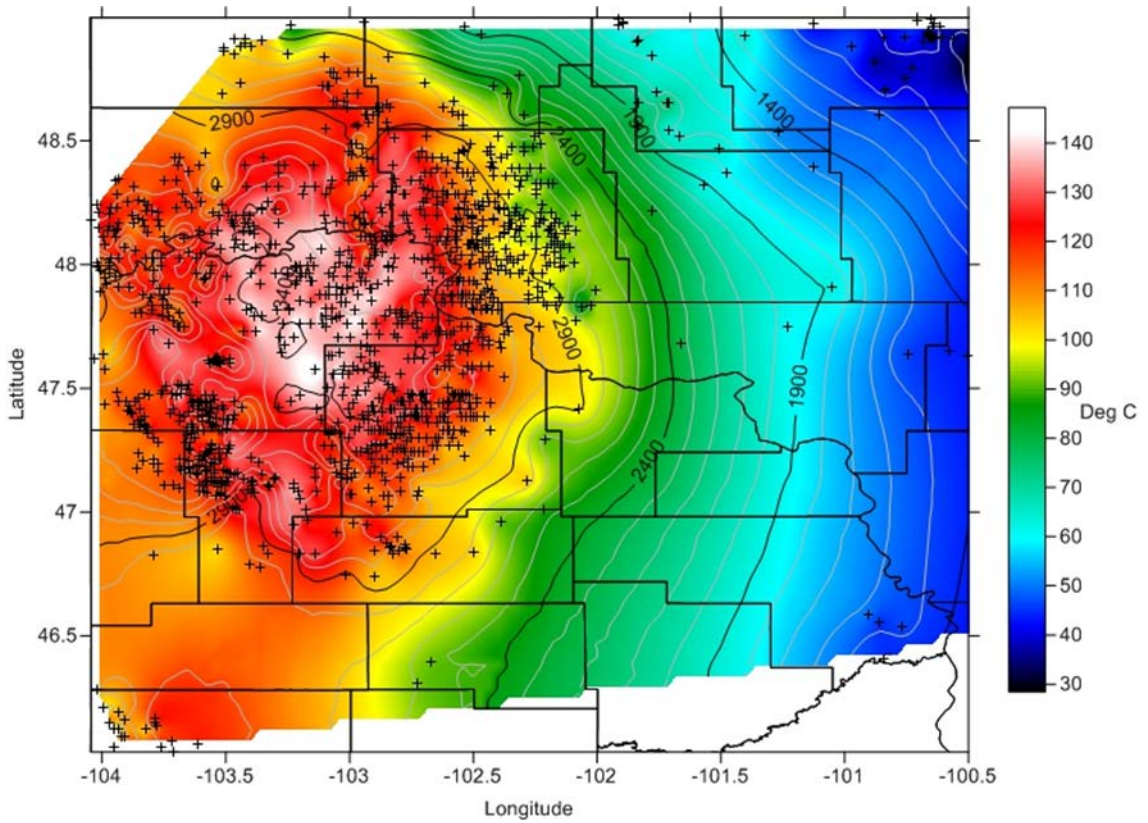
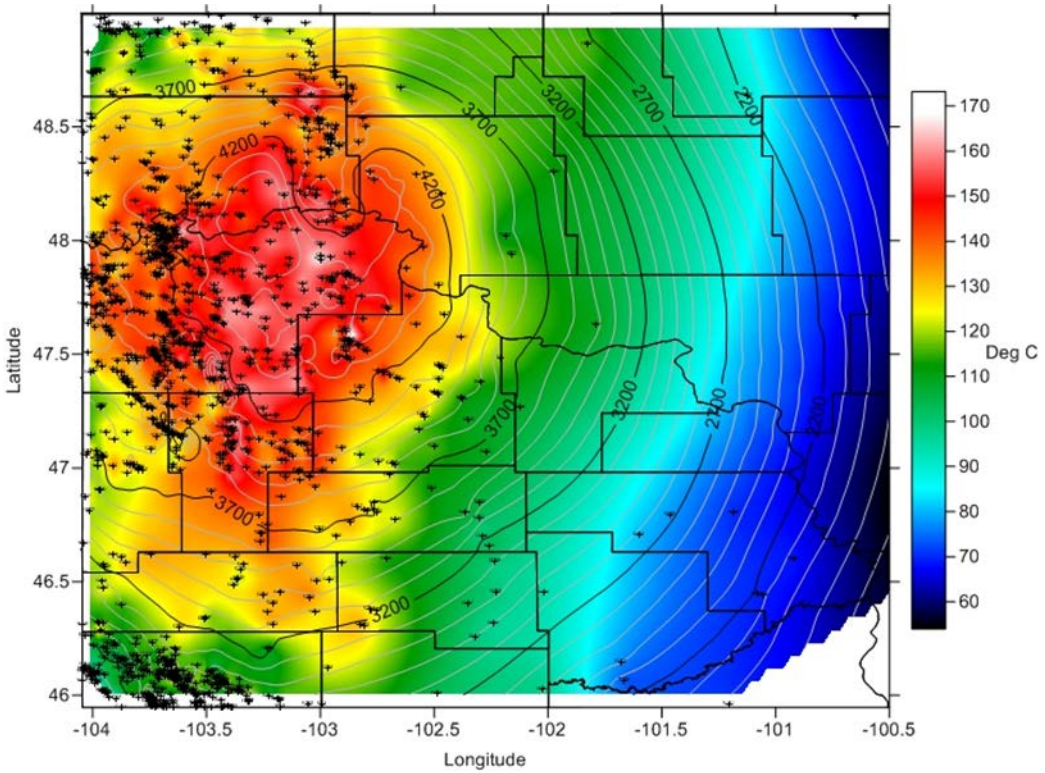
120
140
160
0
500
1000
1500
2000
Depth (m)
2500
3000
3500
4000
4500
5000
Heat flow, thermal conductivity, and stratigraphy permit accurate temperature determination
Red dots are BHT
Green dots are "corrected" BHT
Madison LS 325 Ma
Duperow LS & Do 375 Ma
Red River LS 450 Ma
Thick blue line is equilibrium temperature log
Red-gold triangles are calculated temperatures



