Capturing the Heat Beneath Our Feet:

Cornell's Deep Geothermal Heat Project and its Potential to Change the Energy System

Don Haas, PRI; Teresa Jordan, Cornell University

STANYS 2022

The changing energy picture

A few key ideas for climate change education

- Talking about climate change without talking about energy is like talking about lung cancer without talking about smoking.
- Fire is the at the root of modern climate change.
  - We need to talk more explicitly about fire - everyone knows what it is, unlike GHG emissions.
  - There was no fire for 90% of Earth history, now humans burning stuff is causing dangerous changes in climate.
- The best way to reduce anxiety is to reduce the threat causing the anxiety.
  - In other words, work on the problem.

The largest sources of energy used in NYS (2020):

In alphabetical order:

- Biomass
- Distillate fuel oil (mostly for building heat)
- Gasoline
- Hydroelectric power
- Jet fuel
- Natural gas
- Nuclear electric power

Rank order them from largest to smallest.

In rank order:

- Natural gas
- Gasoline
- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

The largest sources of energy used in NYS (2020):

In rank order:

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- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

See current data **here**, on EIA.gov.

Discuss:

- What's most surprising?
- How do other states differ?
- How is New York different from the US on the whole?
- What's likely different in NYS in 2022?
- How are different regions of the state different?
- How will it likely be different in 2035?

The largest sources of energy used in NYS (2020):

In rank order for NYS (2020):

- Natural gas
- Gasoline
- Nuclear electric power
- Hydroelectric power
- Distillate fuel oil
- Biomass
- Jet fuel

See current data **here**, on EIA.gov.

In rank order for the US (2021):

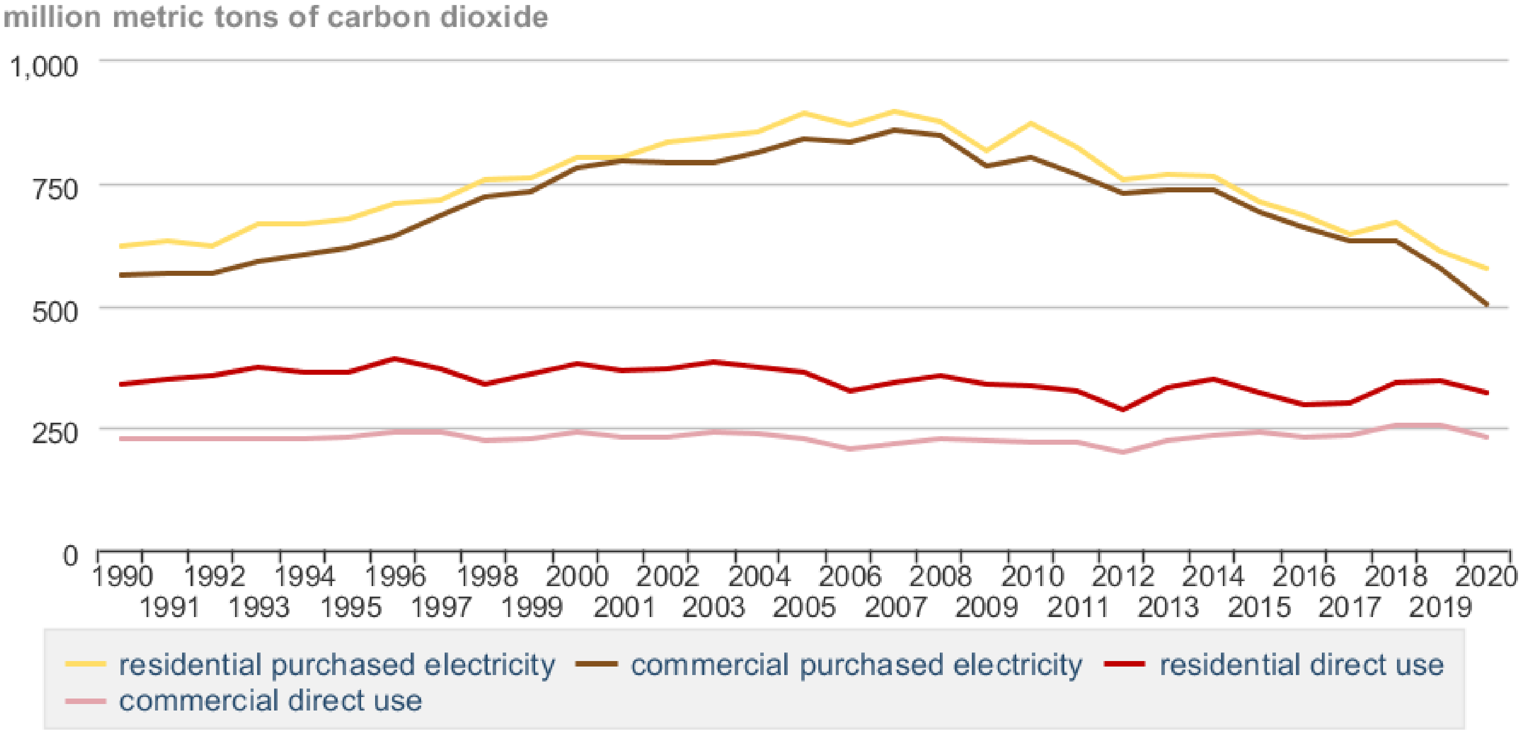
- Petroleum (mostly gasoline)
- Natural gas
- Coal
- Nuclear electric power
- Biomass
- Wind
- Hydroelectric power

See current data **here**, on EIA.gov.

New York State Energy Quick Facts (from eia.gov)

- New York revised its Clean Energy Standard in 2019 to require 100% carbon-free electricity from both renewable sources and nuclear energy by 2040. In 2020, renewable sources and nuclear power, together, supplied 60% of New York's in-state generation from utility-scale and small-scale facilities.
- Nuclear power accounted for 29% of New York's utility-scale net generation in 2020, down from 34% in 2019 because of the retirement of one reactor. A second reactor retired in 2021, completing the closure of Indian Point, one of the state's four nuclear power plants.
- In 2020, New York accounted for 11% of U.S. hydroelectricity net generation, and the state was the third-largest producer of hydroelectricity in the nation, after Washington and Oregon.
- In 2019, New York was the sixth-largest natural gas consumer among the states. New York's natural gas consumption per capita was less than in almost three-fourths of the states even though three in five households use natural gas for home heating.
- In 2019, New York was the fifth-largest consumer of petroleum among the states, but New Yorkers consume less petroleum per capita than residents of any other state in the nation.

Figure 8. Energy-related carbon dioxide emissions from residential and commercial buildings



