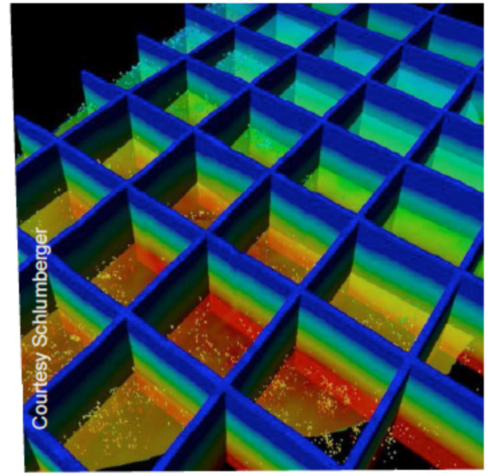
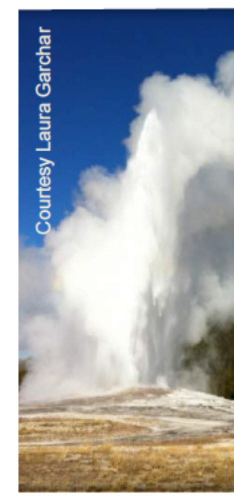
State and Regional Geothermal Data

Advances in Direct Use | Golden, CO | March 18, 2015





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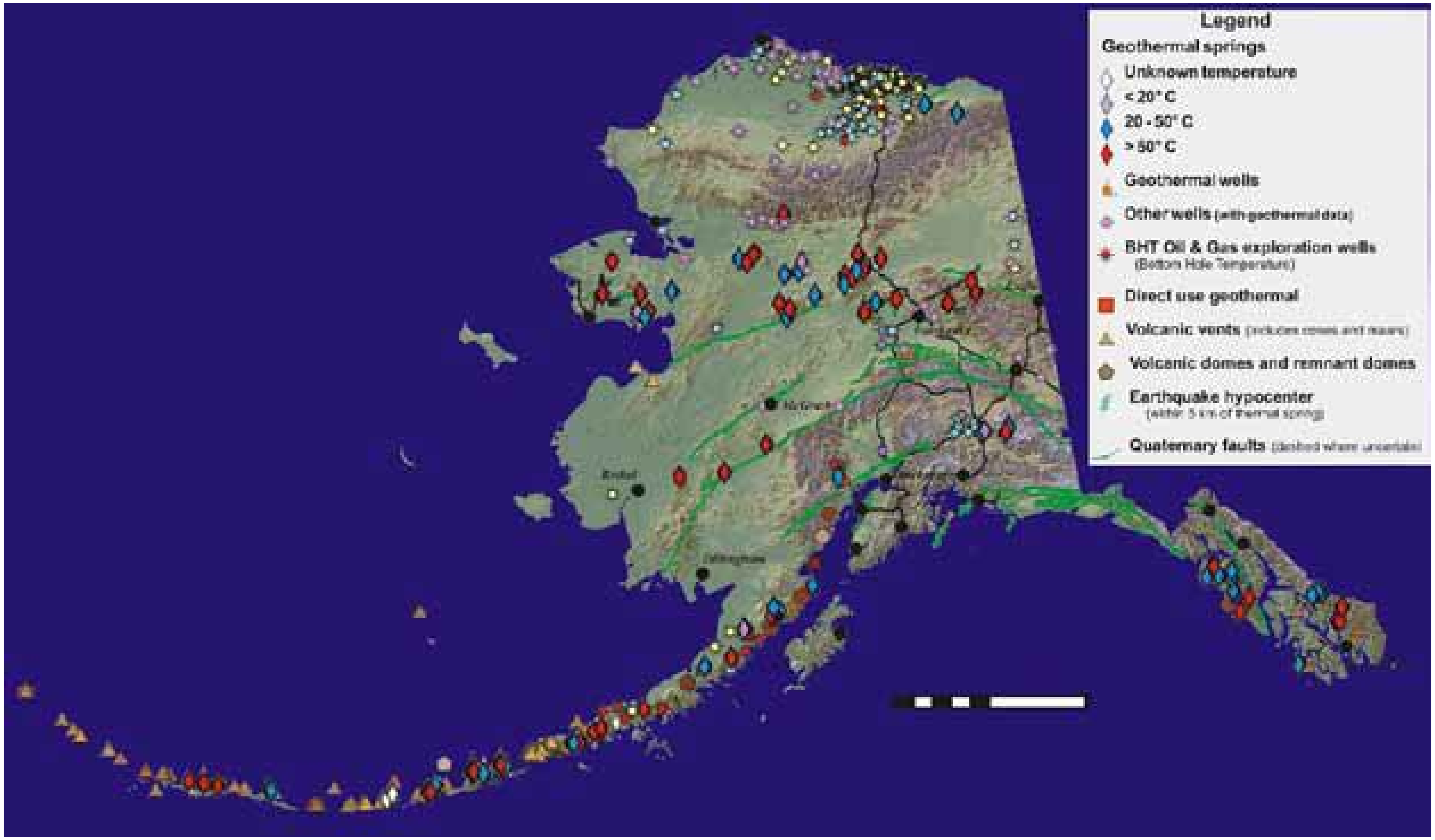
Arlene Anderson, Technology Manager
Geothermal Technologies Office

Alaska Geothermal Springs



Geothermal springs, well data, **direct use geothermal sites**, and seismic and volcanic features.

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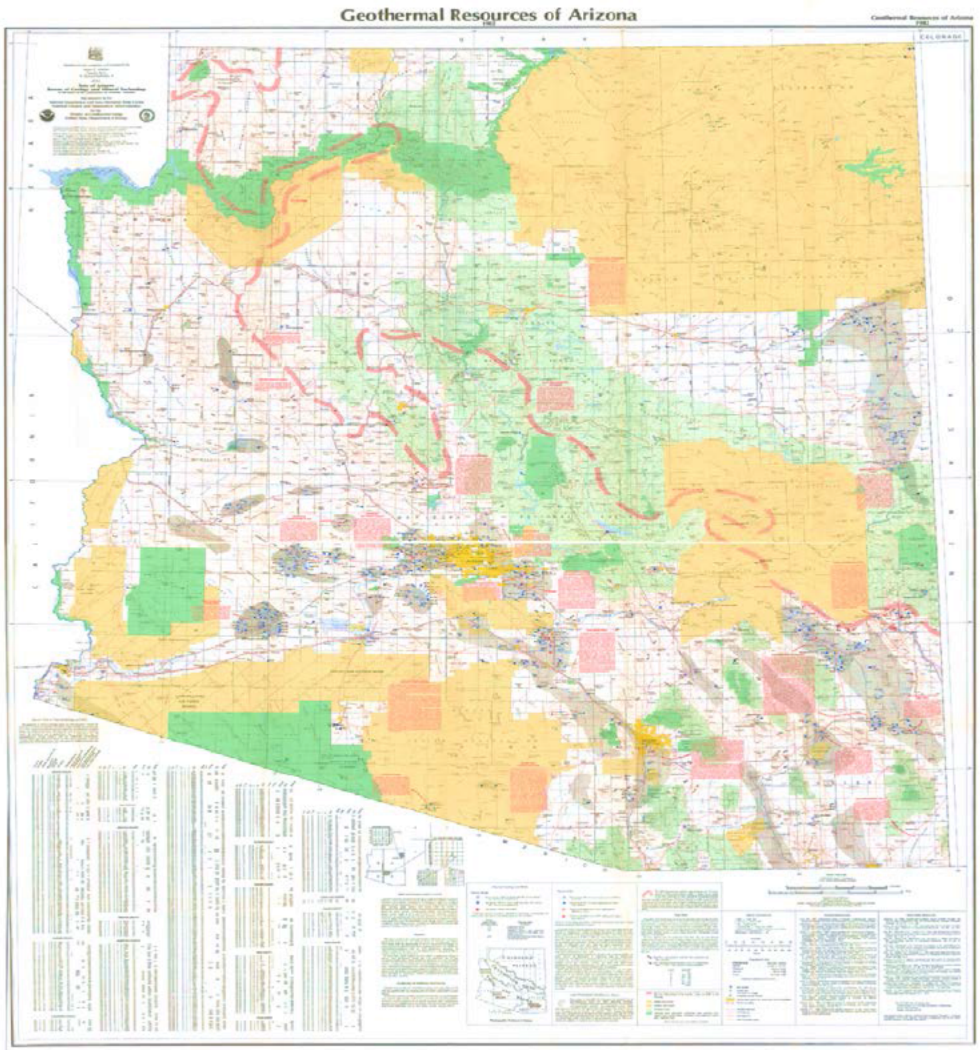
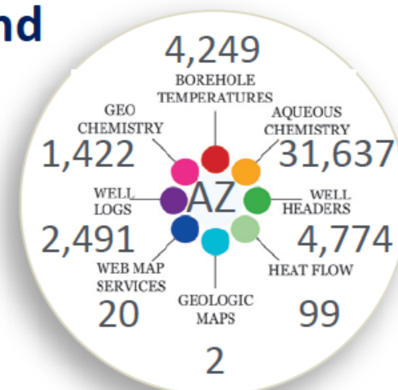
Arizona Basin and Range Province

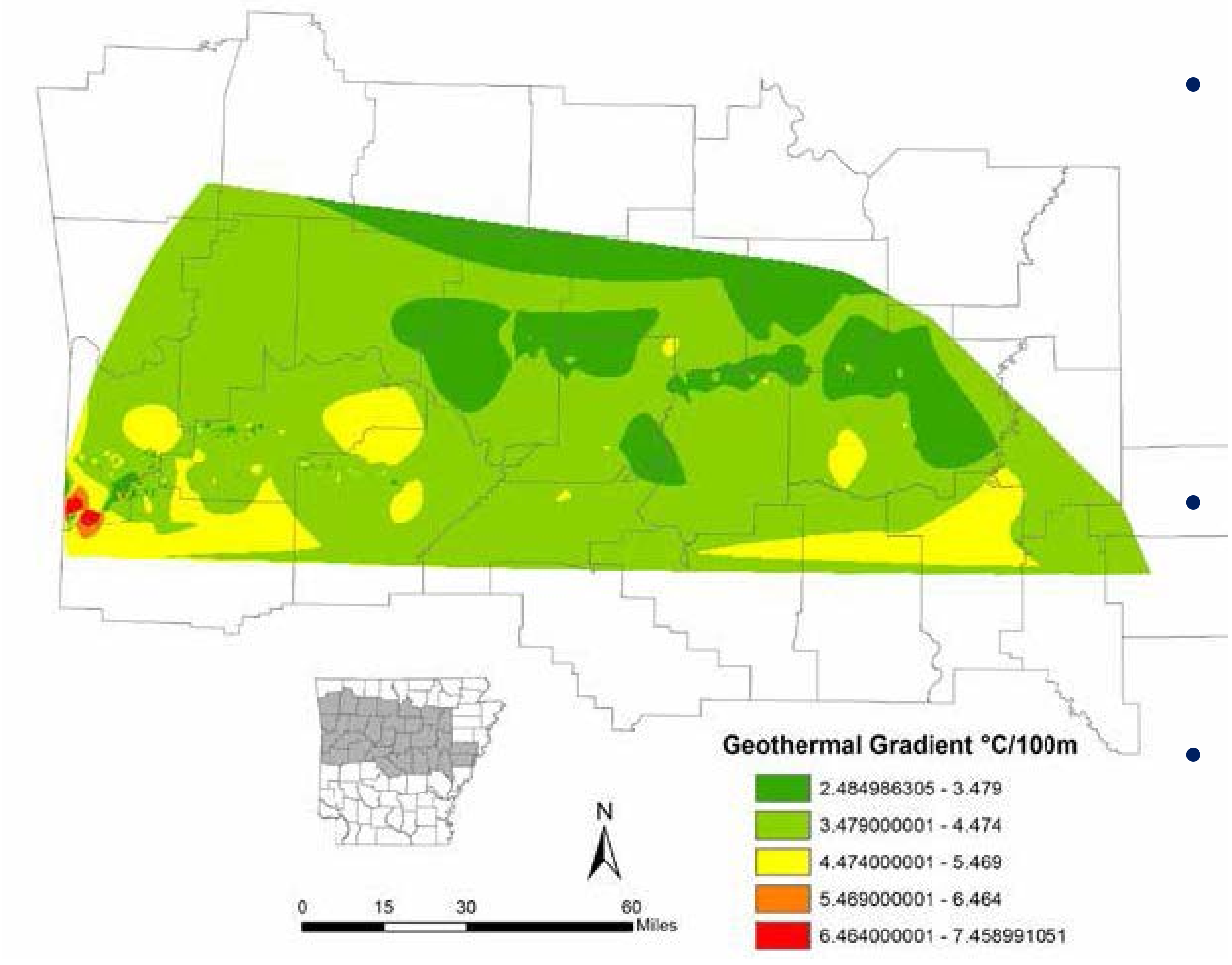


ARIZONA GEOTHERMAL RESOURCES (1980)

- Potential for **high-to-moderate heat flow**
- Temperatures (in oil and gas wells greater than 8,000') **may exceed 100°C**
- Although surface hot springs can exceed 50°C, most thermal springs **range from 20°C to 50°C.**
- Abundant existing deep water-supply wells and irrigation wells have **potential** for **conversion** to **private and small com-mercial geothermal direct-heat uses.**



Arkansas – *More Than 2,800 Digital Well Logs*



NORTH-CENTRAL ARKANSAS GEOTHERMAL GRADIENT MAP

- Arkoma Basin NW AR (Fayette-ville Shale Gas Play) BHT and temperature to depth data from **over 1,600 well logs**.
- **120 Thermal Conductivity Measurements** and data from brine industry in Southern AR
- Core samples from 18 wells in the Smackover Formation suggest **SW AR** (Columbia and Lafayette Counties) **highest geothermal potential**

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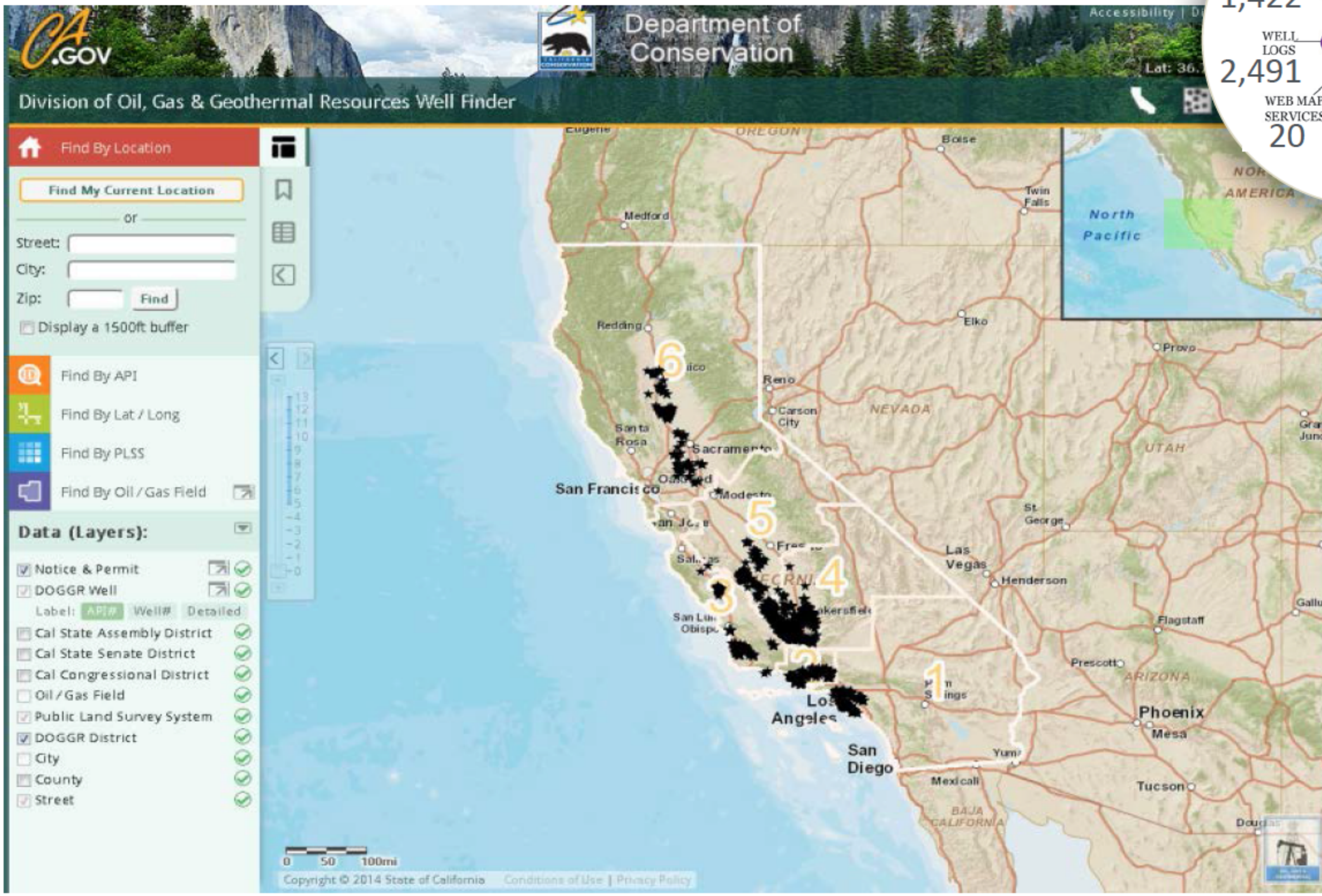
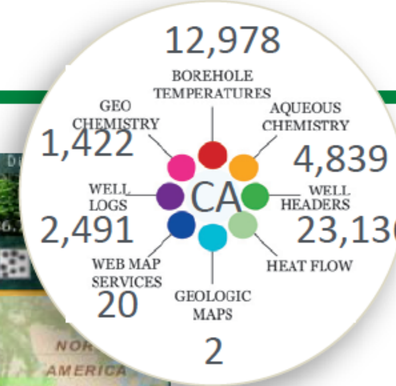
California – *87,000 records*