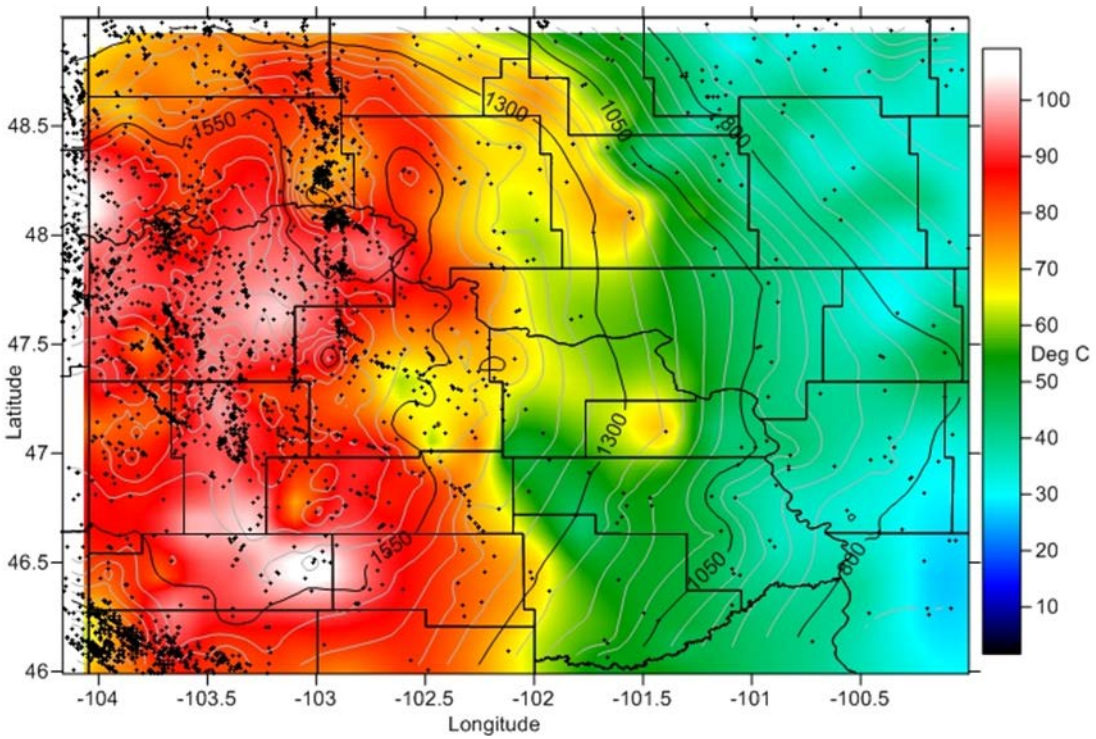
Temperature and depth contours
Deadwood Fm.