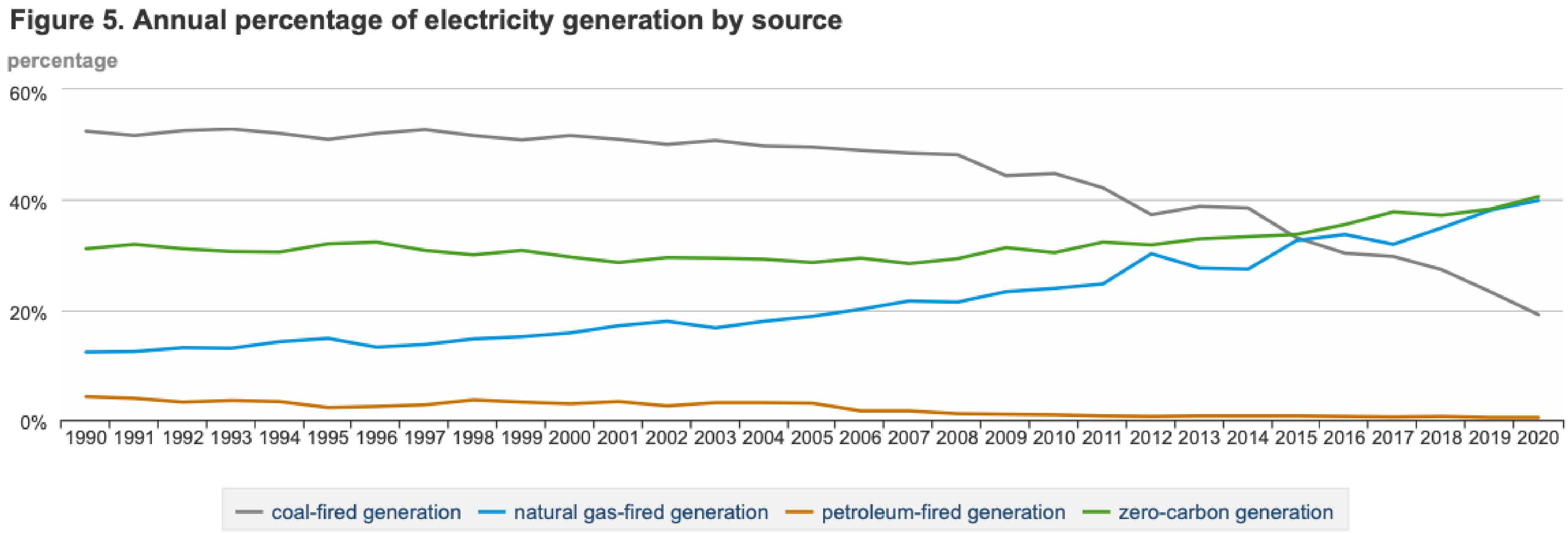
Source: Graph created by the U.S. Energy Information Administration (EIA), based on data from EIA's *Monthly Energy Review*, October 2021, Tables 11.2 and 11.3

Interactive version of this graph **here**. Scroll down to Figure 8.

Direct use (in buildings) is primarily for heating.

Explore & discuss the interactive graph, with an eye to the so far largely unchanged direct use data.

Note that total building square footage has increased substantially.



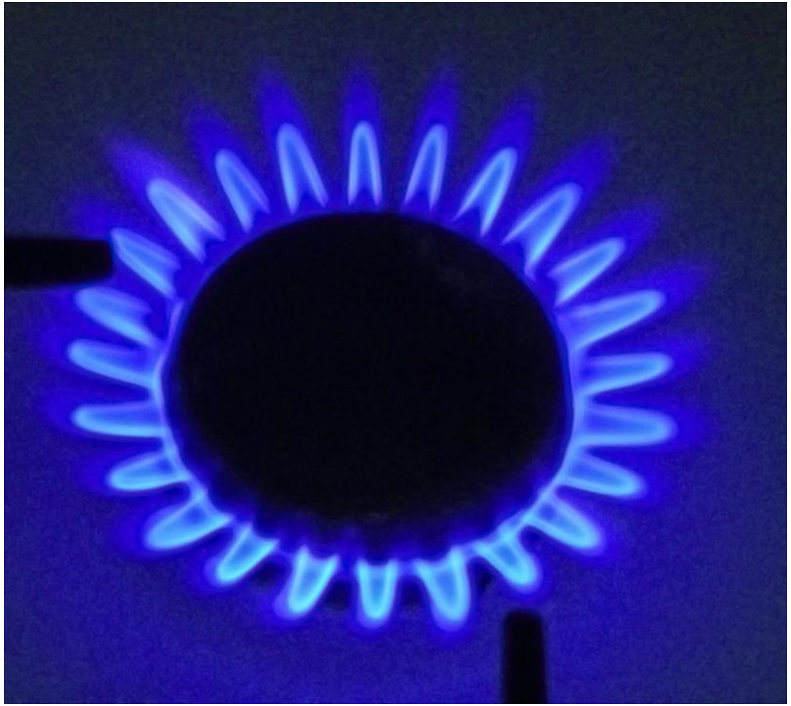
Source: Graph created by the U.S. Energy Information Administration (EIA), based on data from EIA's *Monthly Energy Review*, October 2021, Table 7.2a, Electricity Net Generation: Total (All Sectors); Table 10.6, Solar Electricity Net Generation

Interactive version of this graph [here](). Scroll down to Figure 5.

Zero-carbon generation includes nuclear, hydro, wind, and solar.

Wind is overtaking hydro as the 2nd largest zero-carbon source behind nuclear power.

How hot is it?



Methane burns at

3,560˚ Fahrenheit /

1,960˚ Celsius

Gasoline, coal, and wood are more complicated as they are more varied in composition.

The thermal spectrum of low-temperature energy use in the United States

Is it wasteful to burn a fossil fuel at over 1000 °F if we then cool it down to under 300 °F to use it?

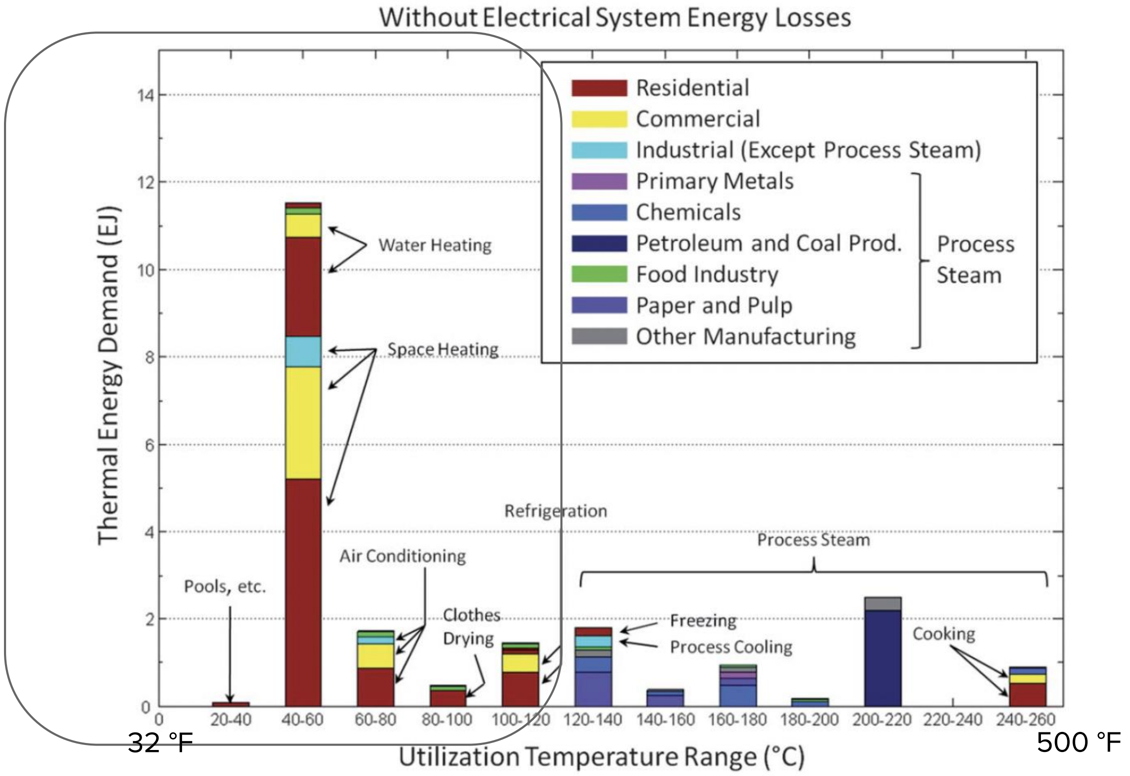
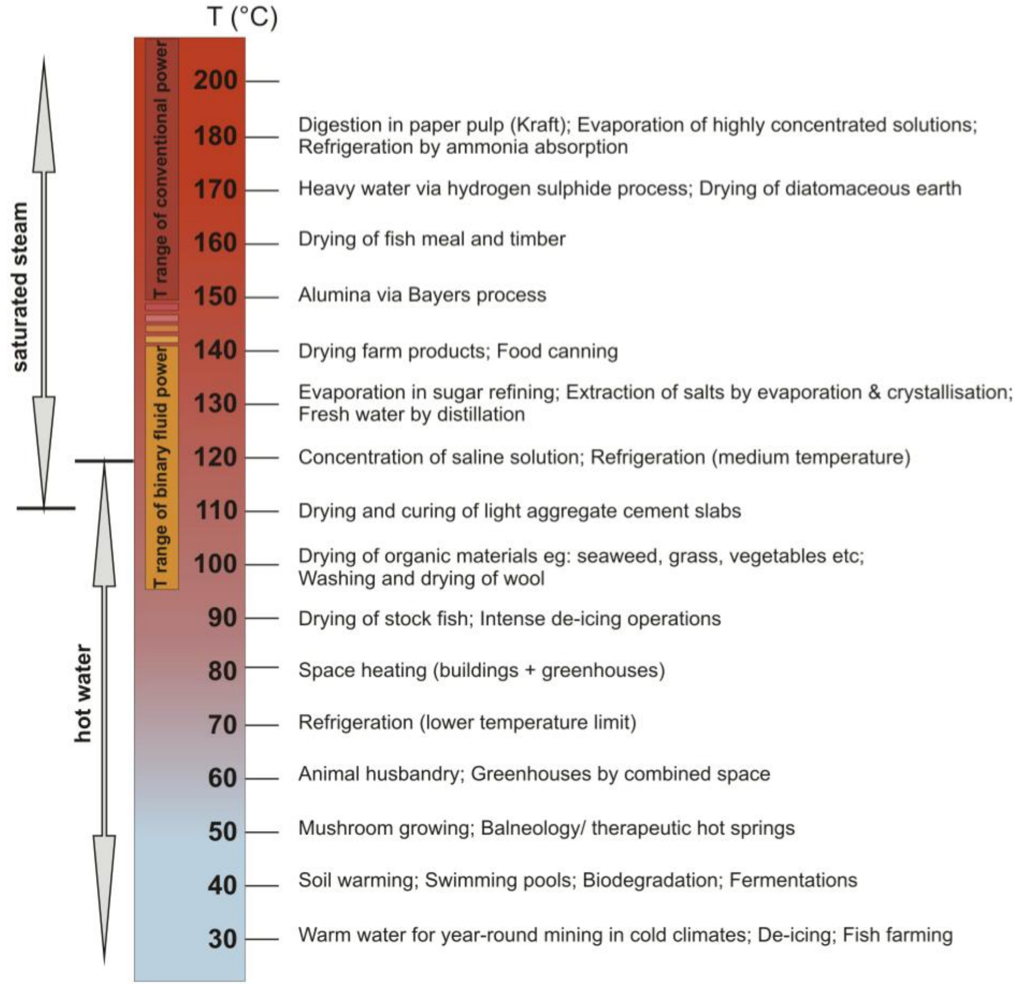