INTERACTIVE WELL FINDER FOR OIL, GAS AND GEOTHERMAL WELLS THROUGHOUT CALIFORNIA

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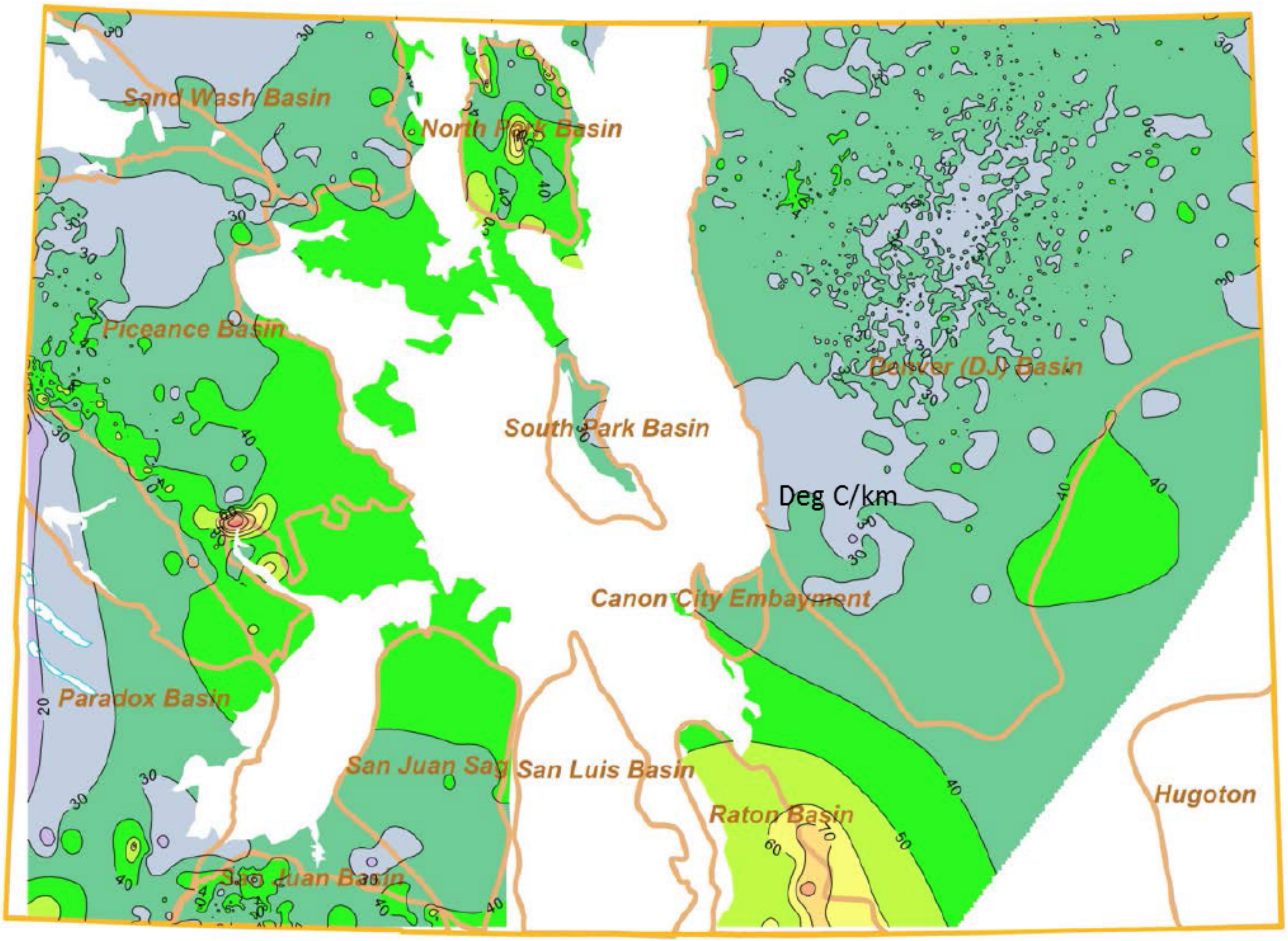
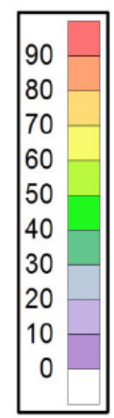
Colorado – *Legacy Analog Data Now Searchable*



New exploration and assessment maps for **siting electricity production** in sedimentary basins



Deg C/km

TEMPERATURE GRADIENTS DERIVED FROM SURFACE GROUND TEMPERATURES AND BOTTOM-HOLE TEMPERATURES MEASURED FROM THE TOP OF DAKOTA TO TOP OF PERMIAN

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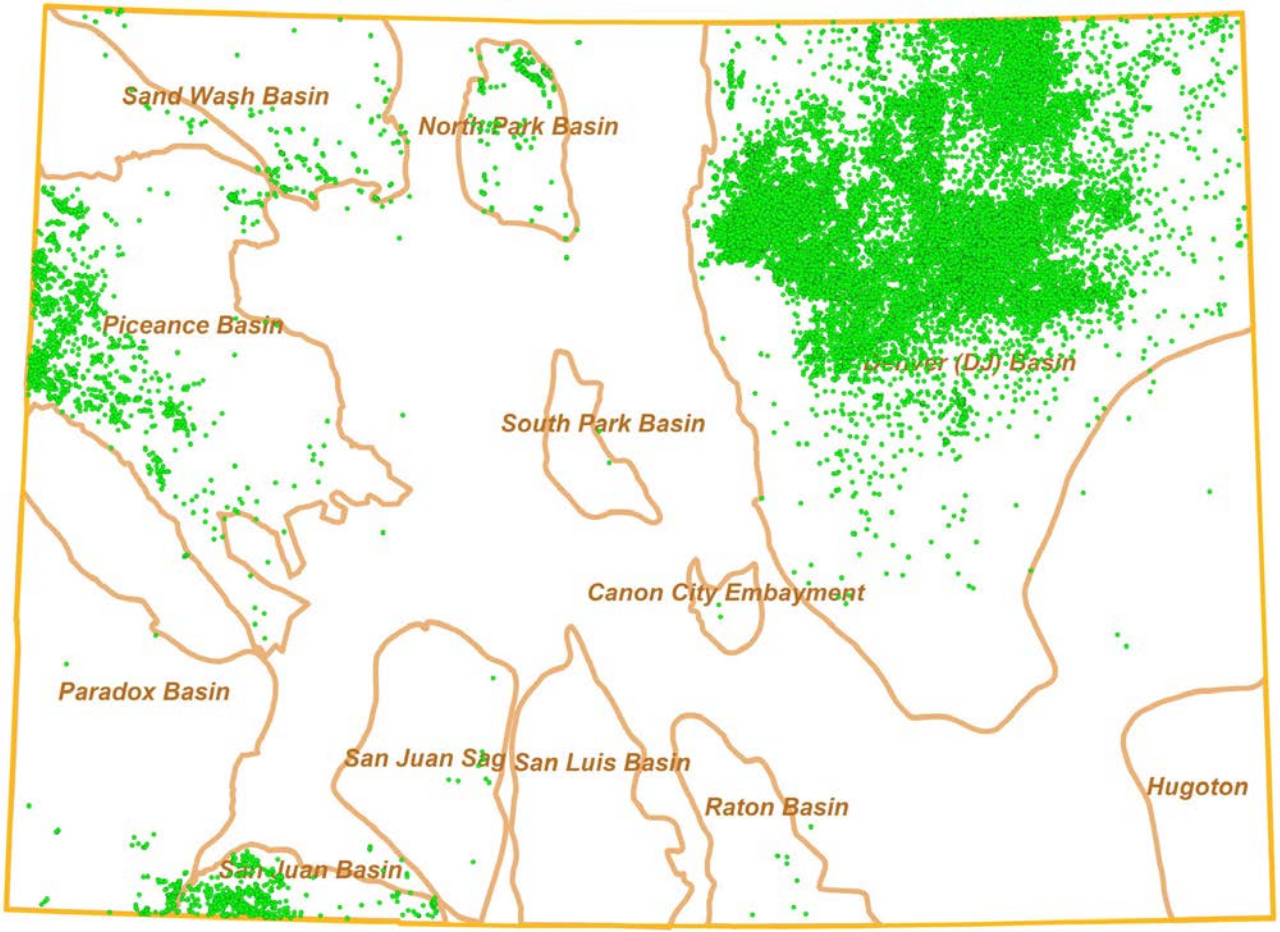
Colorado – *Thermal Gradients of Shales*



LOCATIONS OF 26,178 WELLS USED TO CONSTRUCT TEMPERATURE GRADIENT MAP

- Effects on thermal gradients of the low thermal conductivity shales
- Previous maps show anomalies function of shallow wells and shallow lithology
- New maps used with geologic maps and depth sections to **reliably estimate temperatures at depth**

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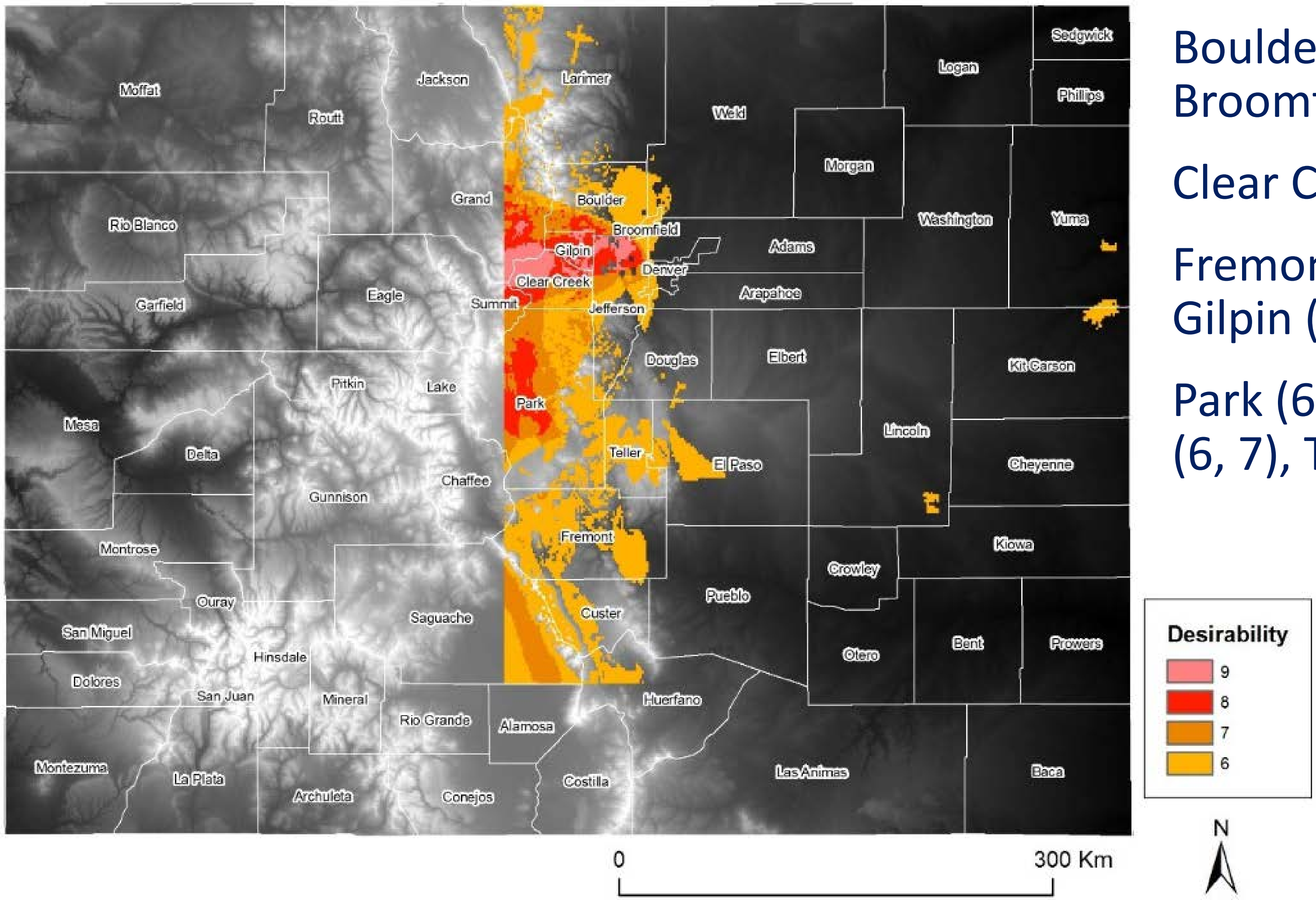
Denver – *Julesberg Basin Highest Geothermal Potential*



Boulder (6-8), Broomfield (6-9)

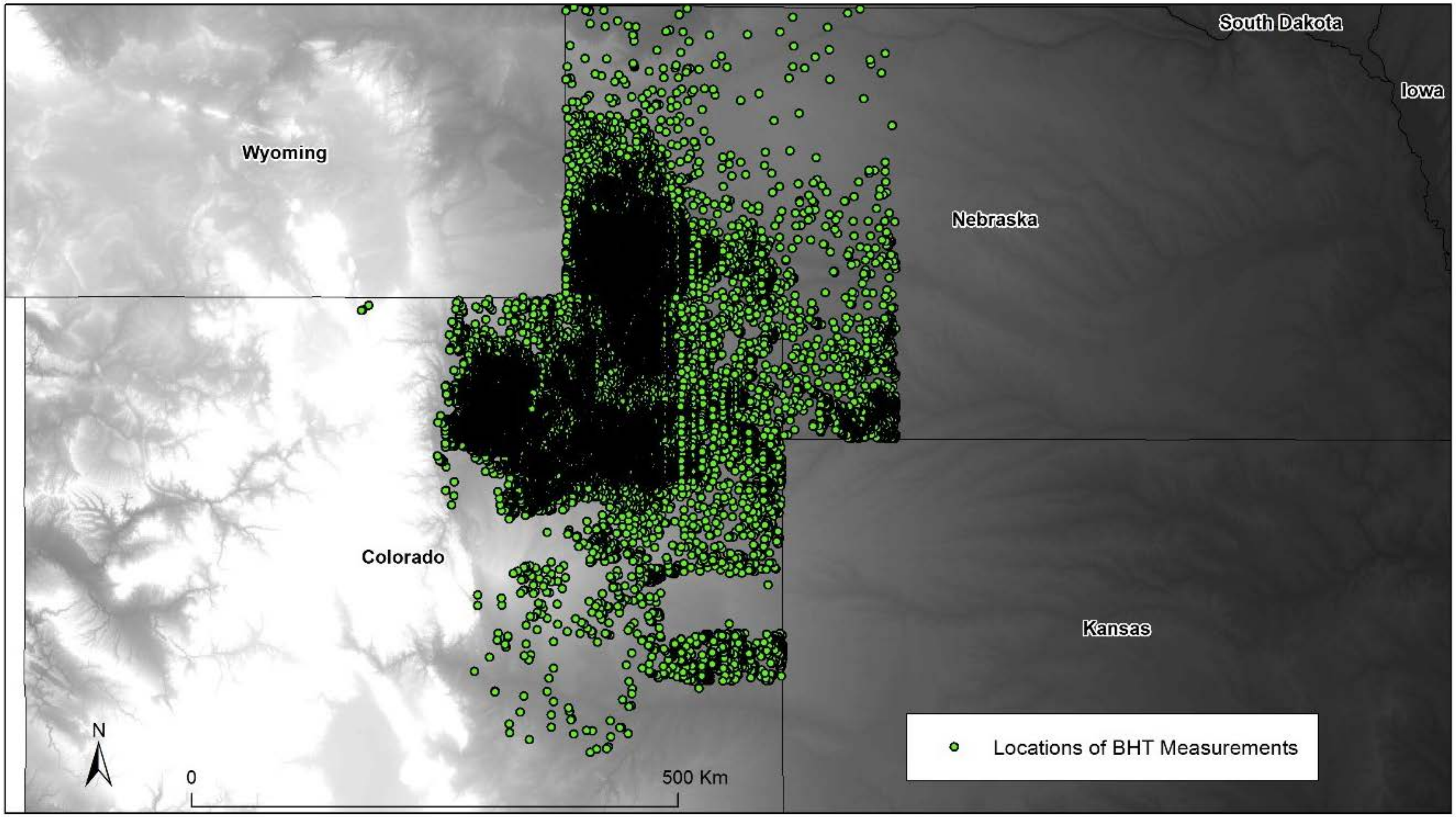
Clear Creek (6-9)

Fremont (6, 7), Gilpin (7-9)

Park (6-8), Saguache (6, 7), Teller (6)

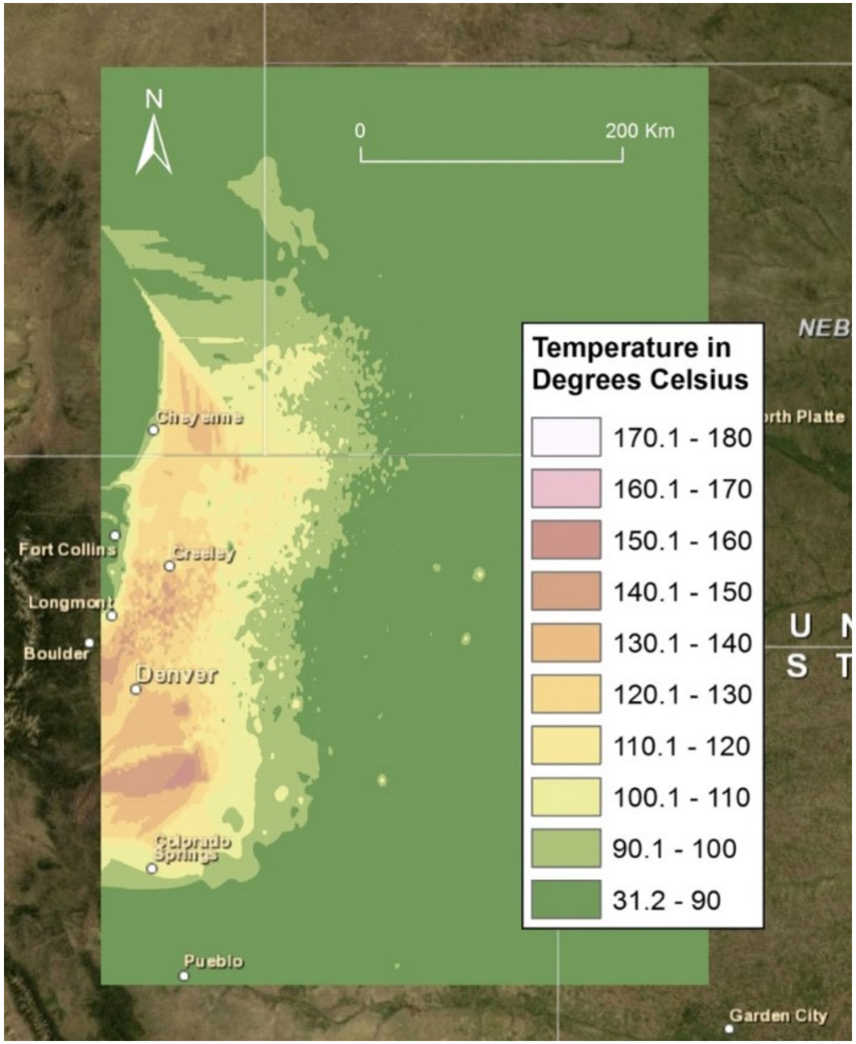
INTEGRATING GEOPHYSICAL DATA IN GIS FOR GEOTHERMAL POWER PROSPECTING
UNIVERSITY OF NORTH DAKOTA, ANNA CROWELL AND WILL GOSNOLD

Denver – *Julesberg Basin – Data Extent*



INTEGRATING GEOPHYSICAL DATA IN GIS FOR GEOTHERMAL POWER PROSPECTING
UNIVERSITY OF NORTH DAKOTA, ANNA CROWELL AND WILL GOSNOLD