Temperature and depth contours
Madison Fm.



Temperature and depth contours
Red River Fm.

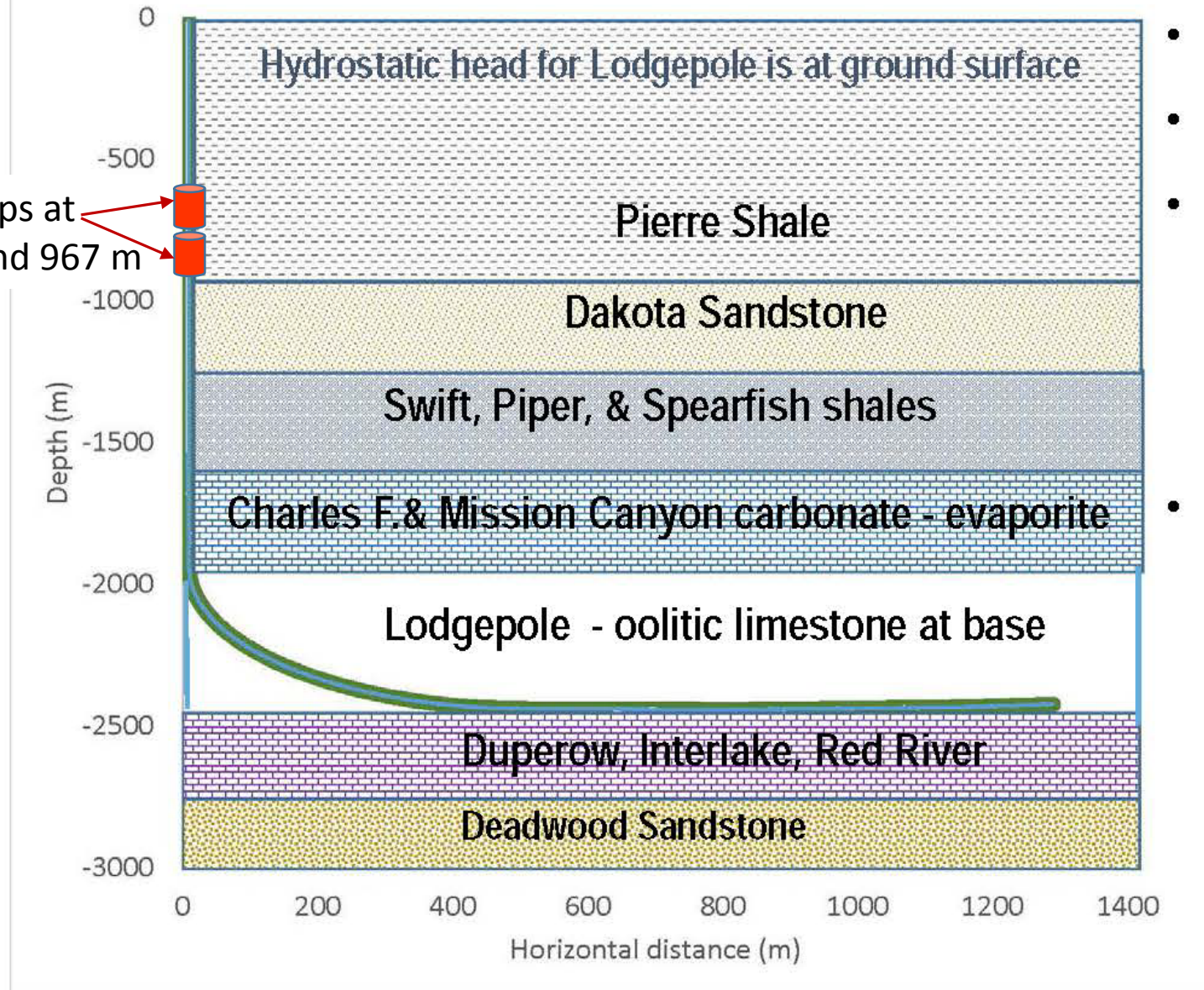


Temperature and depth contours
Dakota Group.