Fig. 4 Thermal energy use temperature distribution from 0 to 260 °C without Electrical System Energy Losses. The end-uses with the largest contribution are annotated. The total thermal energy demand from 0 to 260 °C in 2008 was 22.1 EJ (20.9 quads). Refer to the electronic supplemental information† or the Cornell Energy Institute report[13] for tabulated values of each temperature bin.

Fox et al. 2011

Direct-use applications for geothermal resources



Courtesy of Geoscience Australia - Bridget.Ayling@ga.gov.au (after Lindal,1973)

The geology of geothermal

Capturing the Heat Beneath Our Feet: Cornell's Deep Geothermal Heat Project and its Potential to Change the Energy System

STANSYS

November 2022

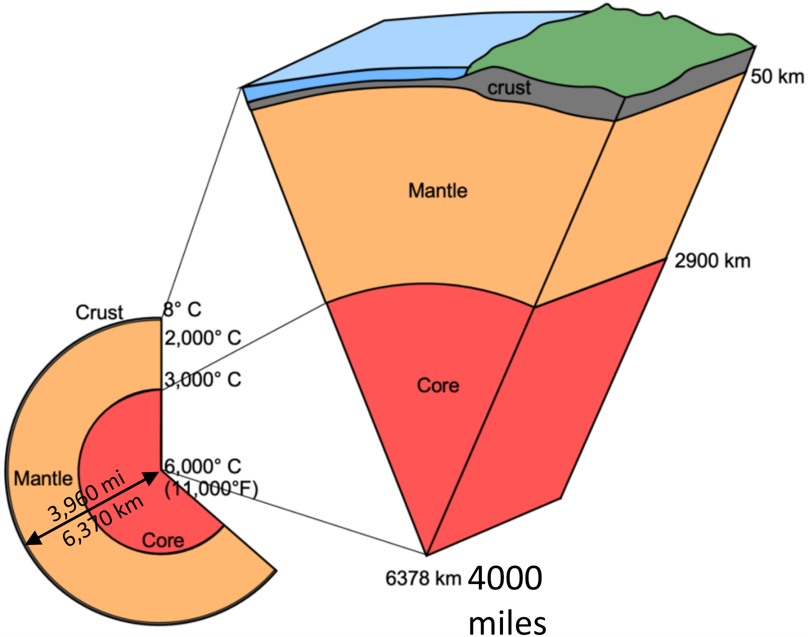
Teresa Jordan

Cornell University

Don Haas

Paleontological Research Institution

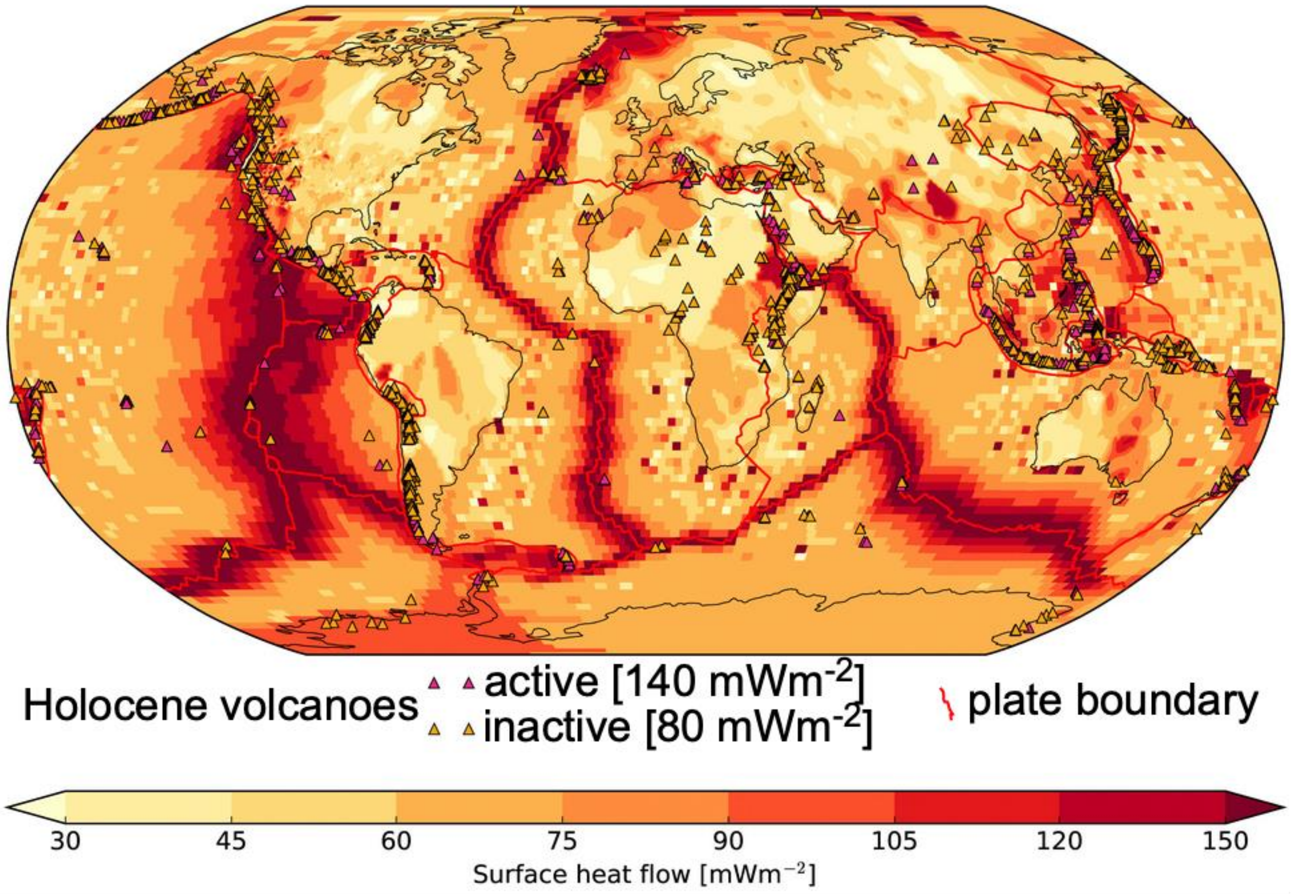
What is geothermal energy and how can we tap it?