Denver – *Julesberg Basin – BHT Interpolation*

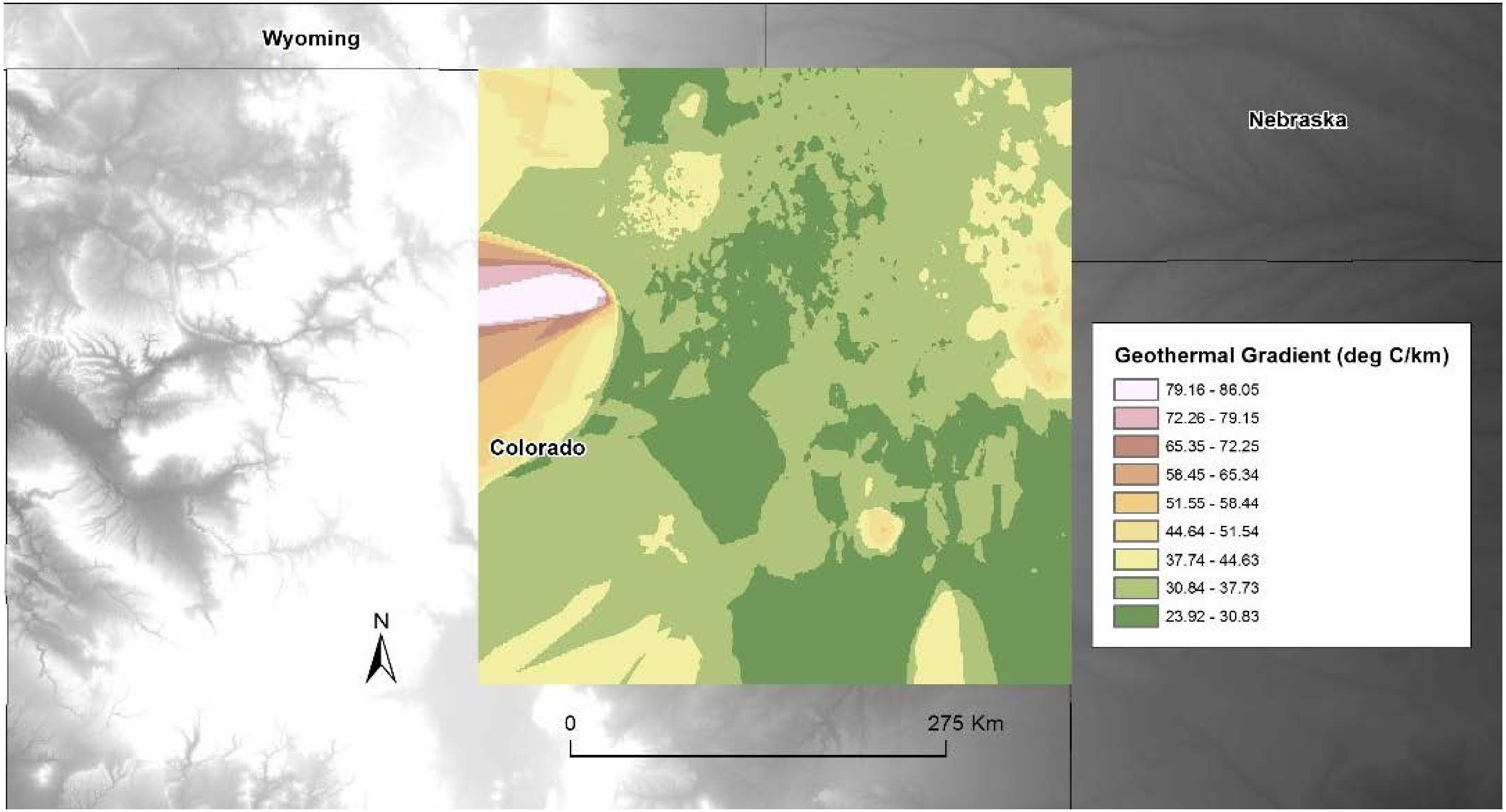


Geothermal gradients calculated using the following formula:

$$\frac{\partial T}{\partial Z} = \frac{(BHT - Surface\ Temperature)}{depth}$$

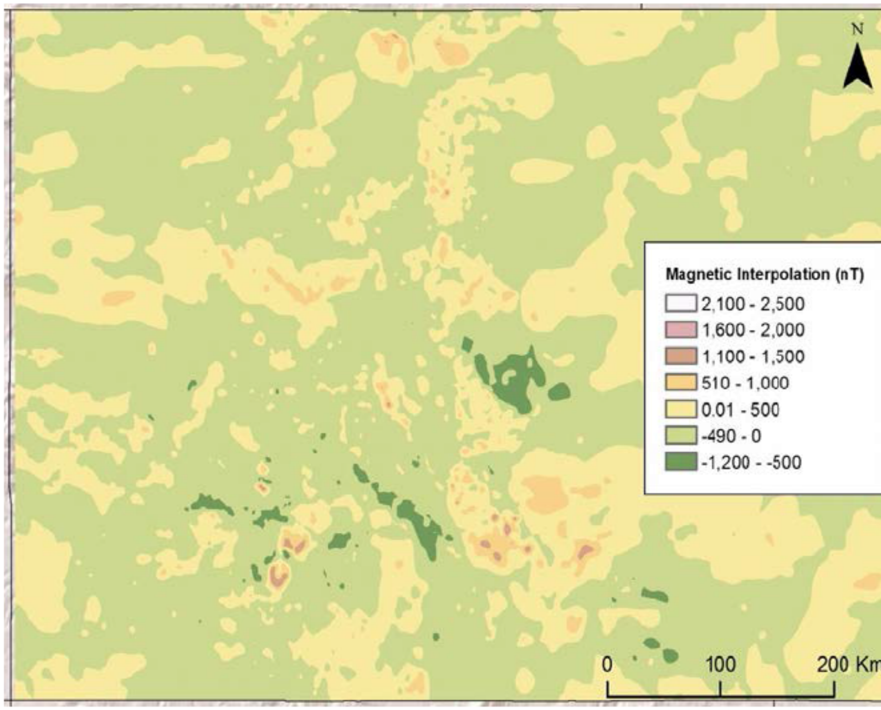
Average surface temperatures used for each state obtained from the National Climate Data center, listed as: Colorado at 7.3° C

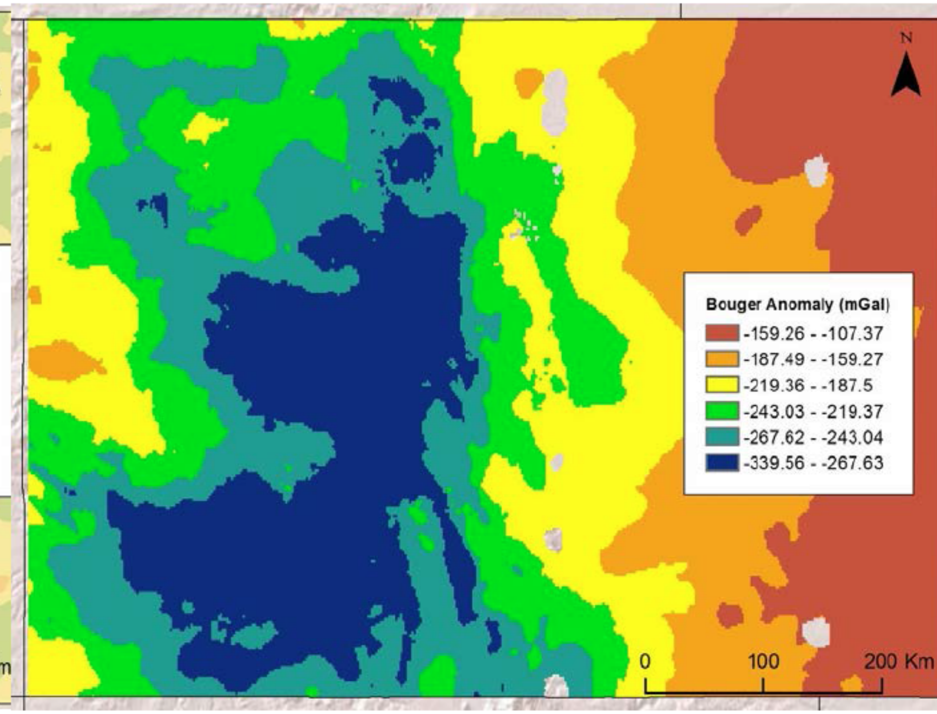
Denver – *Julesberg Basin* Geothermal Gradient Interpolation



Geothermal gradient values for each basin were interpolated using the Kriging method and analyzed for areas in which hotter temperatures could be found at relatively shallower depths

Denver – *Julesberg Basin – Gravity & Magnetic Data*

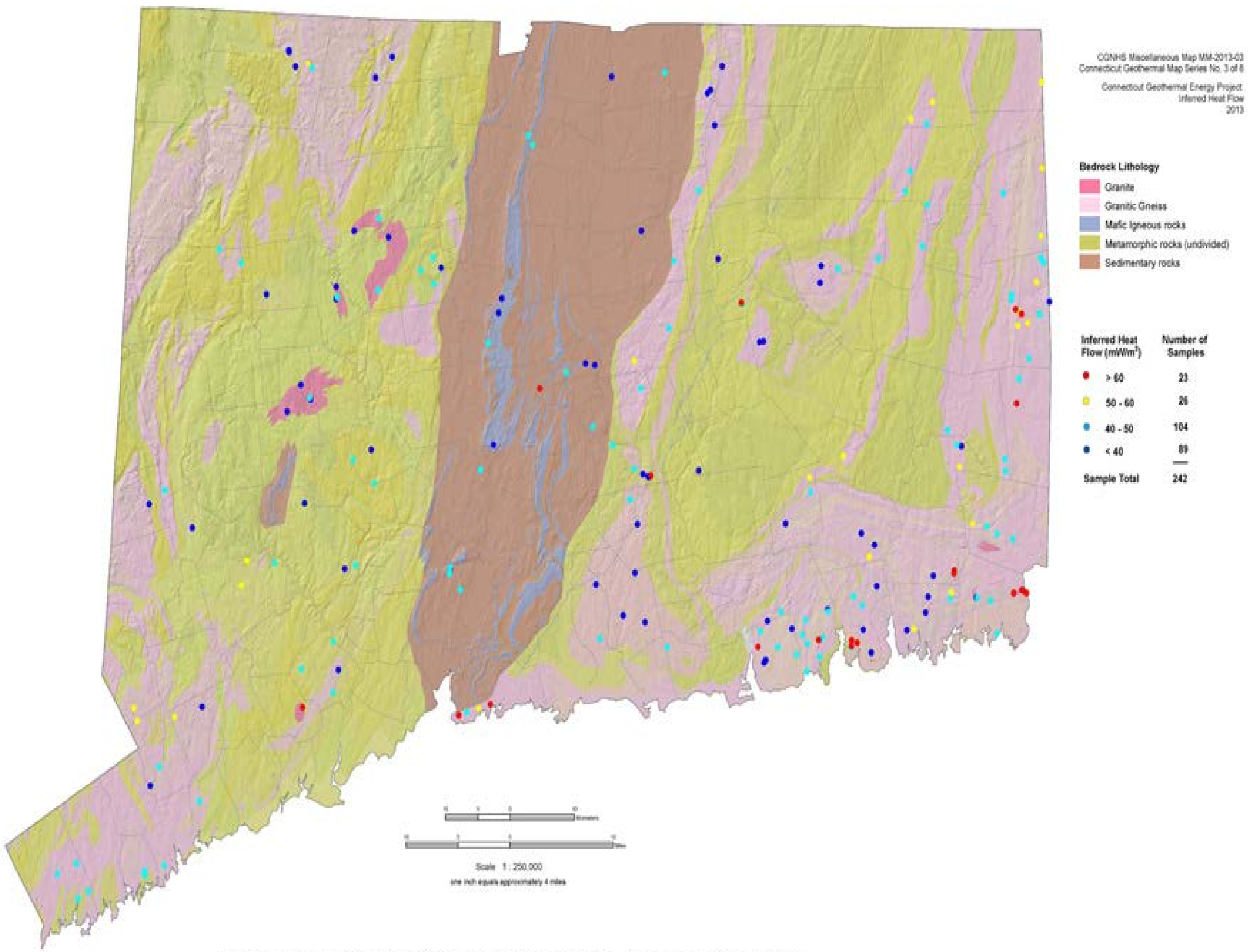




232,129 magnetic and 46,535 gravity data points for Colorado from University of Texas at El Paso Gravity and Magnetic Database of the U.S.

INTEGRATING GEOPHYSICAL DATA IN GIS FOR GEOTHERMAL POWER PROSPECTING
UNIVERSITY OF NORTH DAKOTA, ANNA CROWELL AND WILL GOSNOLD

Connecticut - *First Statewide Geothermal Potential Assessment*



Connecticut Geothermal Energy Project: Inferred Heat Flow

By: T.K. Gagnon[1], G.C. Koteas[2], R.P. Steinen[1], A. Ryan[2], and M.A. Thomas[1]

- Help **site EGS** in bedrock and unconsolidated sediments
- Series includes: heat production, inferred heat flow, thermal conductivity, and thermal profile maps for bedrock, and thermal conductivity for sediments

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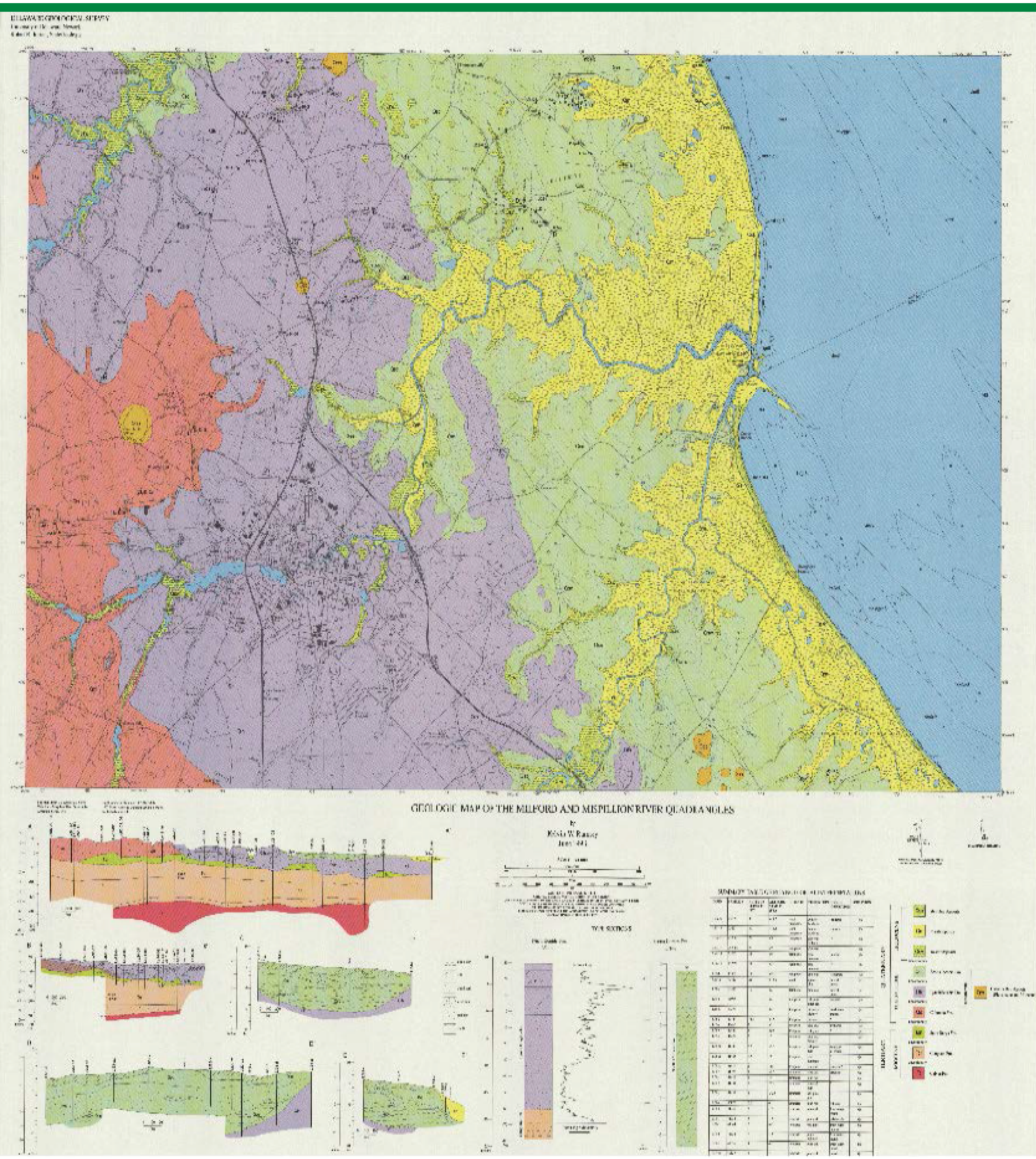
Delaware – *Digital Map Services*

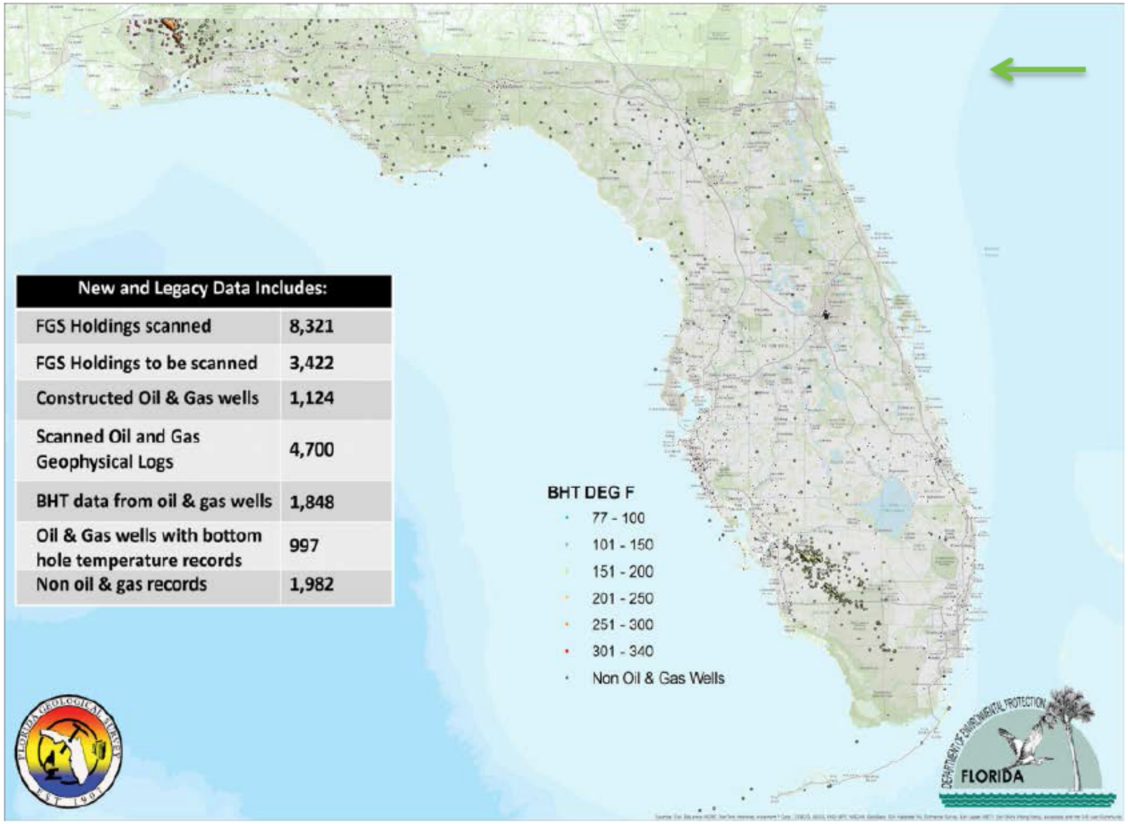


Datasets include:

- well logs
- well headers
- thermal conductivity
- Heatflow
- borehole temperatures

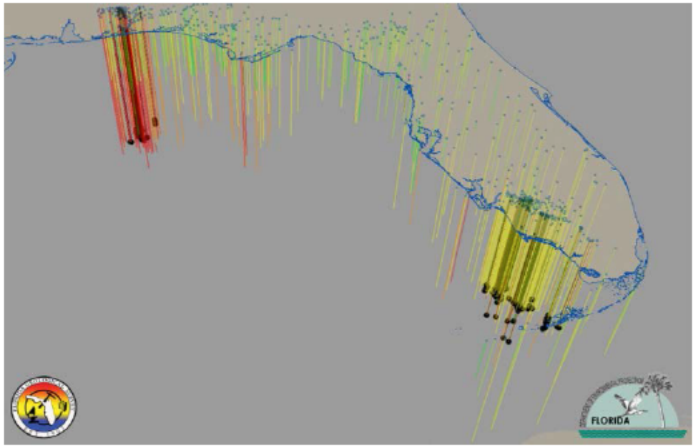
Geologic map of the Milford and Mispillion River Quadrangles