The UND-CLR binary power plant demonstrated that the low temperature resource can be produced economically

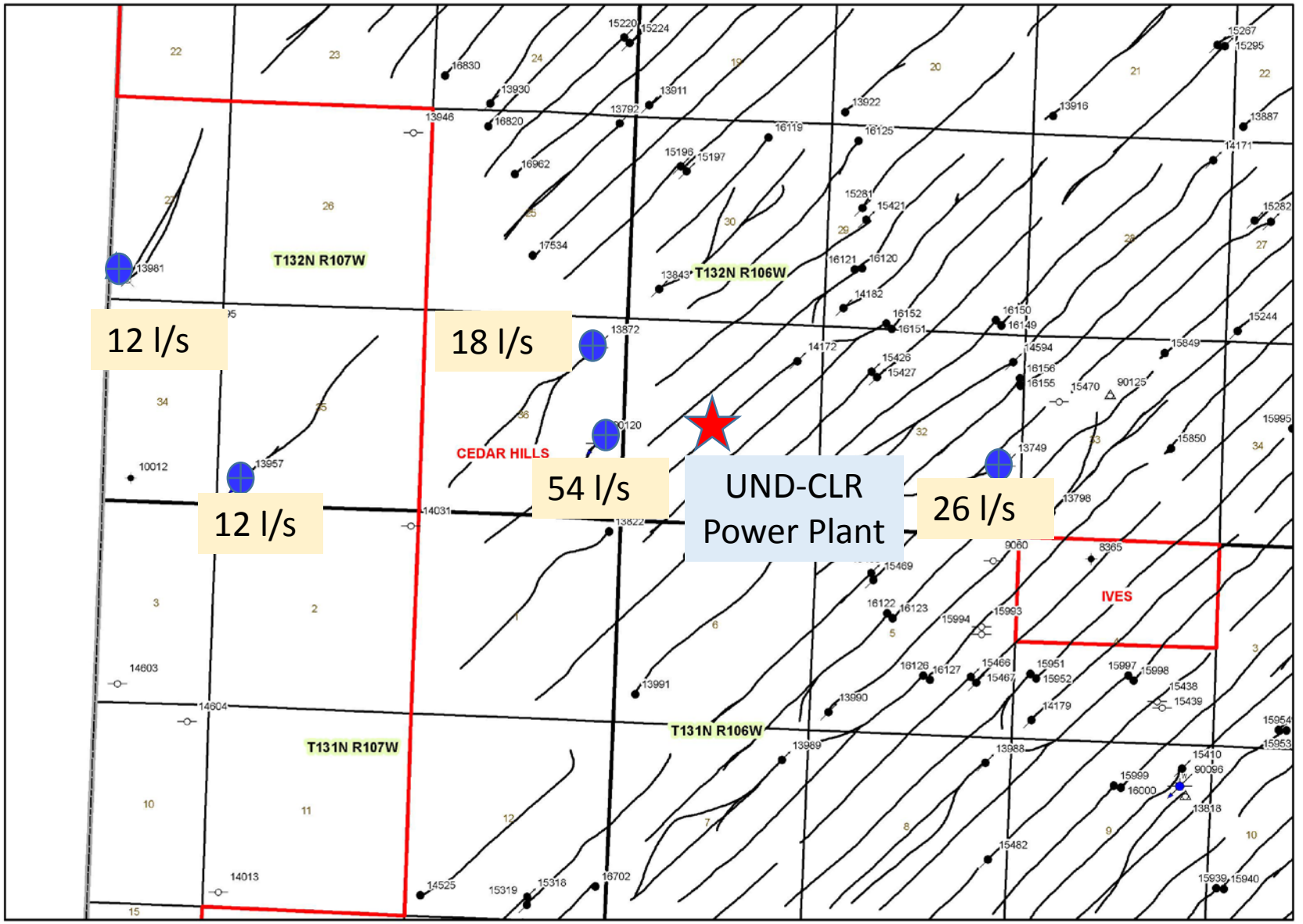
Production is from the Lodgepole formation: 3 km deep, 98 °C -103 °C