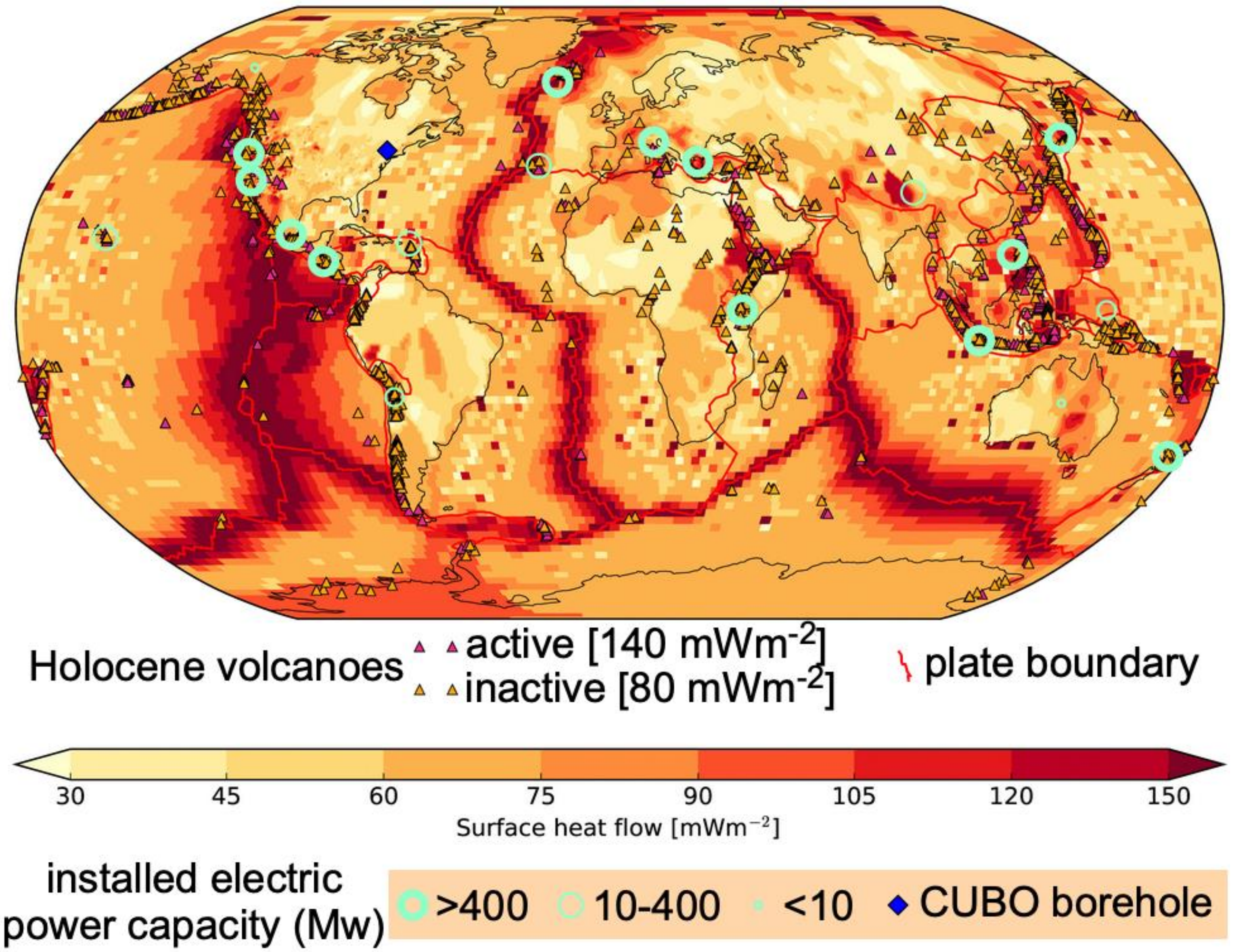
4000 miles

Earth's center is ~6000 °C (10,800 °F)

Heat Flow to Earth's surface varies greatly across planet Earth

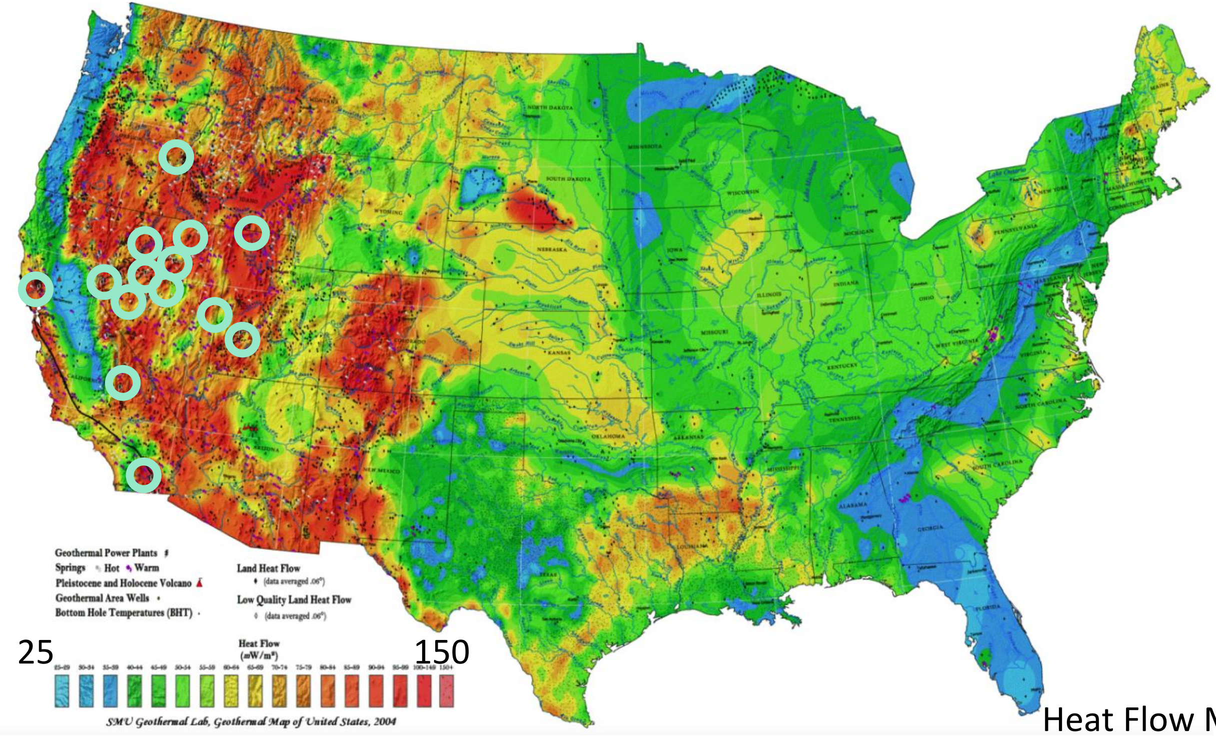


Powerplants that convert Geothermal Energy to electricity are located where the heat flow is most vigorous