Florida – *2 Million Temperature Records +*



FGS oil and gas wells, well logs & borehole temperatures

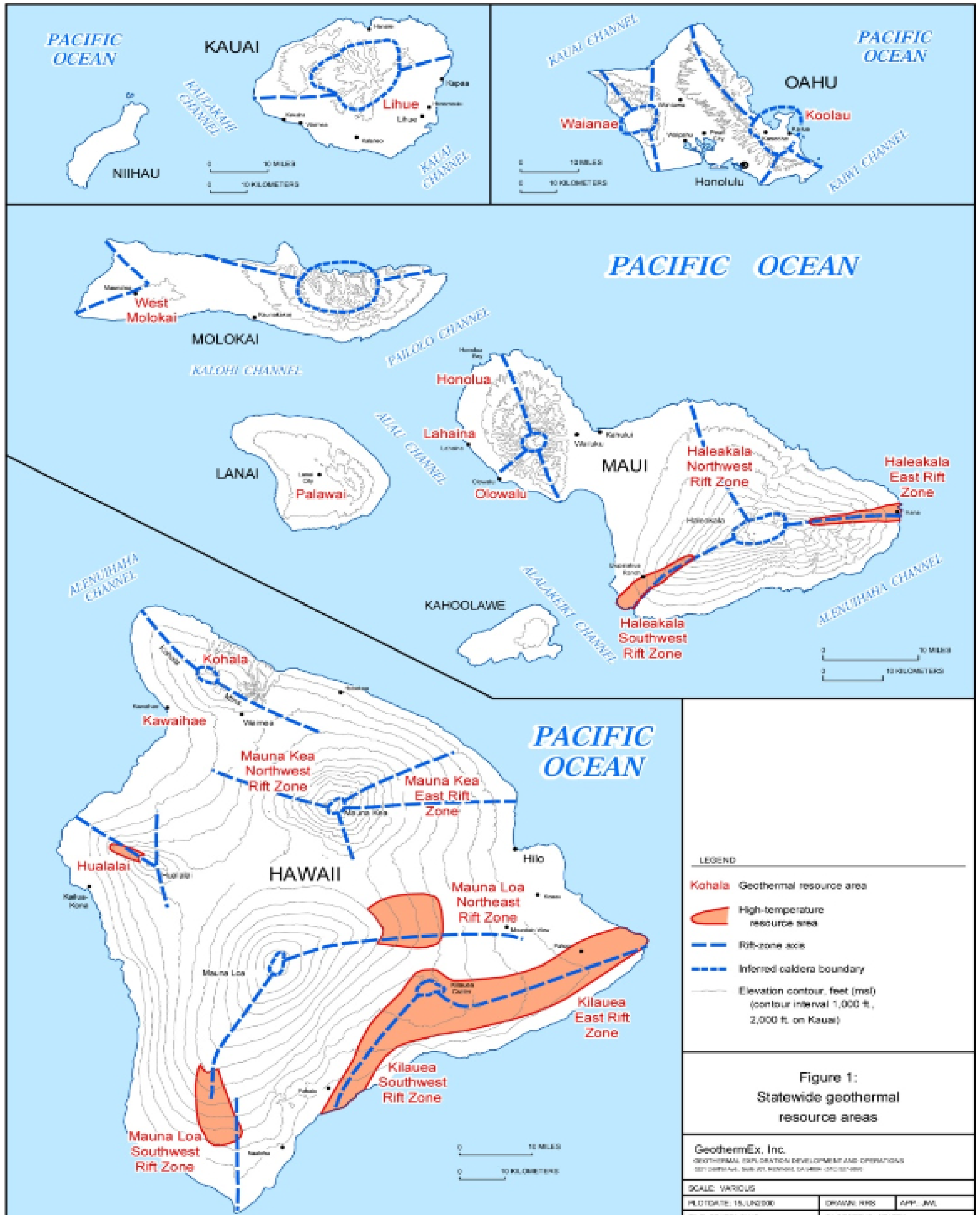
- Geothermal energy use mainly for **residential and commercial heating and cooling**
- Co-produced geothermal fluids in oil and gas wells in NW FL produced between 0.20 and 1.0 MW



Borehole temperature at depth:

- longer lines deeper wells
- green lines cooler borehole temperature
- warm colors hotter borehole temperature

Hawaii – *New State-Wide Assessment Using MT Data*



Map of Geothermal Resource Areas (Source: GeothermEx, 2005)

- Magnetotelluric (MT) surveys cover all the major geologic structures with geothermal resource potential
- Site-specific hydrologic and geologic data contained with the Water Commission files, enhance the ability to interpret and analyze MT data
- State's Commission on Water Resources Management transitioned to e-document system of water resource oversight and permitting

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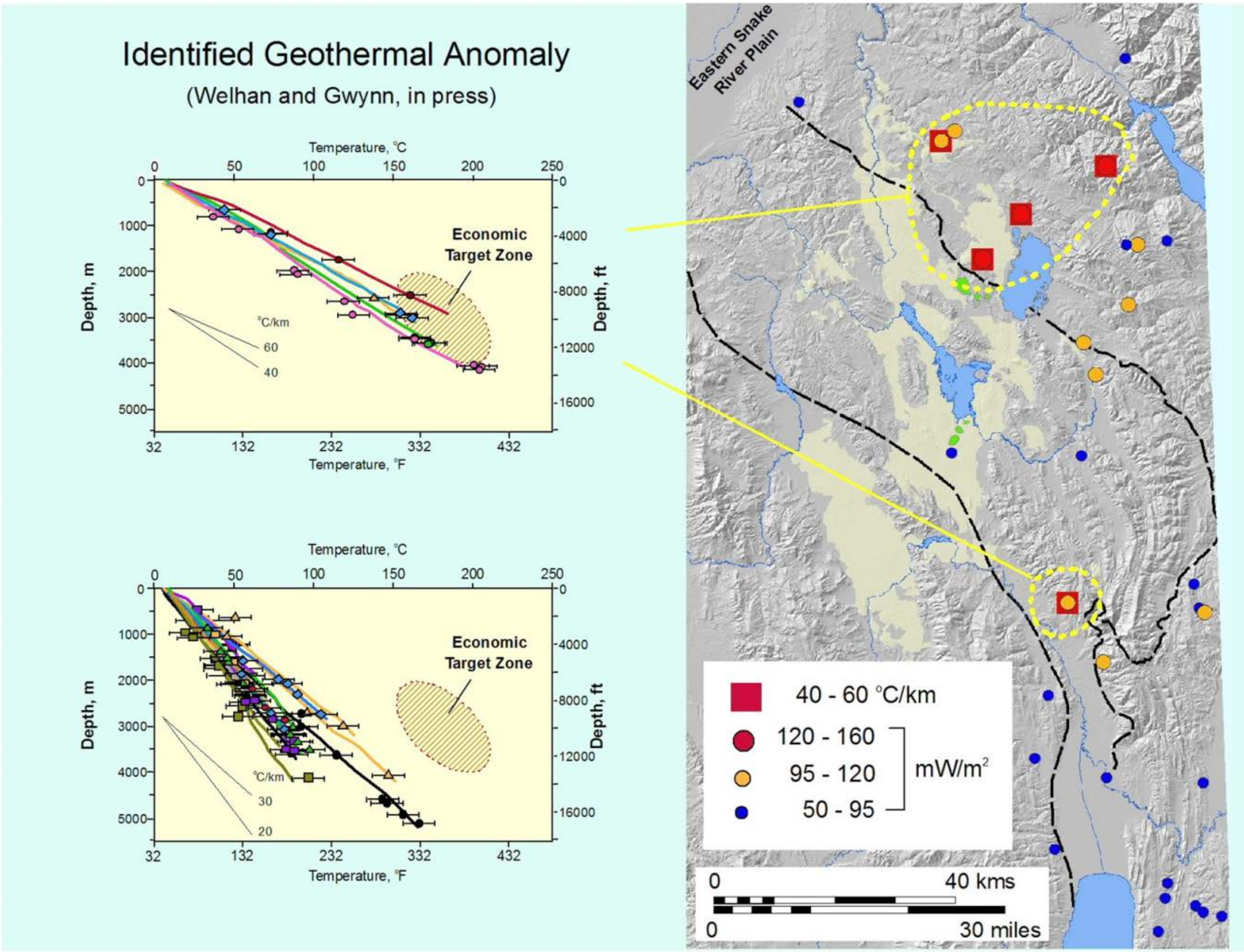
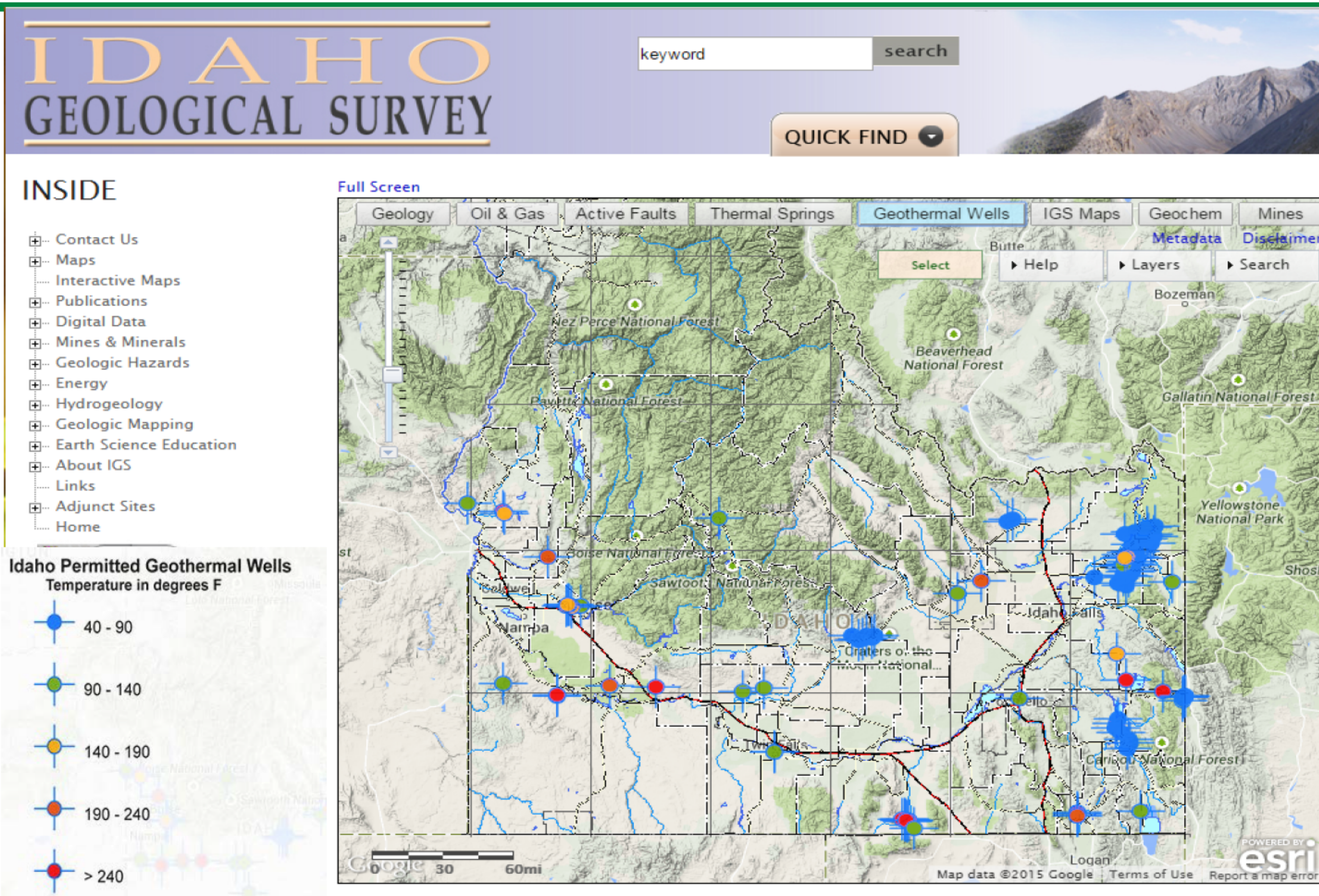
Idaho – *New Geothermal Resources Detected*



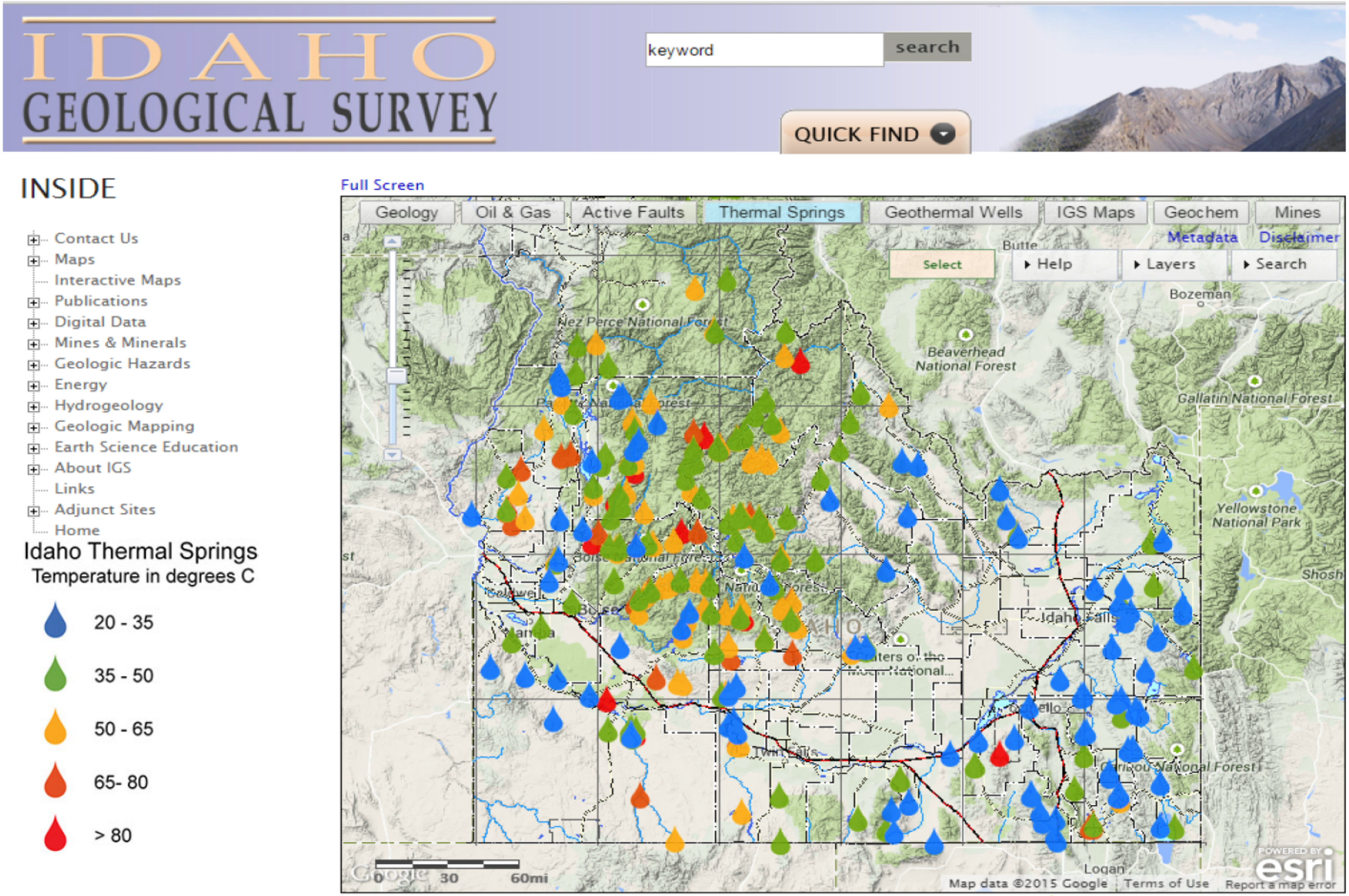
- Exploration drilling resulted in data from four wells with acceptable flow rates and temperatures of 150–200°C at 2.5 to 4 km deep
- The Blackfoot volcanic field may prove to be an economically valuable geothermal resource

Evidence of a hidden, high-temperature magmatic-hosted geothermal resource—a **potential location for geothermal development.**

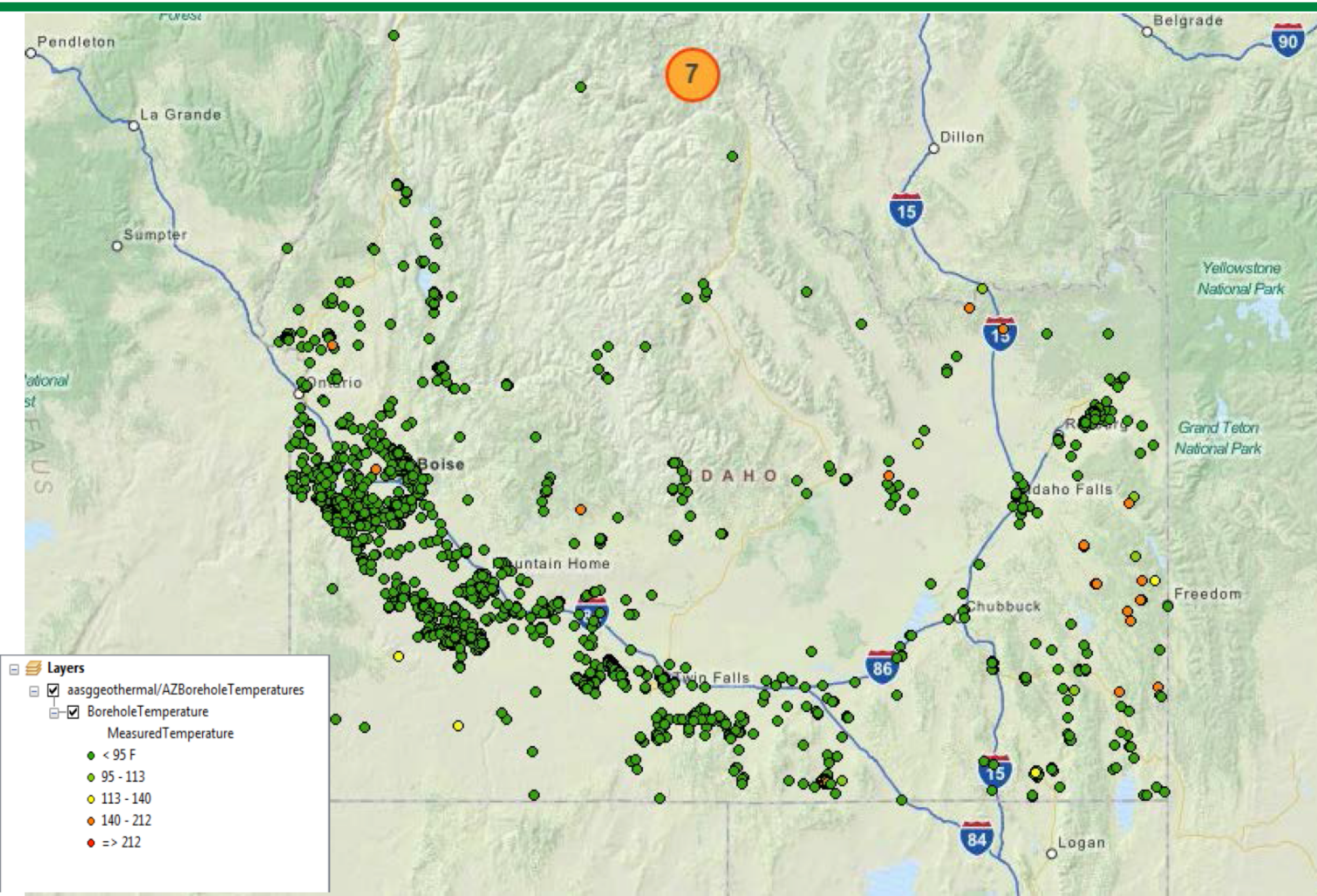
Idaho – *Increasing Data Exposure: Geothermal Wells*