Schematic of Water Supply Wells at CLR Davis Water Injection Plant



- Two 125 kW ORC engines
- 98 °C water 875 gpm
- Two 8.75” open-hole drilled horizontally 1.29 km and 0.85 km in the Madison Fm. at vertical depths of 2.3 km and 2.4 km.
- Concept – 8 horizontal wells drilled radially from a single pad could produce 3,500 gpm. Power yield ranges from 8.75 MW to 17.5 MW depending on air temperature.

NDIC map of horizontal wells in Cedar Hills Red River B Unit.



CLR operates 5 WSW pumping a total of 122 l/s (1,934 gpm) near the CLR-UND power plant

Power Conversion Options

- Scalable ORC systems
- 50 to 250 kW modules
- Calnetix
- Ormat
- Recurrent (Kalina Cycle)
- Turboden
- Pratt & Whitney
- Electratherm
- Climeon

The Calnetix machines installed at the UND-CLR demonstration site produce 250 kW

The Climeon system could produce approximately one mW with the available water

CLIMEON C3 TECHNOLOGY

C3 TECHNOLOGY

- ✓ Vacuum based, 2,5 bar(a) nominal working pressure
- ✓ Direct Contact Condenser
- ✓ Future proof working media with no GWP, non-toxic, low cost
- ✓ Efficiency above >50% of Carnot

CLIMEON HEAT POWER

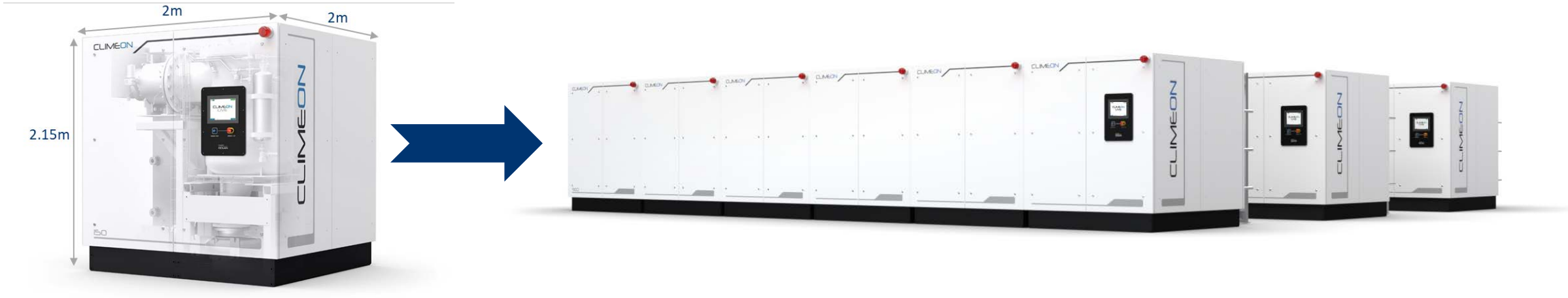
- ✓ 150kW modules
- ✓ Stackable enables 1,8MW$_{el}$ on 24m^2 (260ft^2) footprint
- ✓ Serial and parallel setup
- ✓ Plug & Play

>12 patents/applications and counting...