Across our continent, heat flow also varies

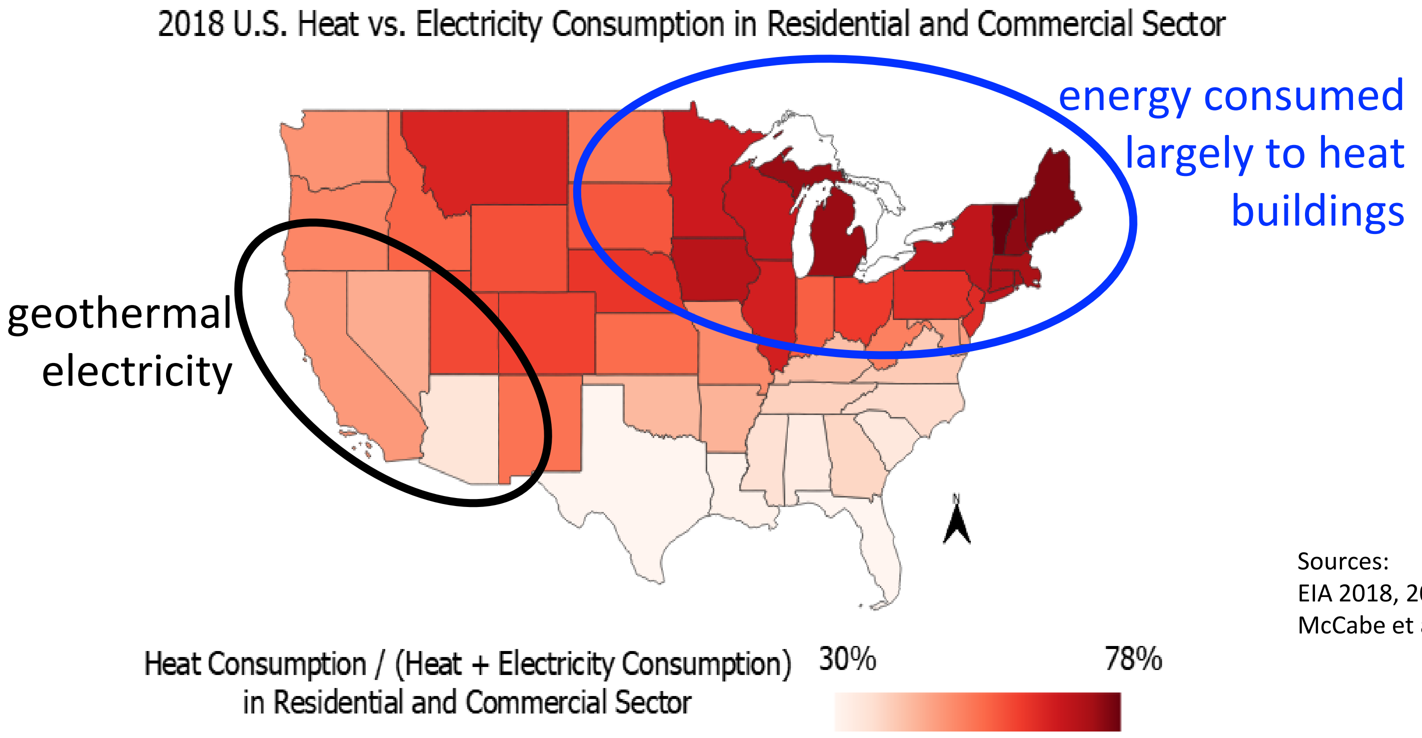
Geothermal power plants produce electricity only in areas with high heat flow



low high

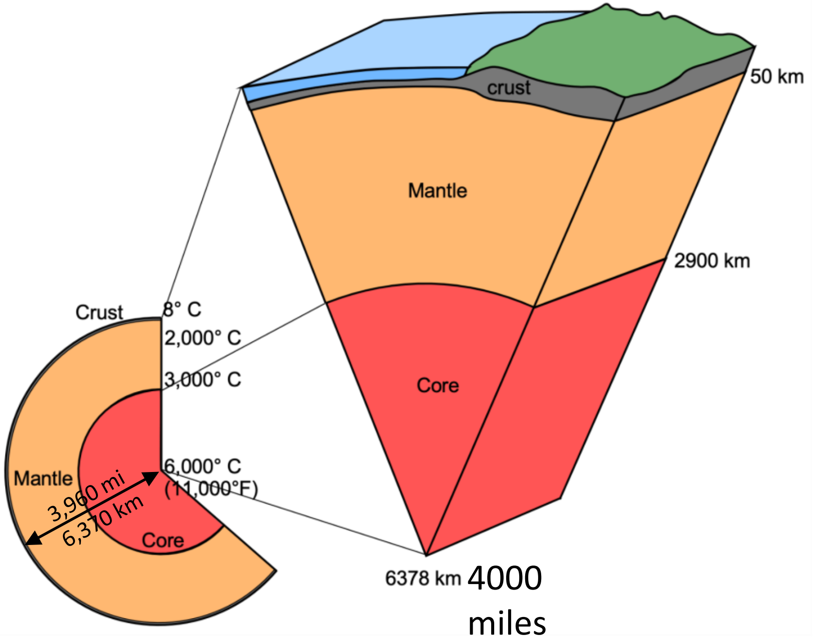
Heat Flow Map of United States
Blackwell & Richards (2004)

Unfortunately, geothermal electric power is not available in the states that consume most of their energy to heat buildings



Sources:
EIA 2018, 2019
McCabe et al. 2016

Yet there IS **geothermal energy *everywhere*.** Can we tap it without converting it to electricity? How about using the heat *directly*?