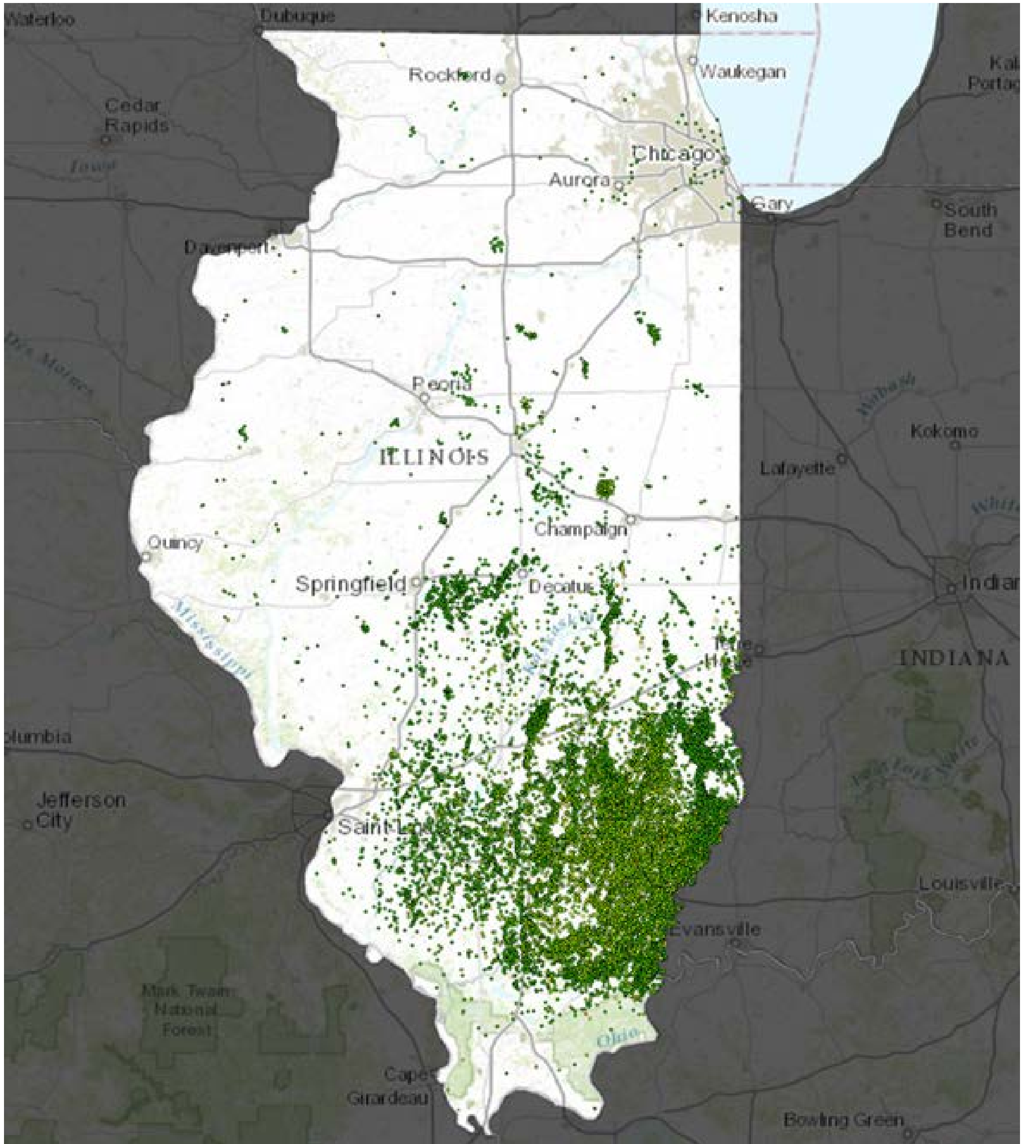
Idaho – *Increasing Data Exposure: Thermal Springs*



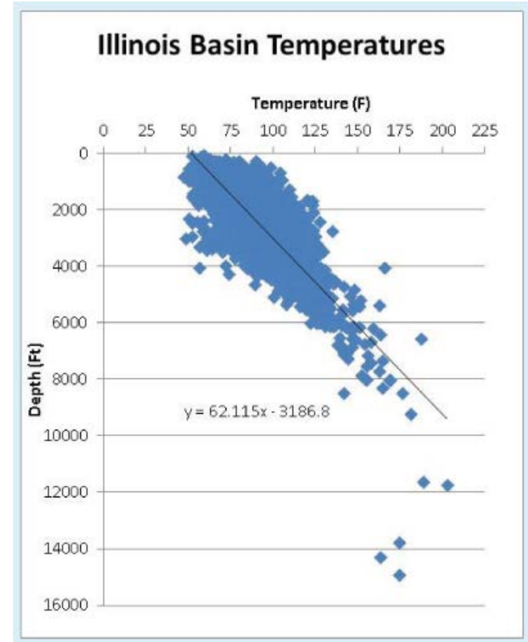
Idaho – *Increasing Data Exposure: Borehole Temperatures*



Illinois – *Thermal Blanket Effect*



29,000 + BOREHOLE TEMPERATURE OBSERVATIONS



- Mapping confirms increasing temperature, and decreasing gradients with depth
- Low thermal conductivity sediments may enhance temperature gradients due to thermal blanketing

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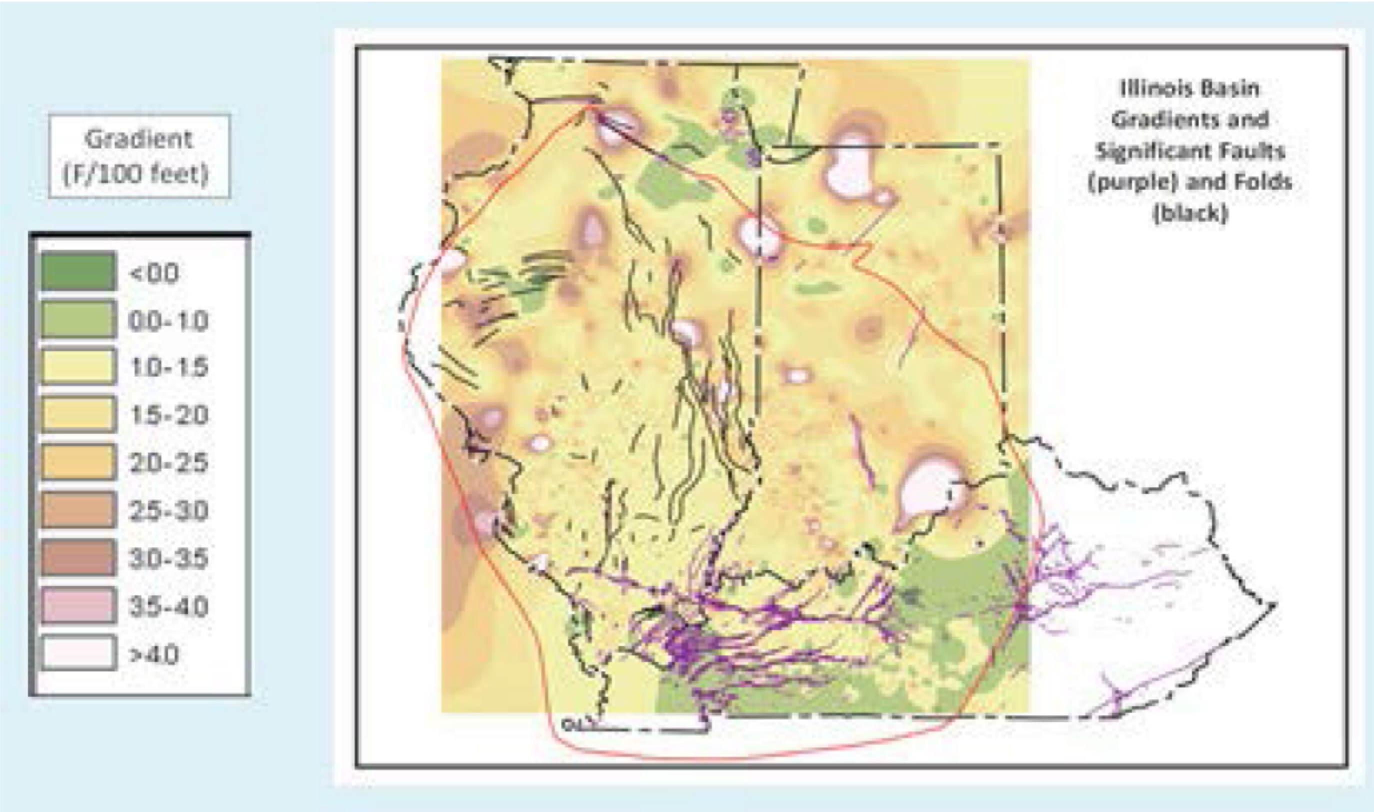
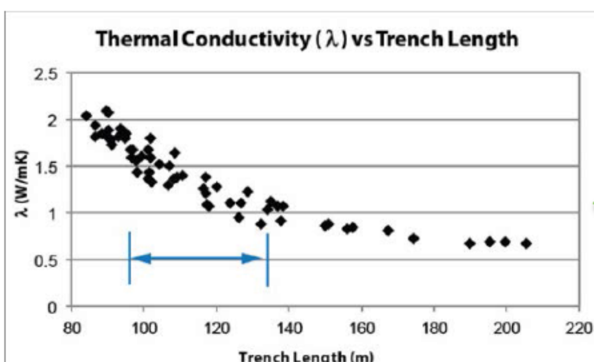
Indiana – *Thermal Gradient Analysis from 26,000 Wells*





Thermal conductivity of unconsolidated sediments plotted vs. calculated horizontal trench length; shows **optimal trench lengths for GSHP**

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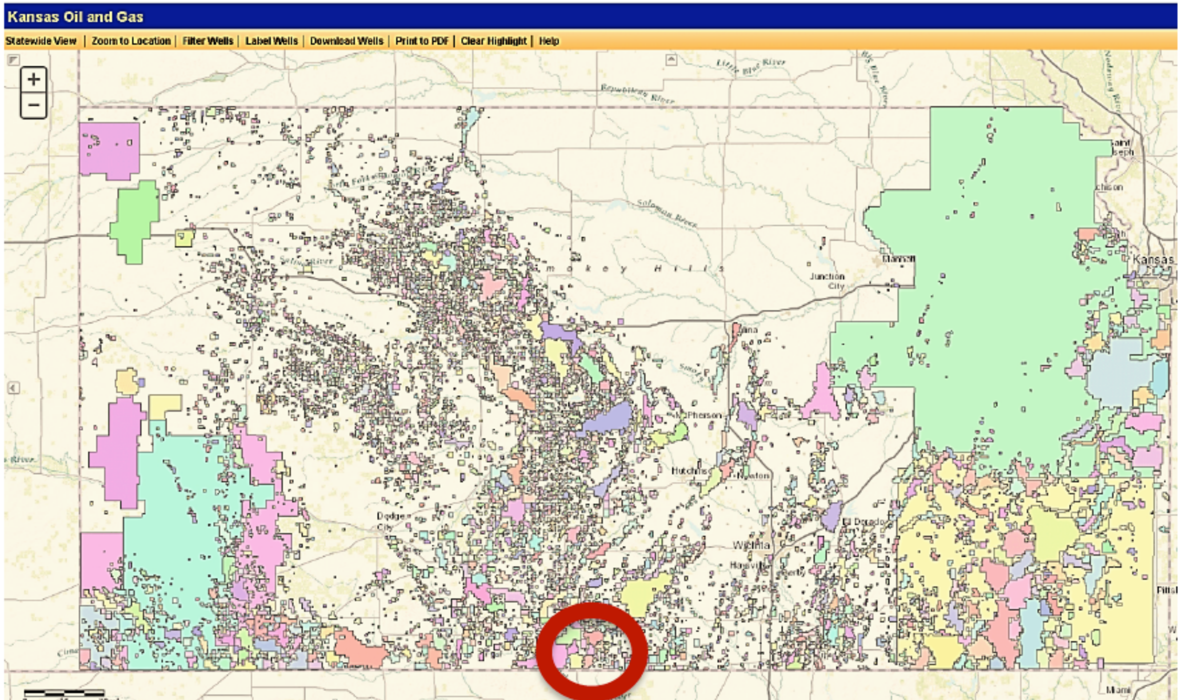
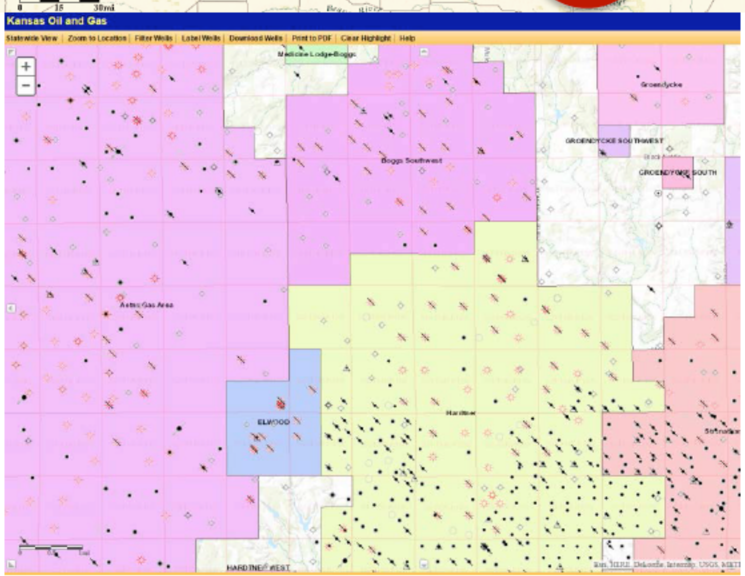
Kansas – *County-Level Geologic Data Now Online*

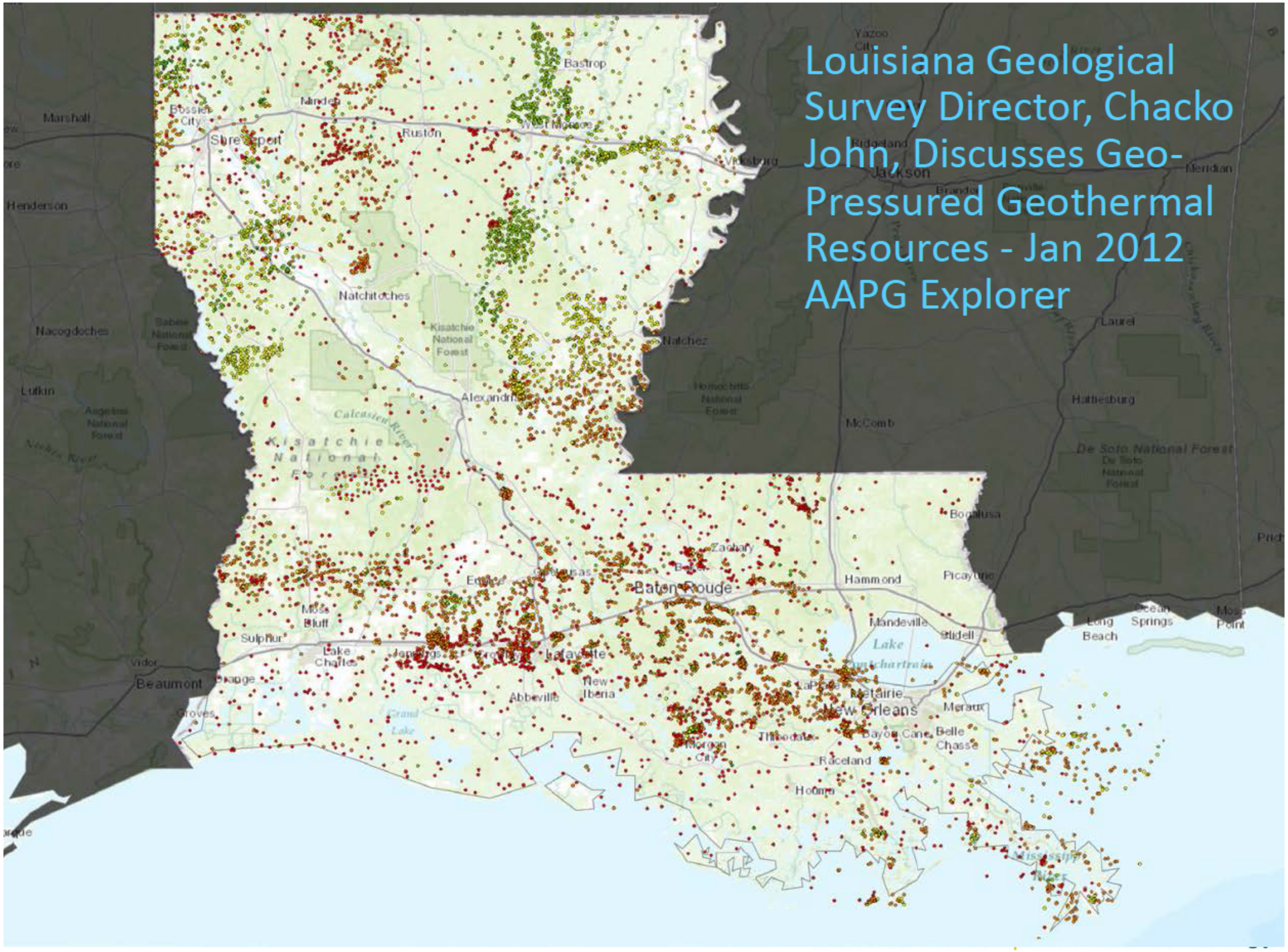


- Drill Stem Test data made public
- Additional 39 counties added to Geologic map (1:24K)

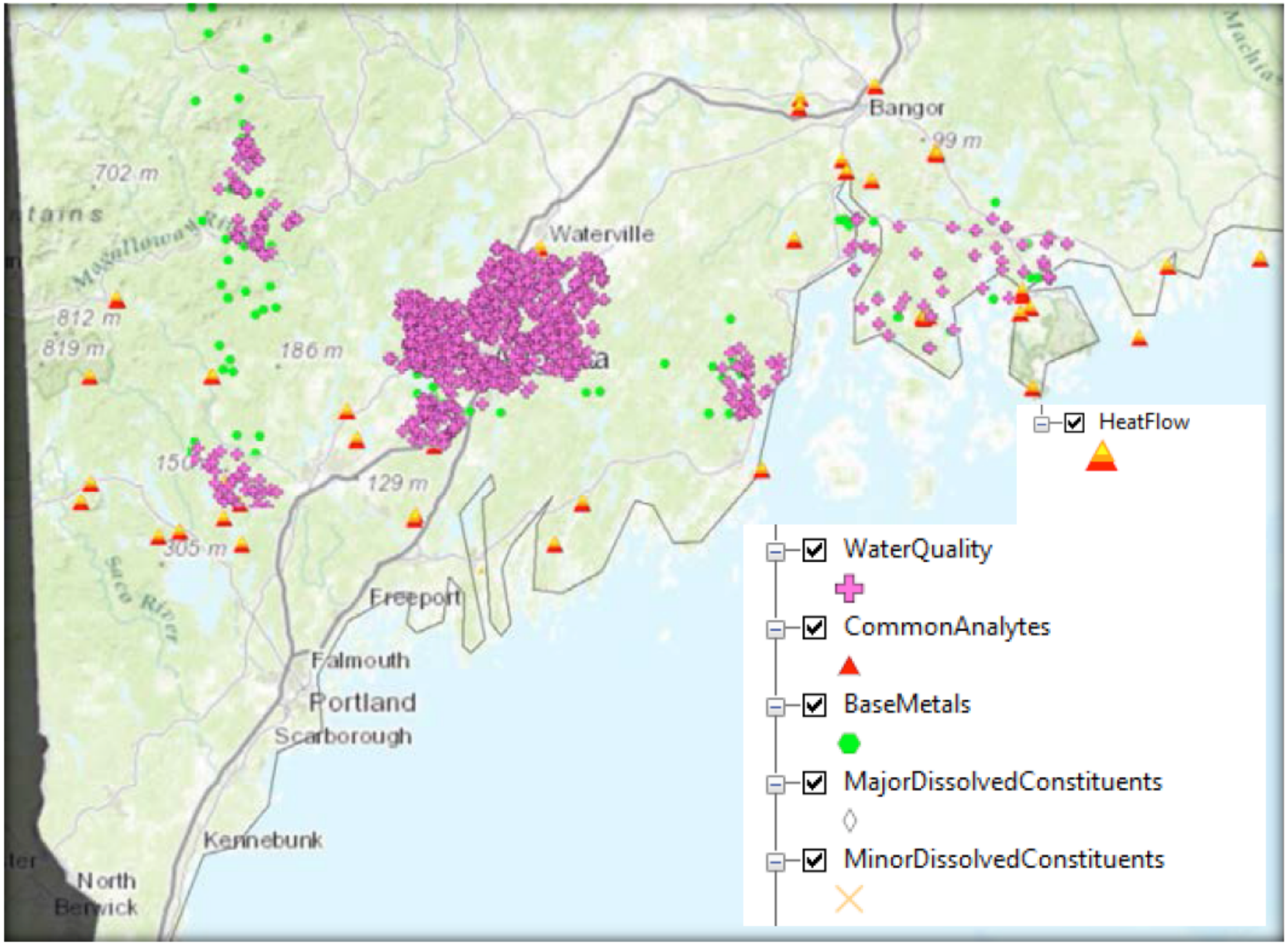


Kraft-PRUSA oil and gas field of Central Kansas – interactive map includes well locations