CLIMEON

MODULAR AND FLEXIBLE

- ✓Enhanced efficiency
- ✓Off-the-shelf
- ✓Cost effective redundancy
- ✓Adaptive Control System



The Distributed Power Corridor Concept

- Temperatures require binary power development
- Although the cold climate is good for air cooling for the condenser phase, water cooling yields best power efficiency and economics
- The 7 °C (45 °F) bottom water of Lake Sakakawea is an source excellent for heat rejection for the ORC
- High geothermal fluid volumes accessible by drilling horizontal wells
  - Average volume from the CLR water flood approximately 23 l/s (400 gpm)
- Good temperature vs. depth data along the course of the Missouri River
- DOE CREST model yields $0.06 per kWh with repurposed wells and $0.08 per kWh with new wells

WHY IS DEVELOPMENT NOT HAPPENING?

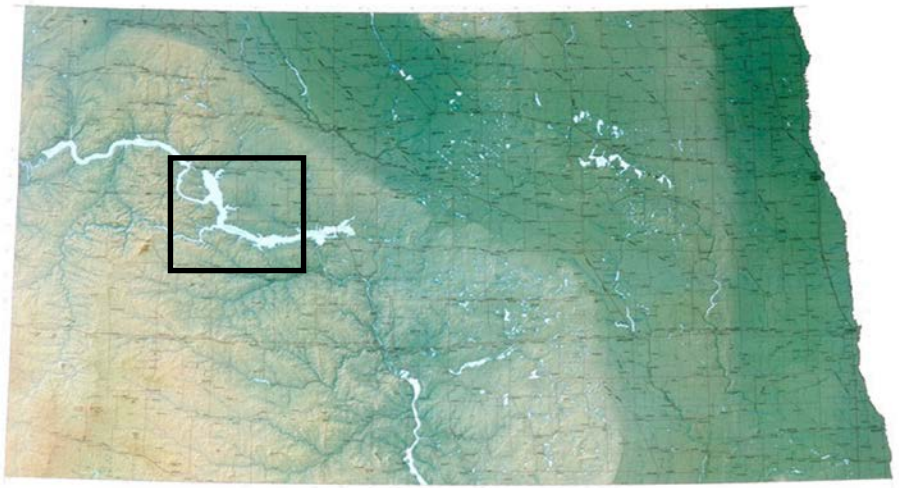
- The oil industry is not interested.
- The electric power industry does not envision replacing 3,355 MW of power with geothermal.
- We need someone who sees geothermal as a promising energy source and who has the will and means to start development.
- An opportunity has presented itself!