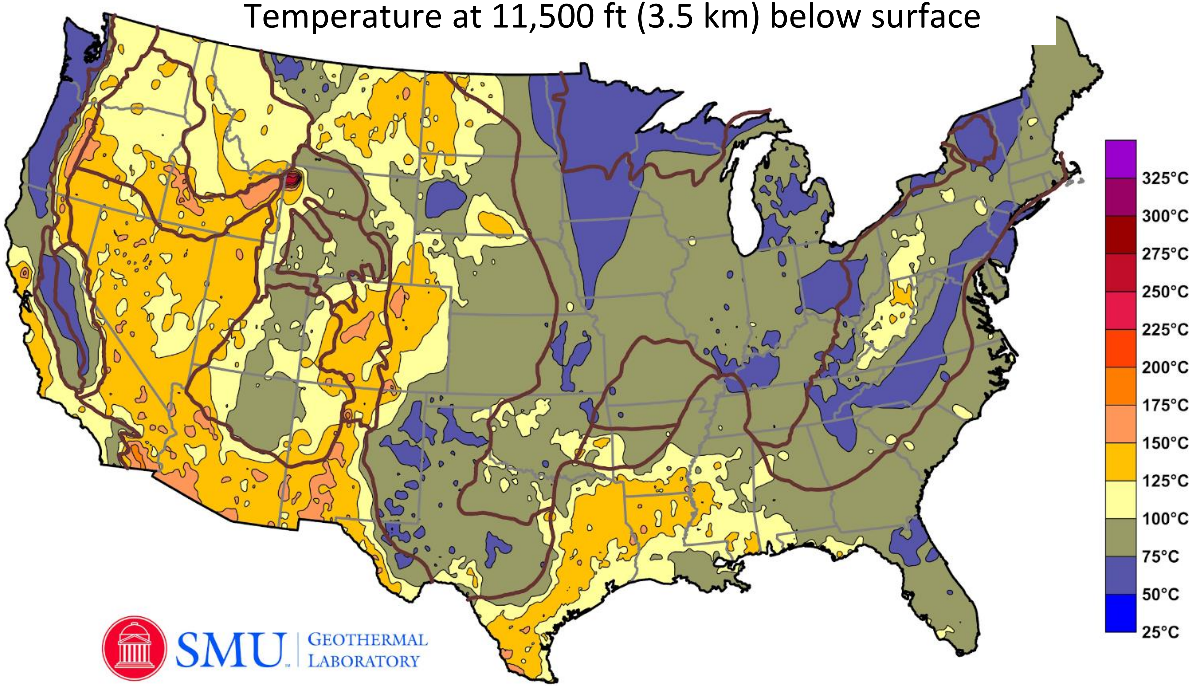


4000 miles

Earth's center is ~6000 °C (10,800 °F)

It can be more useful to think about the depth we need to drill if we want to tap into the hot rocks

Temperature at 11,500 ft (3.5 km) below surface



392 °F } electric power

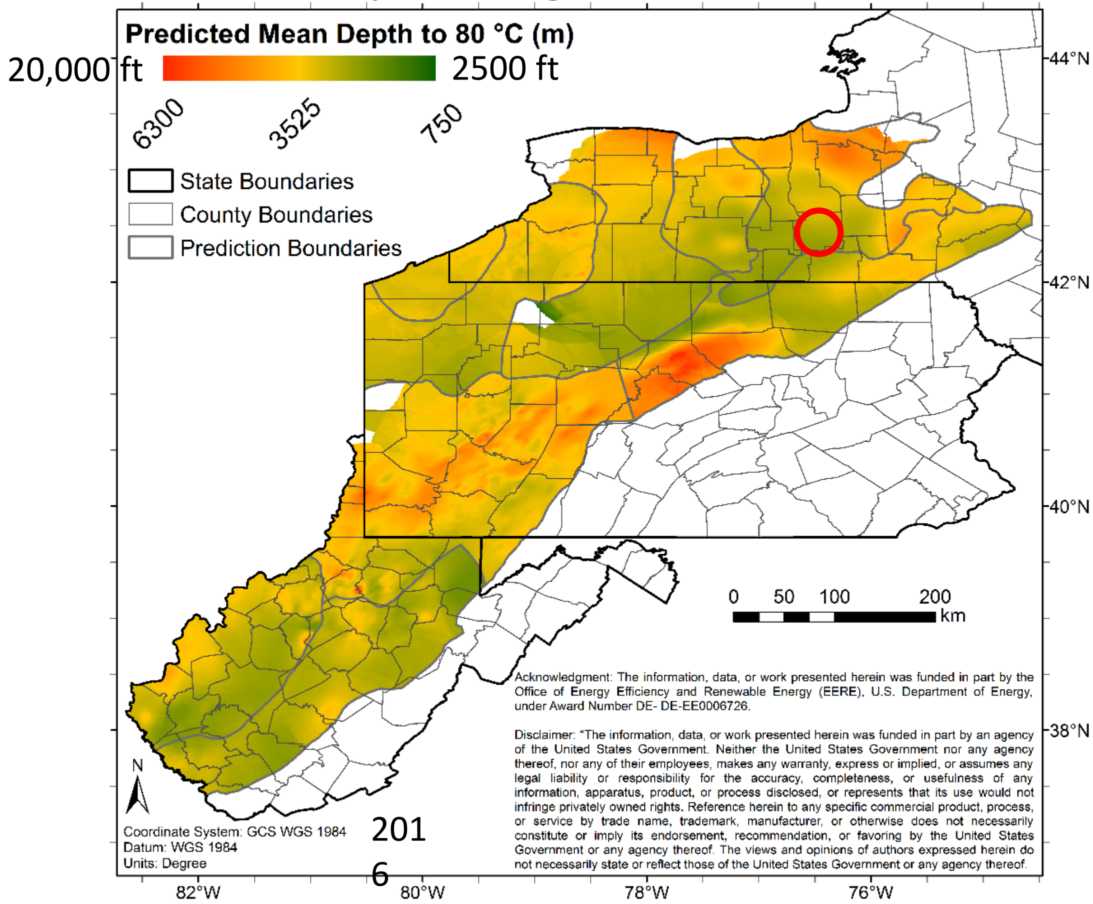
212 °F } direct-use heat

77 °F

SMU | Geothermal Laboratory

~2004

Across New York, Pennsylvania and West Virginia some places require deeper drilling and some less deep drilling to reach rocks as hot as 80 °C (176 °F)

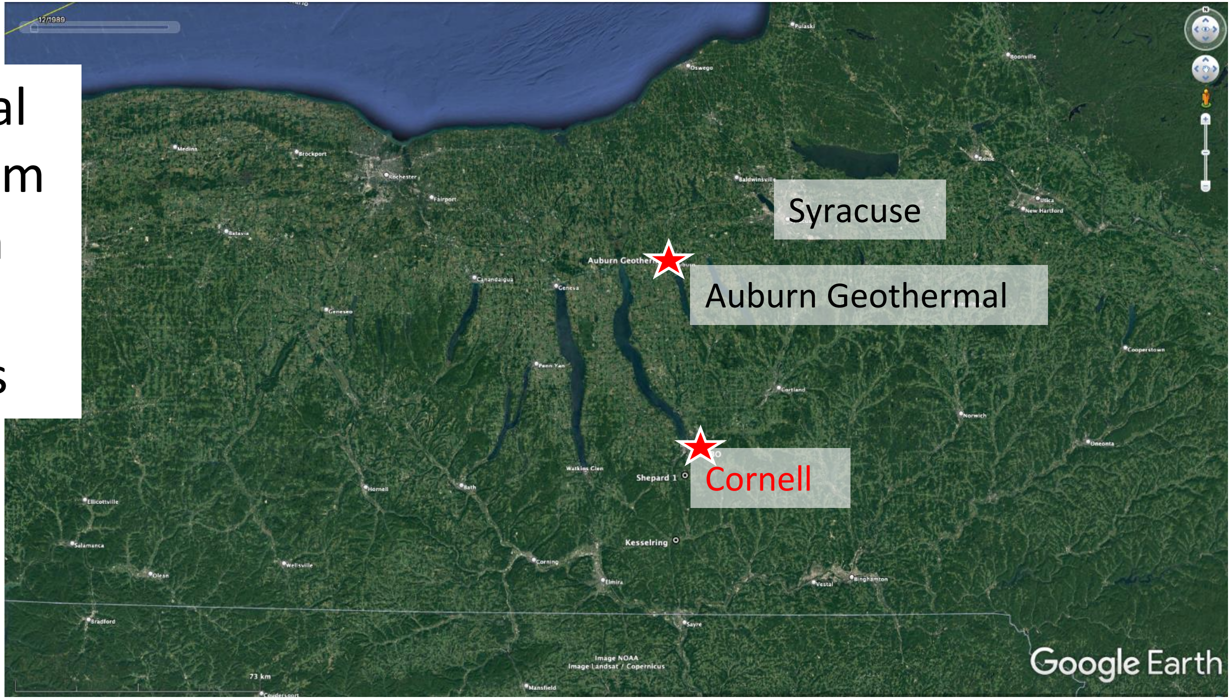


Cornell University

How do we know the gradient of temperature in New York state?