Louisiana – *Borehole Temperatures*



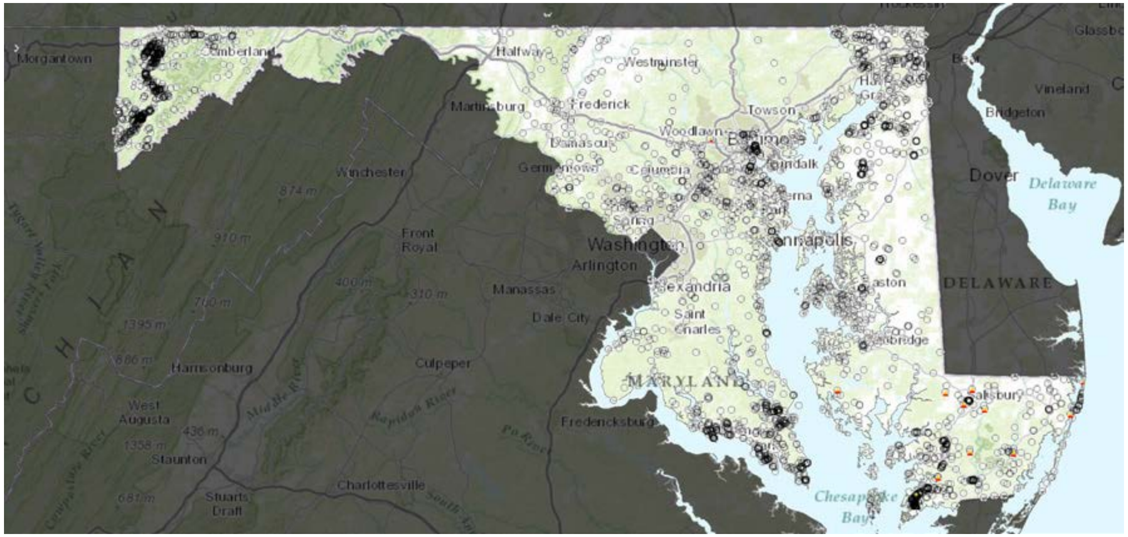
Maine – *Highest Heat Flow in Eastern United States*



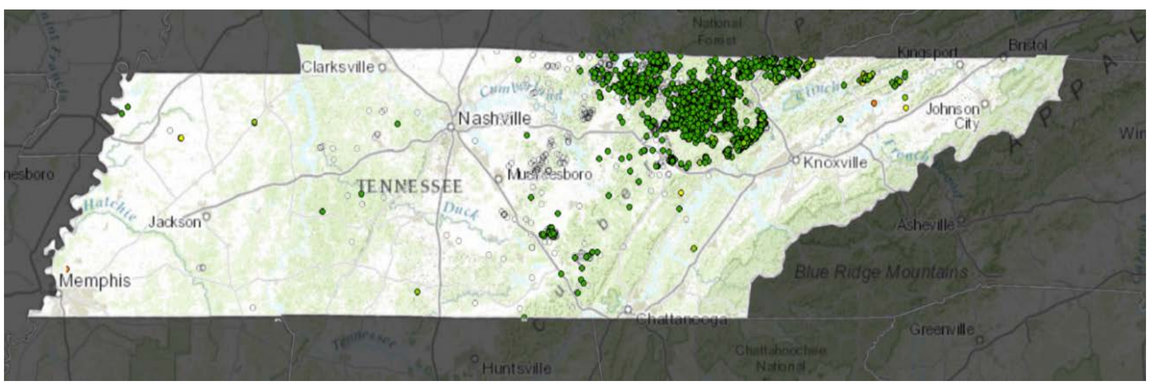
Composite map of Maine aqueous chemistry and heat flow data points as they appear in the NGDS Web Map Service (WMS)

- 1,500 records added to NGDS and new temperature profiles for 30 deep bedrock boreholes
- Heat Flow database
- Aqueous Well Chemistry
- Columbia Groundwater Quality database

Maryland and Tennessee



MD: Heat flow and Well header services



TN: 2,800 Borehole temperature measurements
3,300 well header measurements
21 Heat Pump Installations
31 Direct Use Sites
66 Conductivity Tests

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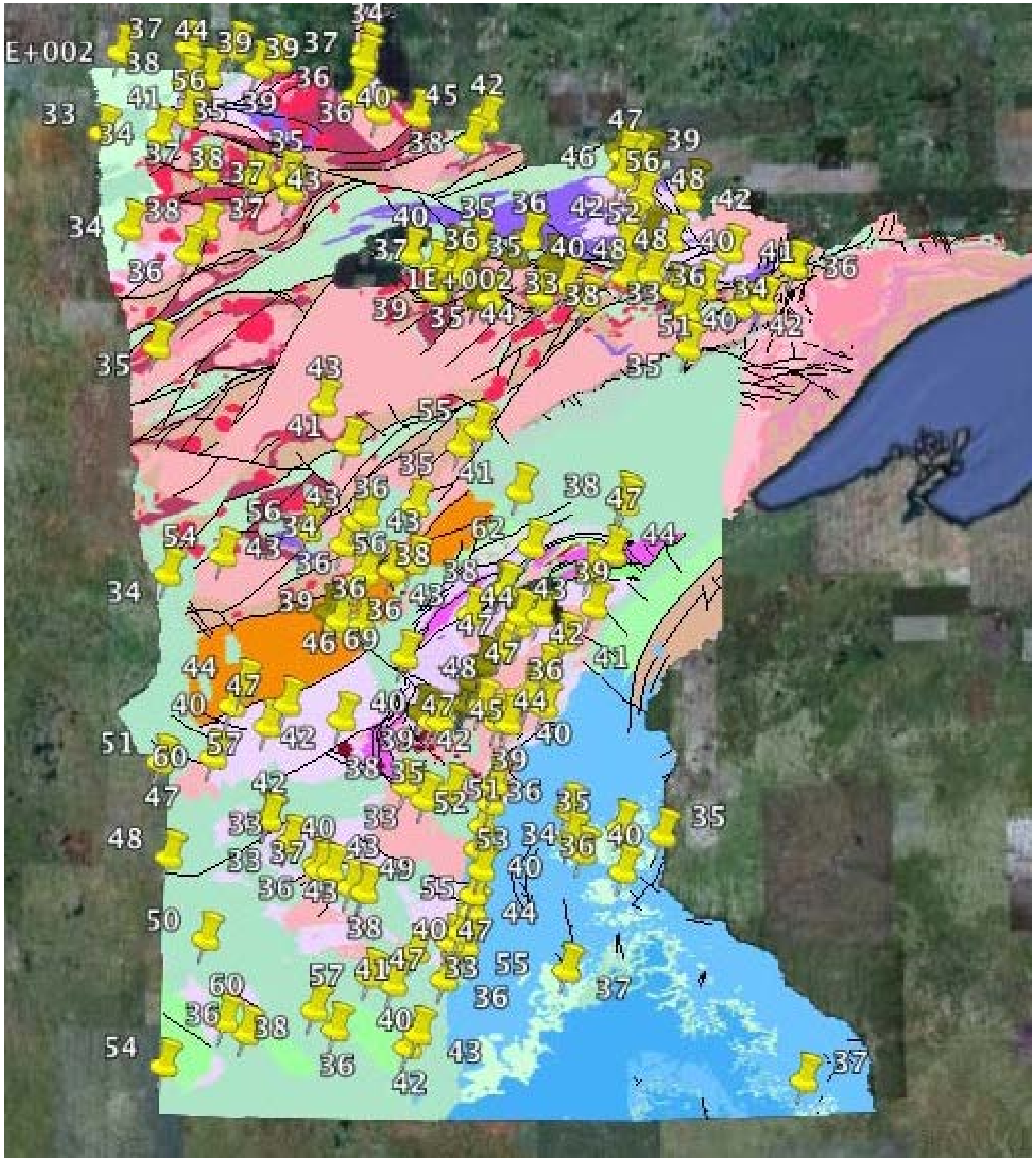
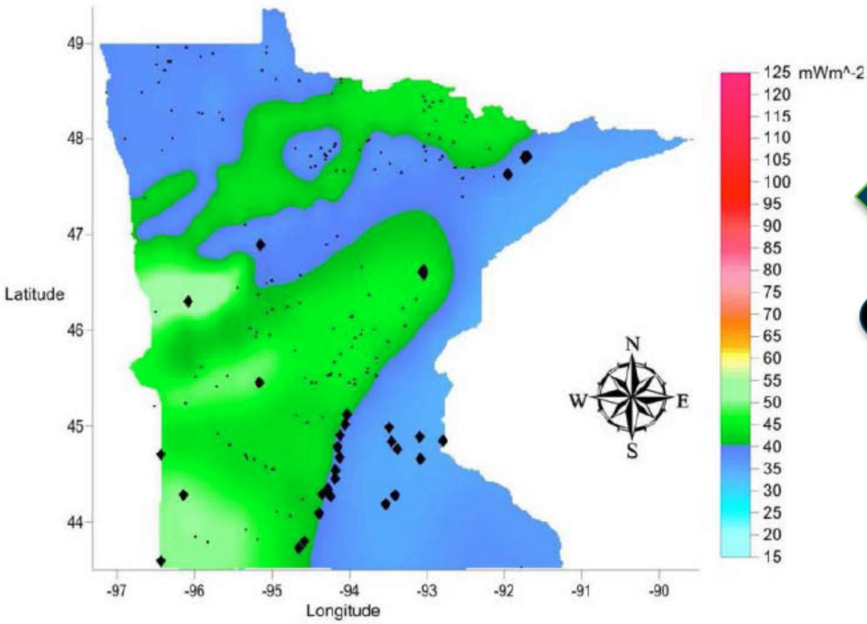
Minnesota – *Heat Flow Locations Over Geologic Map*

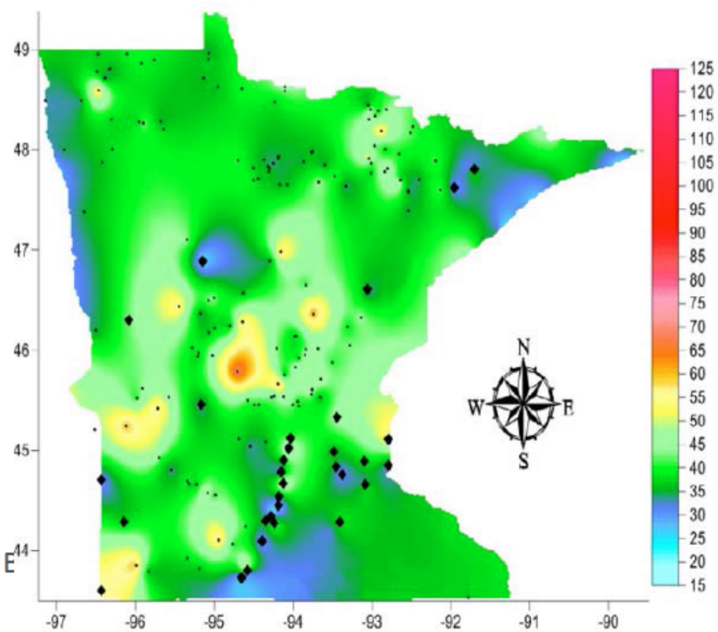


"New Heat Flow Map of Minnesota Corrected for the Effects of Climate Change and an Assessment of Enhanced Geothermal System Resources."

– University of North Dakota

Minnesota – *Heat Flow Map*





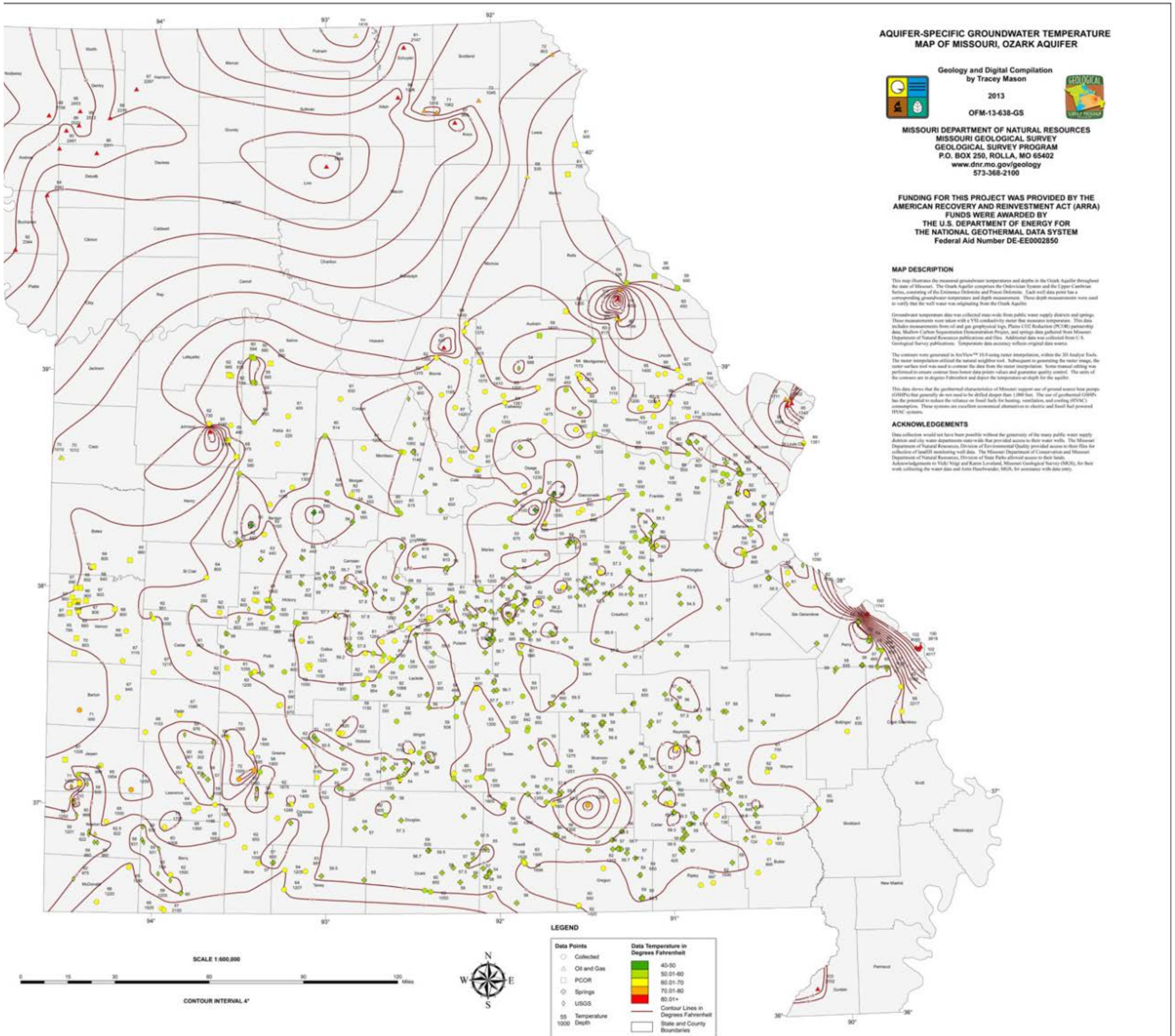
◆ Traditional heat flow measurements

● Calculated heat flow measurements
Uses Q-A relationship

- Vertical scale shows heat flow in mW m-2

- Heat flow measurements systematically lower than the heat flow calculated from radioactivity (dots).
- Correction for post-glacial warming needs to be applied

Missouri – *GSHP and Geothermal Usage*

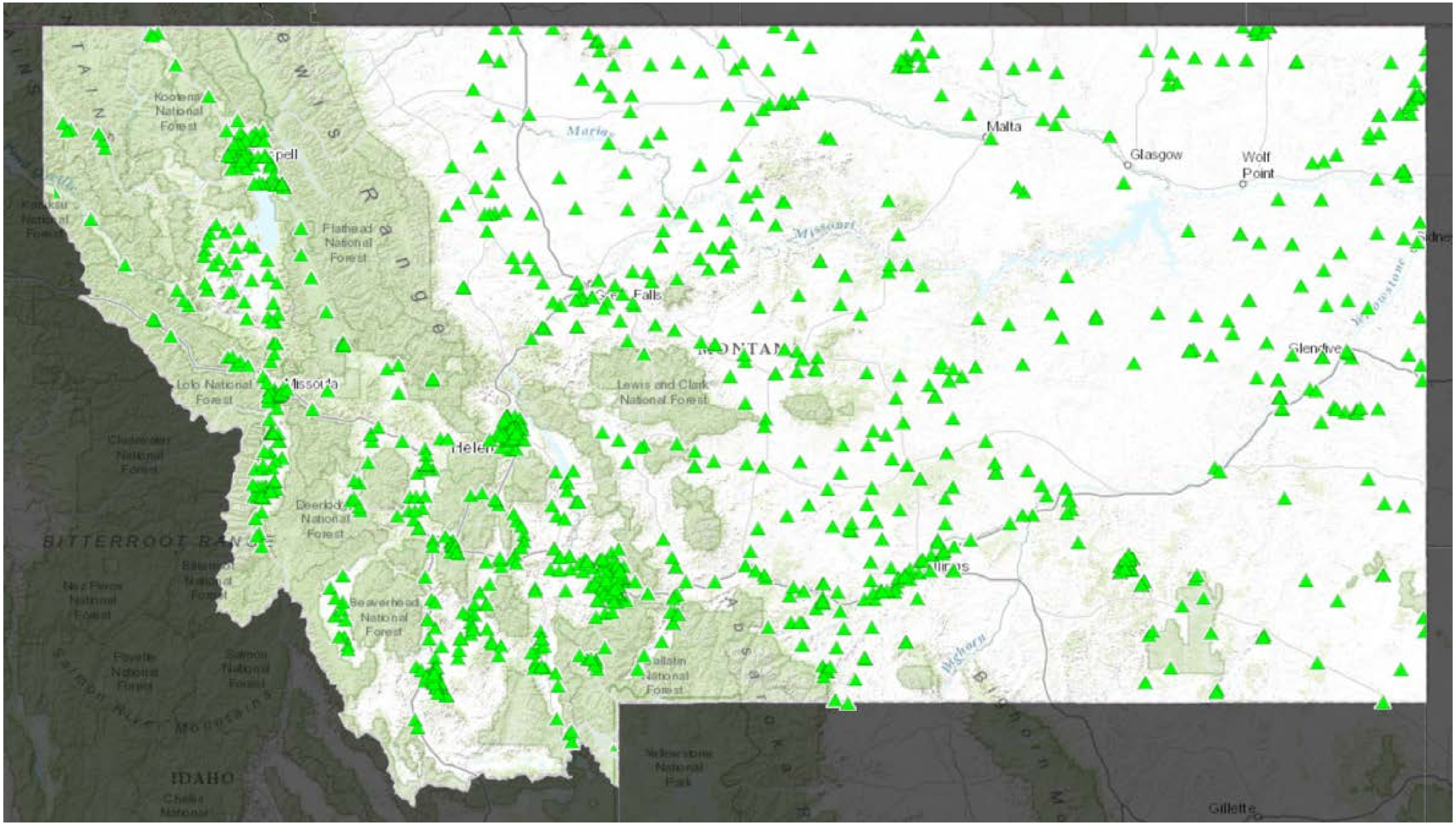


Maps and Datasets:

- Heat pump facilities
- Borehole temperatures
- Lithology logs with well headers
- Aqueous chemistry
- Rock chemistry
- Geodatabase for a 1:500,000 map service
- Depth to bedrock map
- Aquifer-specific groundwater temperature maps include raw temperature and depth data for Missouri aquifers

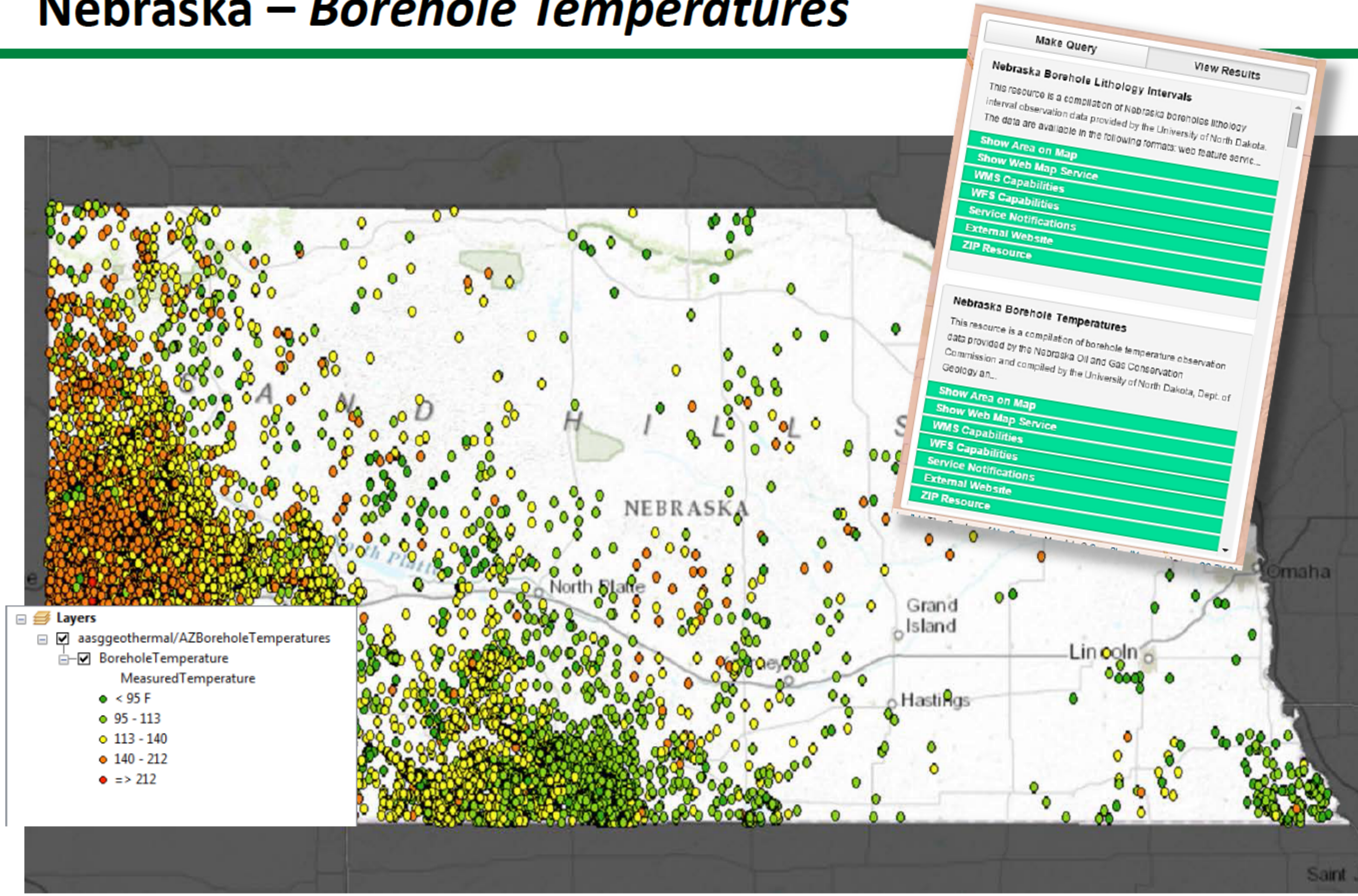
Ozark Aquifer Groundwater Temperatures & Depths

Montana – *Groundwater Monitoring Data*

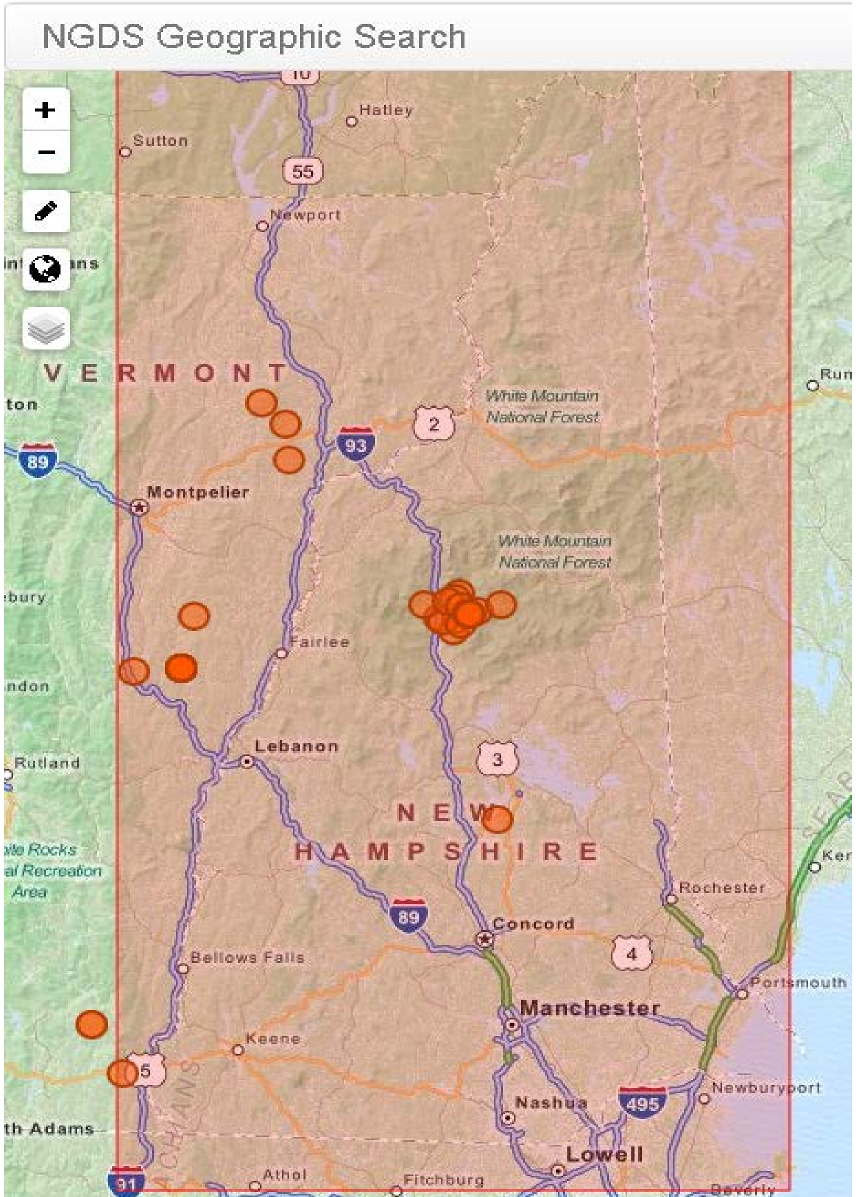


Well construction fields long-term monitoring network used to monitor groundwater could assist in locating geothermal resources. Wells provided by Montana's Ground Water Information Center.

Nebraska – *Borehole Temperatures*



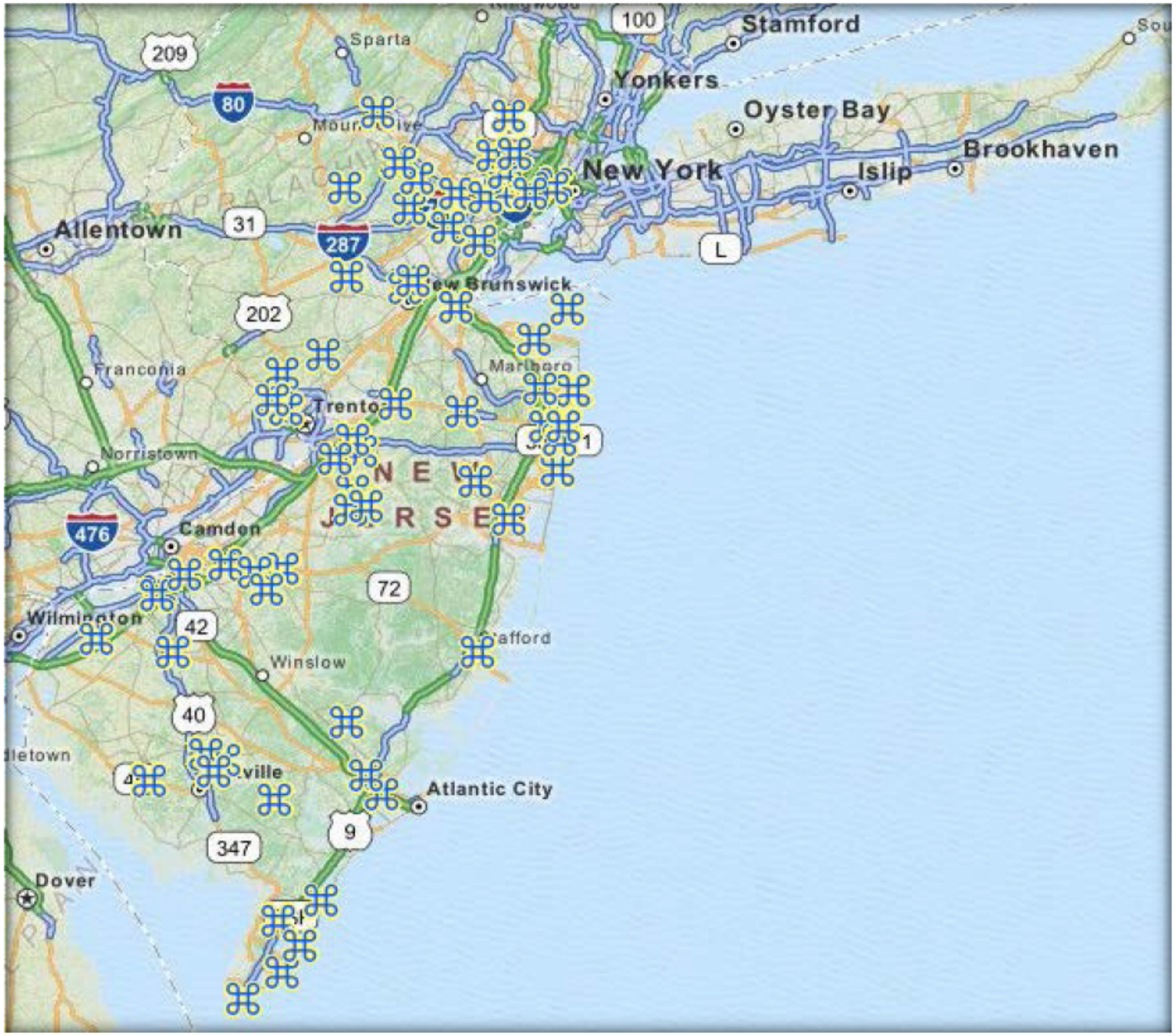
New Hampshire – *More than 50 Datasets*



More than 50 geothermal relevant datasets including:

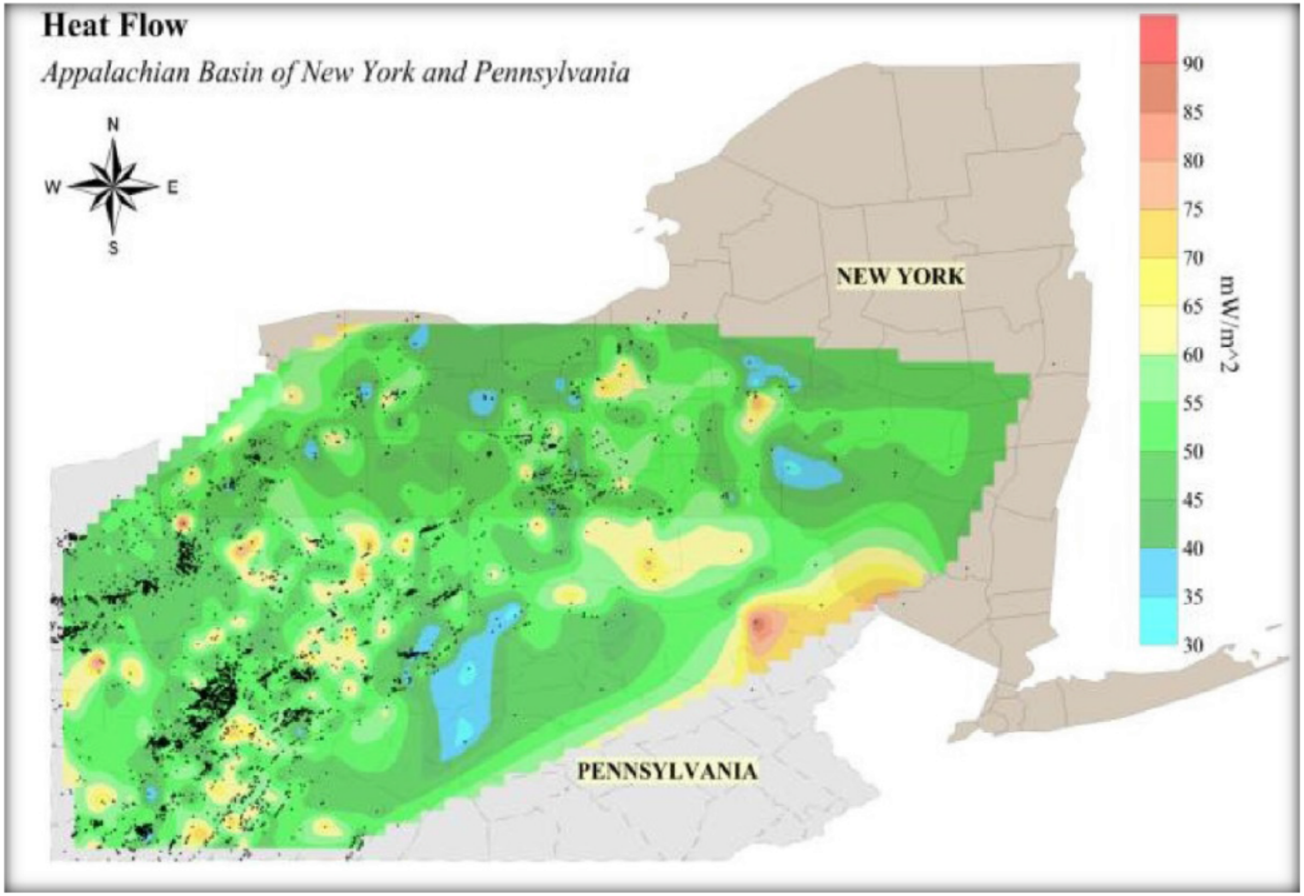
- gravity stations
- well logs
- well headers
- borehole temperatures
- thermal conductivity
- rock chemistry
- depth to bedrock

New Jersey – *Thermal Conductivity and Diffusivity*



Thermal conductivity map of New Jersey as shown through the NGDS web map service

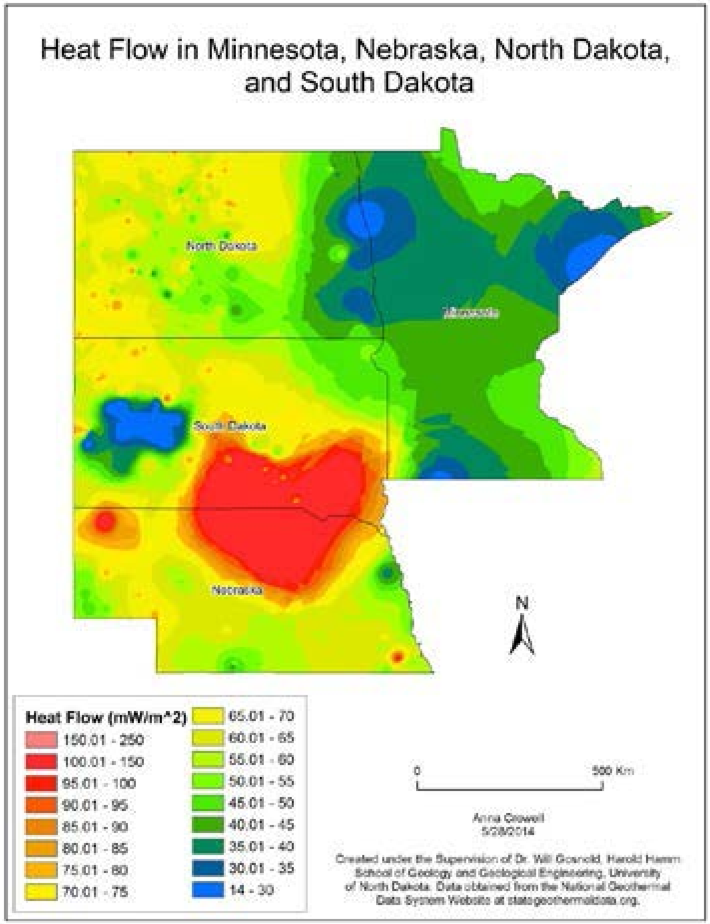
New York & Pennsylvania – *Appalachian Basin*