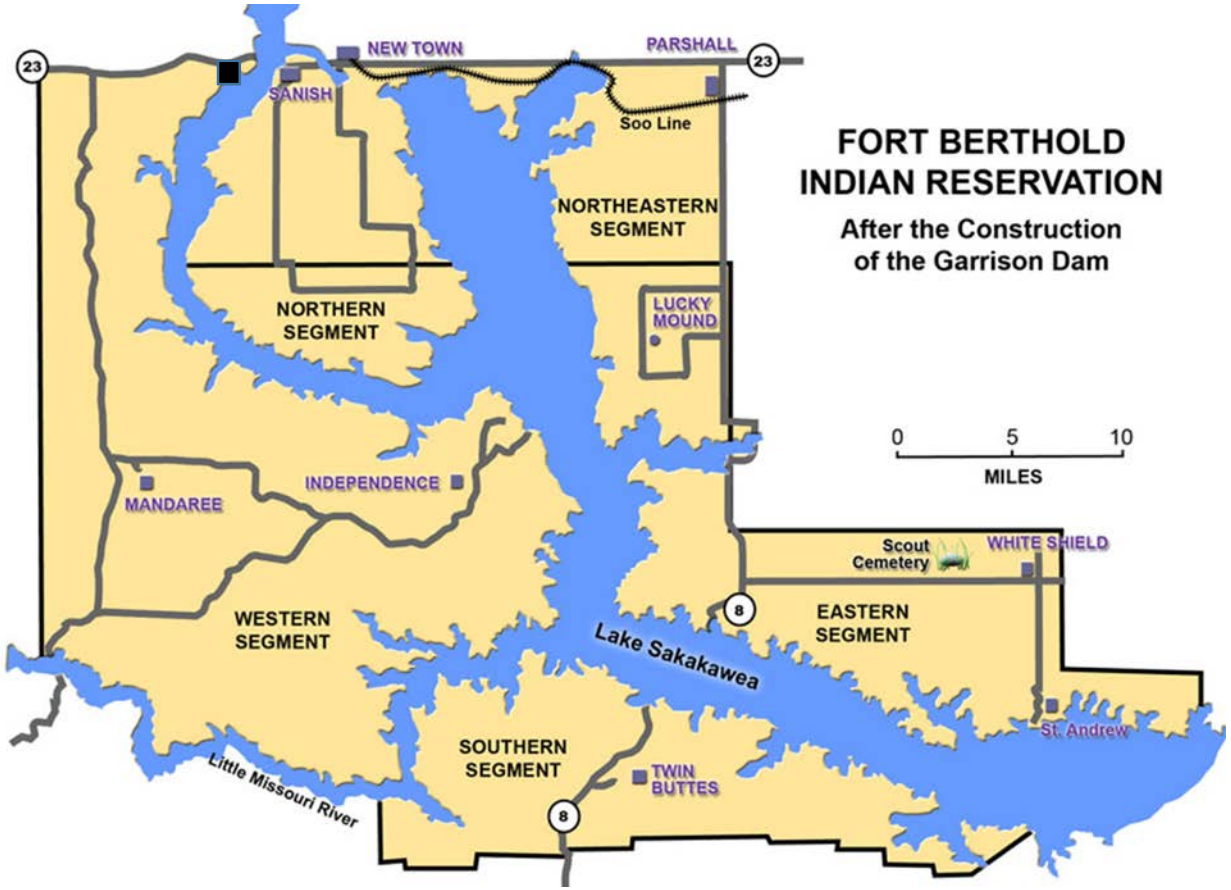
Communities:

- Four Bears Village
- Mandaree
- New Town
- Parshall
- Twin Buttes
- White Shield
- Sanish

Population is approximately 6,500

Land area is 4,000 km^2.