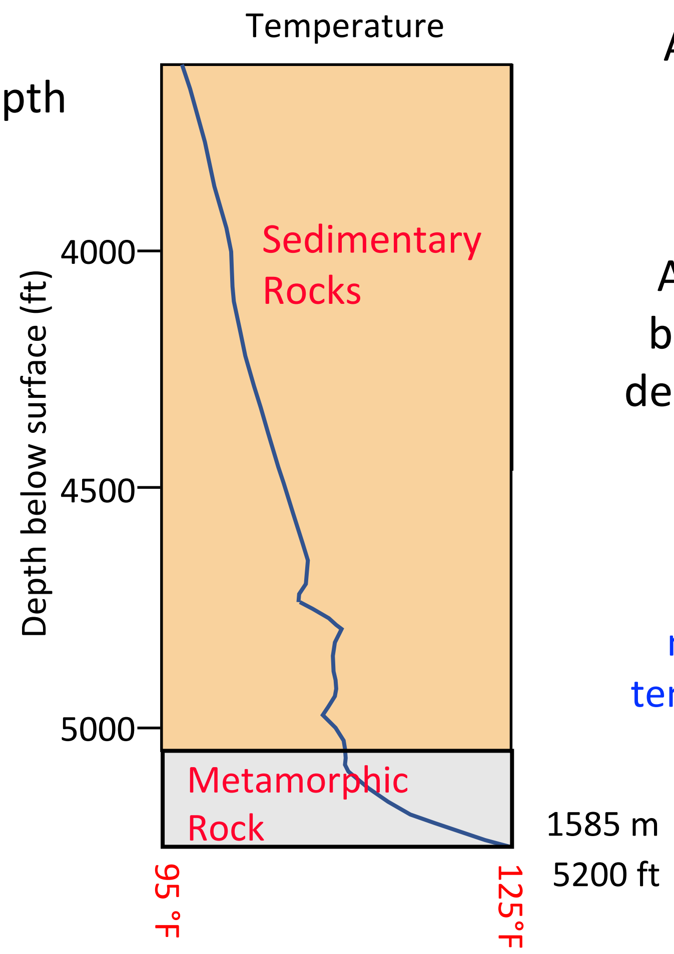
Data come from previously drilled wells, archived by NYS DEC/Museum

A Geothermal Heating System Operated in Auburn, NY in the 1980s



Kesselrin
g

The increase of temperature with increasing depth (geothermal gradient) is apparent in data from Auburn's geothermal well

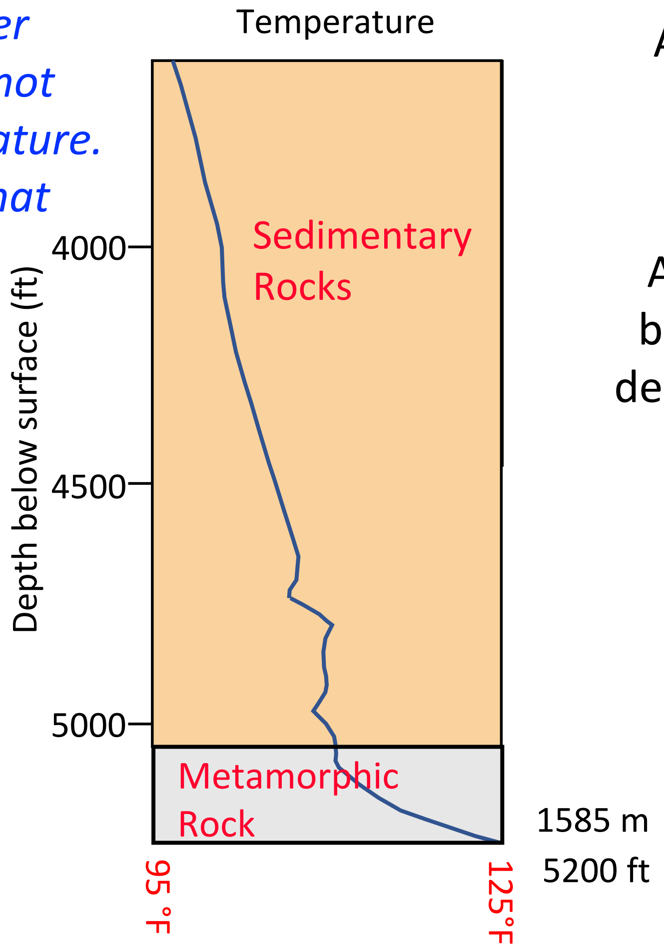


Auburn Geothermal well
Auburn, NY
1983

A rare complete data set, but only to a depth half as deep as Cornell's CUBO well.

The sedimentary rocks are INSULATORS relative to the metamorphic rocks, causing temperature gradient to change near bottom of borehole

These data collected 1 day after drilling ceased. The rocks had not regained their natural temperature. It would take months before that would have fully occurred.



Auburn Geothermal well
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A rare complete data set, but only to a depth half as deep as Cornell's CUBO well.

Why can't we just "tell the temperature"? *(Blame the "mud")*

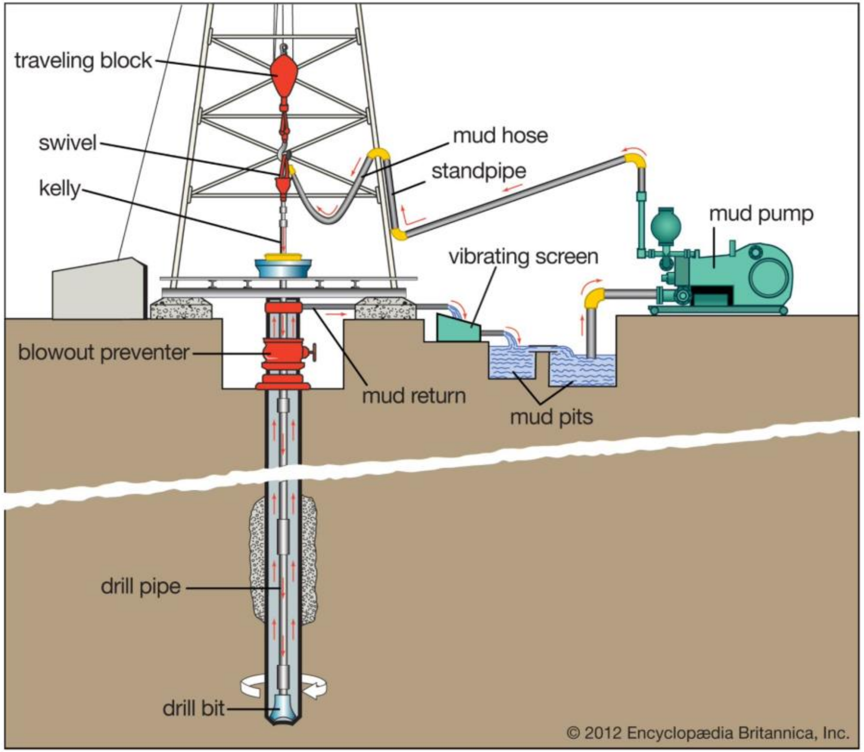
See *deepgeothermalheat.engineering.cornell.edu*, under the heading

What is the temperature in the borehole?