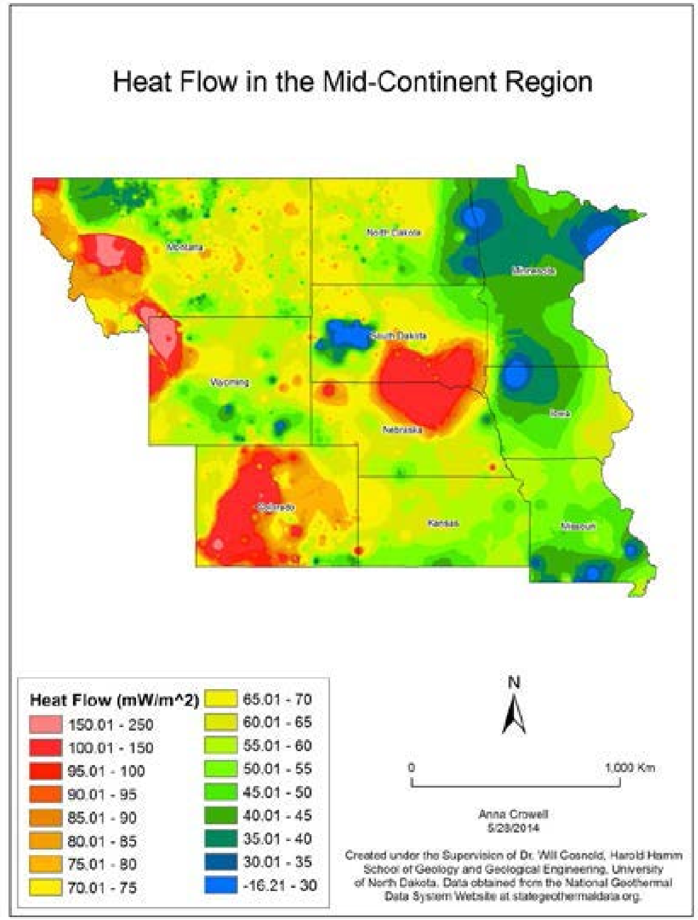


- 700+ temperature curves from scanned well logs
- 5,900+ bottom-hole temperatures from 35,000+ well logs

Surface heat flow in the Appalachian Basin of New York and Pennsylvania, calculated as the product of thermal gradient and average thermal conductivity for a specified location

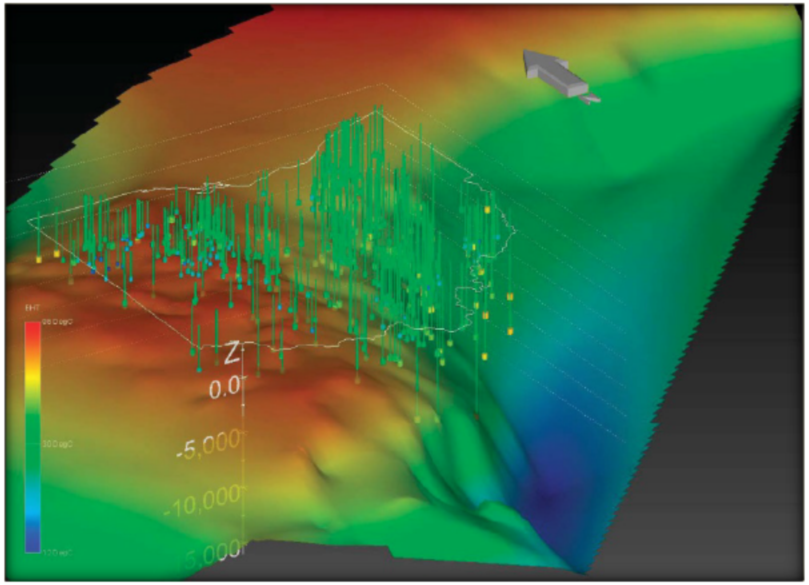
North Dakota – *Heat Flow*

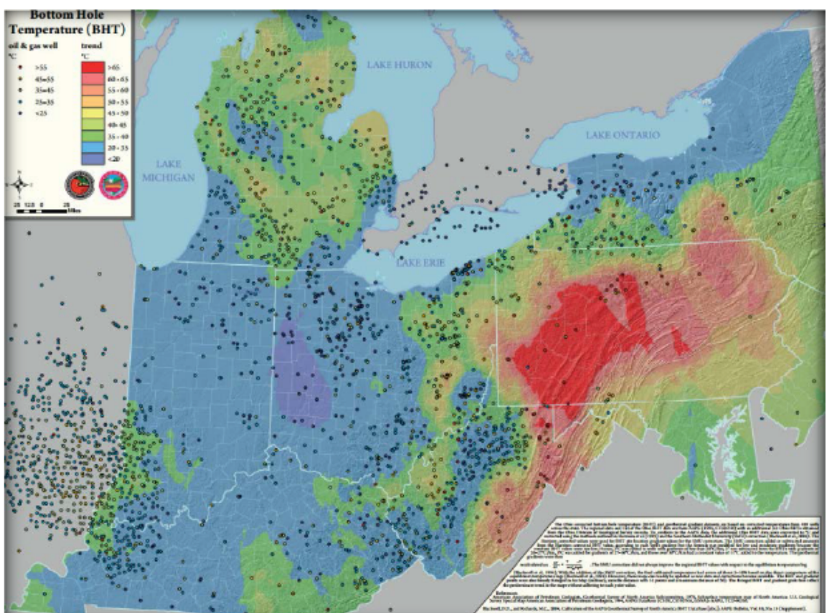




UND maps: heat flow, thermal conductivity, and radioactive heat production featuring uranium, thorium, and potassium, and plots of temperature against depth measurements

Ohio – *Regional, Subsurface Geothermal Environment*





- Corrected borehole temperature observations
- Well locations and observation depths
- Evaluate where geothermal energy, CO_2 injection, enhanced recovery, and electricity coproduction exist

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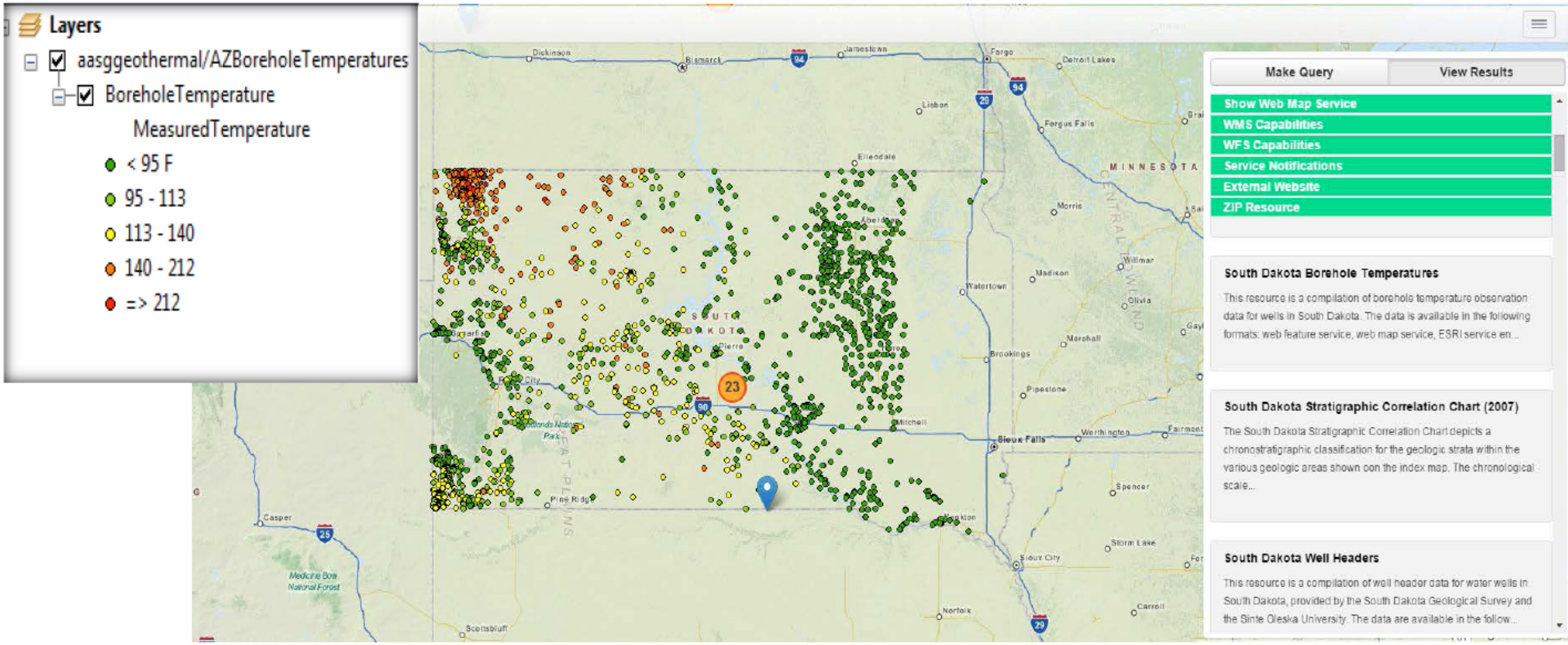
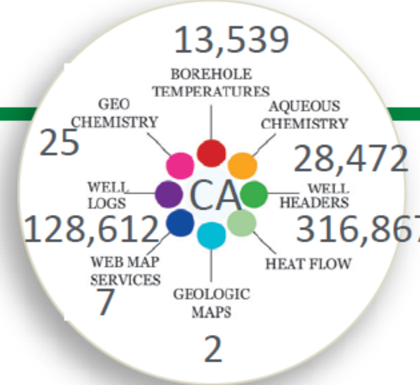
- Bottom hole temperatures and generalized Krieged BHT surface
- 2,643 data points are from AAPG (1994) and 334 new BHT values for Ohio
- BHT data generally reflect the depth of the well with hotter values found in deeper wells

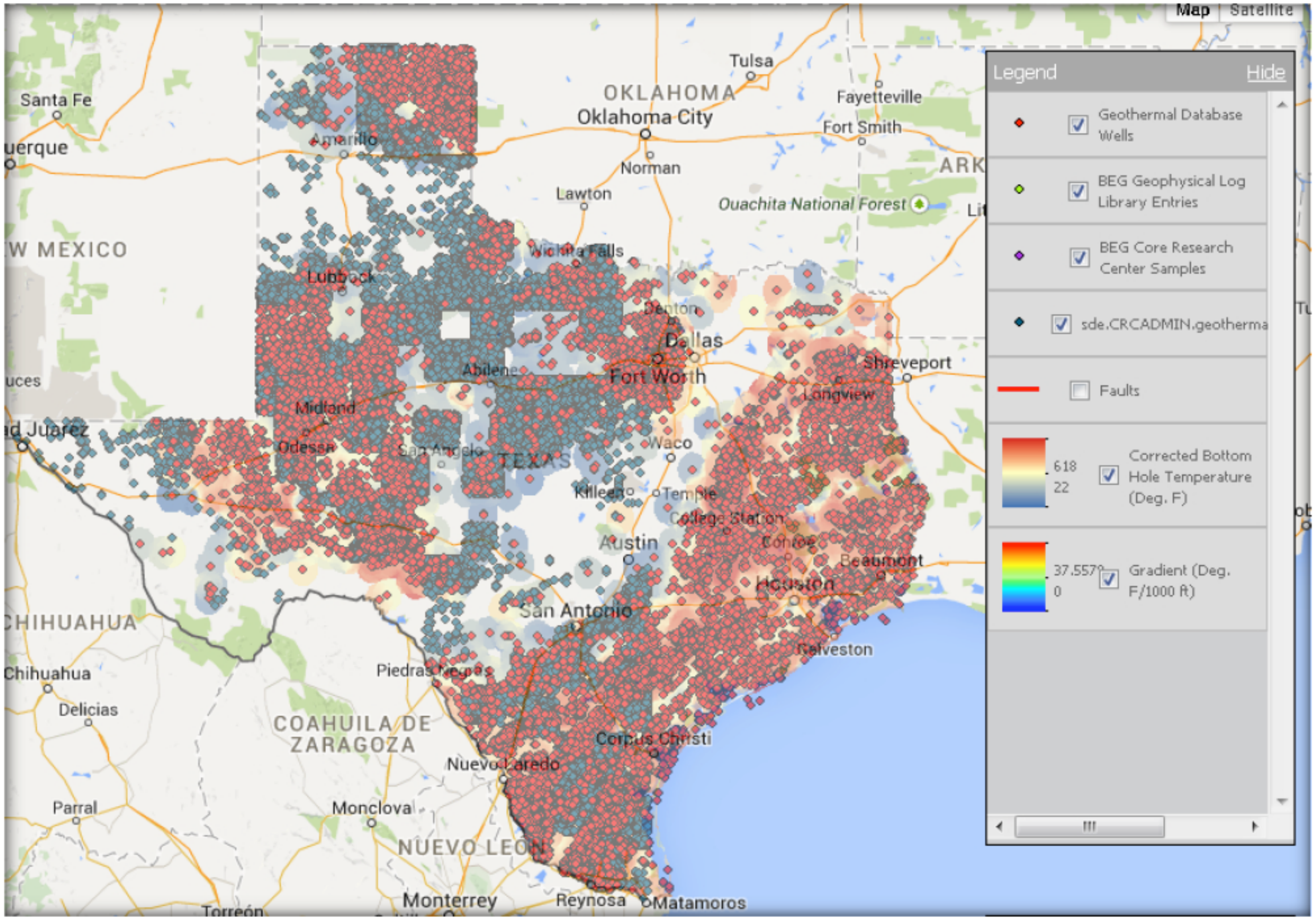
South Dakota – *Sinte Gleska University Data Compilation*



Available Data: temperature, flow volumes, and chemical analysis (12 privately owned artesian wells), lithological, logs, and detailed water analysis for two new geothermal water wells near White River. Also geological/lithological maps for South Dakota, including the Rosebud Indian Reservation.

Texas – *Potential Geothermal Reservoirs*





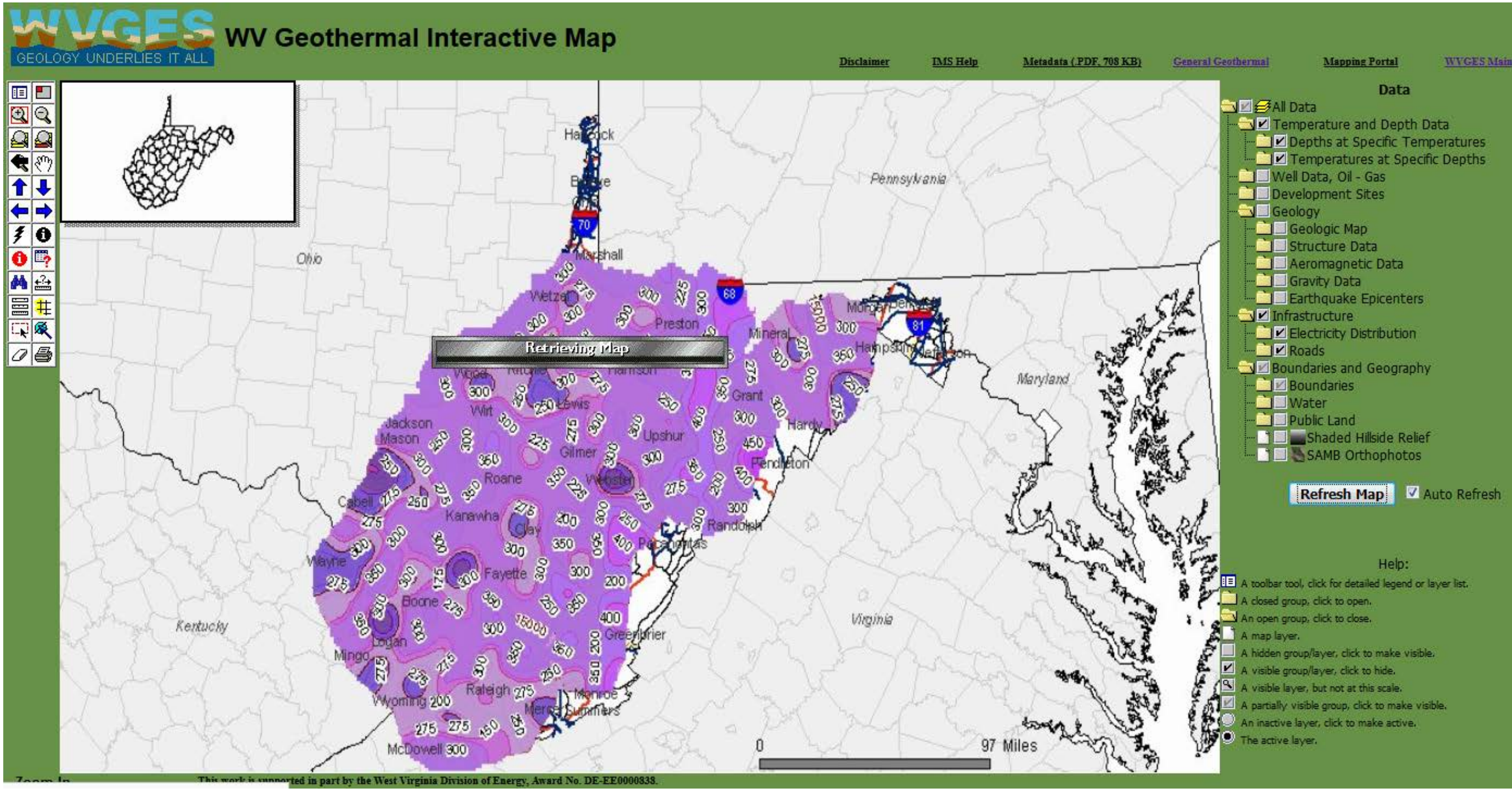
Crockett and Val Verde Counties; Southwestern Gulf Coast and West Texas; Anadarko Basin Exploration ongoing

Raw data

(geophysical logs, core samples, faults, geothermal gradient, well log data and more)

analyzed to measure **potential productivity of deep reservoirs**

West Virginia – *Potential Hot Spot for Geothermal*



Maps Include: geo-referenced basement structure (115+ individual features); gravity and magnetic; geo-referenced faults in Devonian Onondaga Limestone; earthquake epicenter, and geologic.

What is "Heat Flow"? Source: Southern Methodist University

Heat flow is the **movement of heat (energy) from the interior of Earth to the surface**. The source of **most heat comes from the cooling of the Earth's core** and the radioactive heat generation in the upper 20 to 40 km of the Earth's crust. Radioactive heat generation is a product of crustal rocks containing high concentrations of the naturally occurring radioactive elements: thorium, potassium, and/or uranium. Heat flow is **higher in areas with either high radioactivity or where the Earth's crust is thinner**, such as the mid-oceanic ridges or the Basin and Range Province of the Western United States. Additionally, there are areas with heat flow 'anomalies' that have higher than average crustal heat flow without a clearly identified tectonic or radioactive explanation, usually related to fluid flow such as in South Dakota. Heat flow is calculated using the rock thermal conductivity multiplied by the temperature gradient. The standard units are mW/m2 = milli Watts per meter squared. Thus, think of a flat plane 1 meter by 1 meter and how much energy is transferred through that plane is the amount of heat flow.

Thermal conductivity is determined using rock cores or cutting on a devise that measures the amount of energy the rock sample can transfer. Examples of devices used in a laboratory are a divided bar or needle probe. Thermal conductivity units are typically in W/mK = Watts per meter Kelvin. Thermal conductivity values of a rock (mineral) will change as the temperature increases, which is why the units include Kelvin. The temperature gradient of Earth at the measurement site is determined from collecting the temperature in a well at specific depths. Often gradient units are either °C/km or °F/100 ft. If the temperature measurements are taken after the well is no longer impacted from the drilling fluid, it is considered at equilibrium. These values are of the highest quality and include a series of data points to assist in understanding the changes in the geology/structure of Earth. There is a tutorial on temperature logging with examples explaining why the gradient changes. Temperature measurements are also collected while drilling wells, especially oil and gas wells. These data values are referred to as bottom-hole temperatures, because they are taken at the bottom of the interval the well was drilled to at that time. Thus these values need to have corrections added to them to compensate for the drilling fluid either heating (shallow wells) or cooling (deeper wells). Also one well location can have multiple bottom-hole temperatures (BHT). While less temperature information is collected for each site than equilibrium sites, an oil and gas field usually has numerous BHT values available for comparison; the ability to compare temperatures improves on the accuracy of the single value. In order for a heat flow value to be fully calibrated, after the thermal conductivity and gradient are calculated, there are corrections that may be required based on where the well was drilled. Examples of them are for steep topography (the north facing slope of a mountain is colder than a south facing slope) and the geologic structure (a fault creating a sharp change in rock type with very different thermal conductivities