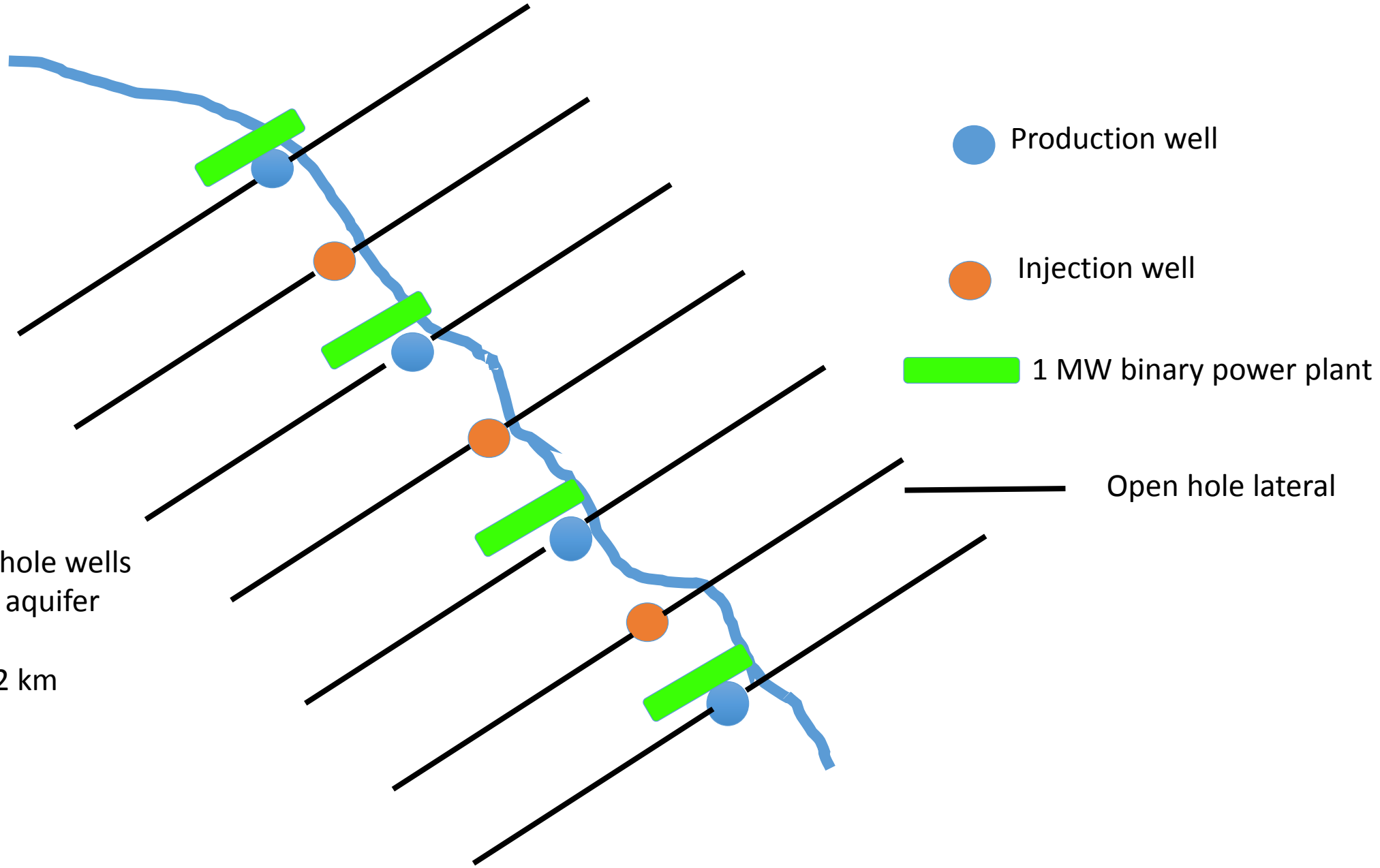




Assume 1 MW would support 650 homes.5 MW could make Fort Berthold energy independent.

Temperatures in the Dakota Fm. are 76-89 C
Temperatures in the Lodgepole Fm. are 111- 129 C

Distributed binary power well field



1 km lateral open hole wells
in the geothermal aquifer

Well spacing 1 to 2 km
To be determined

Science and engineering yet to be determined

- Formation temperature logs
- Formation permeability
- Water quality
- Well spacing
- Well orientation

Summary

- The Williston Basin contains six geothermal aquifers having temperatures ranging from 80 °C to 165°C depending heat flow
- Access to Missouri River water for cooling is conceptually ideal for distributed, binary power development.
- The temperatures, depths and hydrologic properties of the geothermal resource are well documented.
- The efficacy of horizontal drilling for high-volume water production in the basin has been demonstrated at the UND-CLR binary geothermal power plant.
- A network of high-efficiency, modular power plants installed at intervals along the course of the Missouri River, i.e., Lake Sakakawea, could generate as much as 300 MW of electrical power.
- The key elements in this concept are knowledge of the geothermal resource, horizontal drilling in the geothermal aquifers, a high efficiency, modular, system that cascades the geothermal fluid, and the availability of cold Missouri River water for the condenser phase of the power plant.
- The possibility of helping the Three Affiliated Tribes become energy independent could be the catalyst for greater development.