Inside the borehole some feature cause heating and others cause cooling (constantly):

The heating/cooling requires us to understand "mud" circulating in the borehole

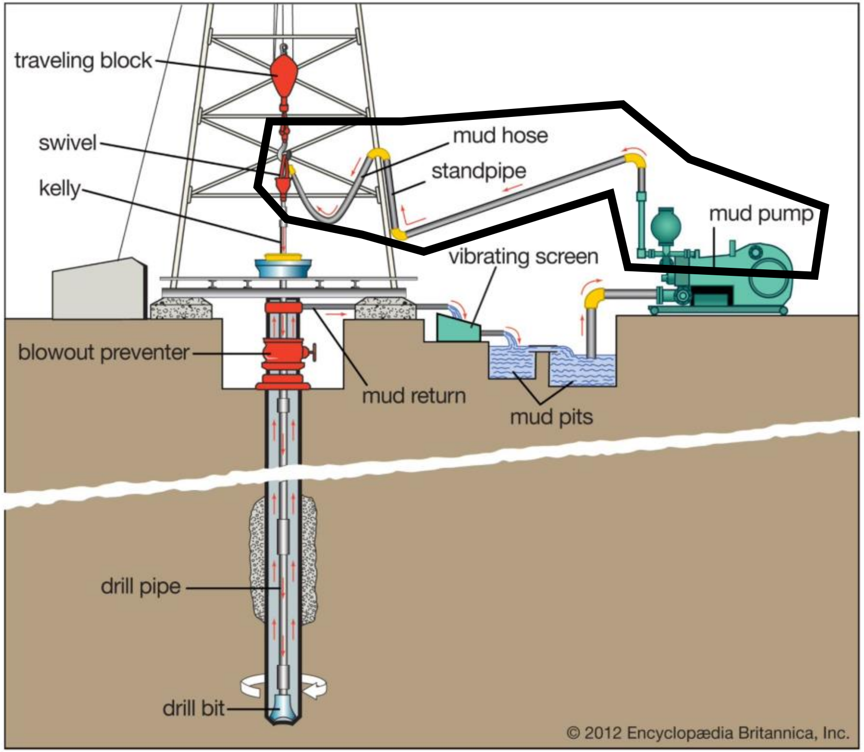
Drilling Mud – the circulation system for the borehole



bins of solids to add to water, to form “mud”

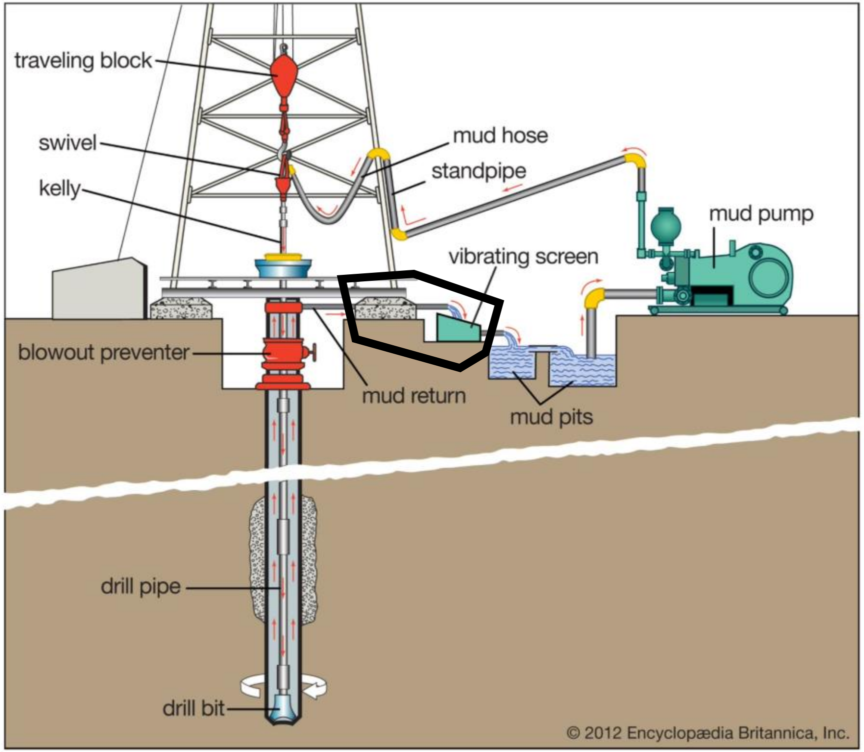
stirring
tank

Drilling Mud – the circulation system for the borehole



mud pumped up into the drill pipe (continuously)

Drilling Mud – the circulation system for the borehole

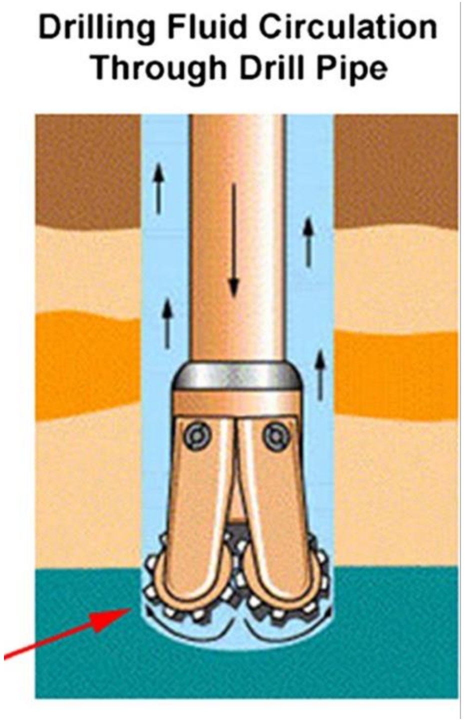


Mud comes back up out of the well,
to be cleaned and recirculated.

Why can't we just "tell the temperature"?

Drill bit – grinding rock creates heat at the well bottom

Drilling lubricant ("mud") – carries "drill-generated heat" out of the hole



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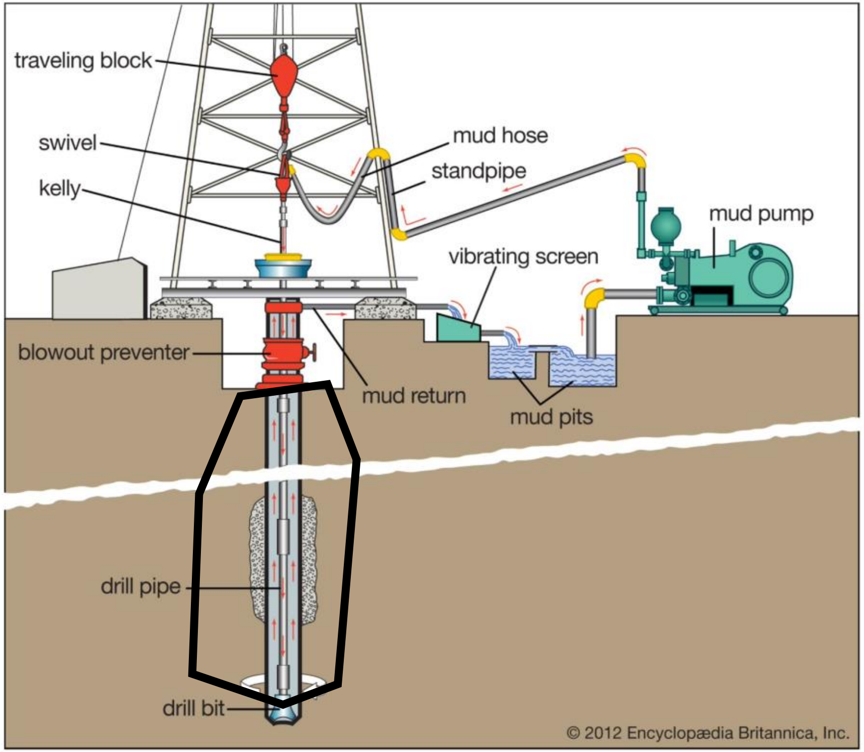


Mud itself gains or losses heat while

1) **going down the well in the middle of the drill stem (frictional heating)**
2) coming up the well outside of the drill stream (frictional heating)
3) exchanging heat with the rock walls while coming up: rocks are colder than the mud at shallow depths, and hotter than the mud in deeper parts of the well

Why can't we just "tell the temperature"?

See *deepgeothermalheat.engineering.cornell.edu*, under the heading

What is the temperature in the borehole?

Inside the borehole some features cause heating and others cause cooling (constantly):

Drill bit – grinding rock creates heat at the well bottom

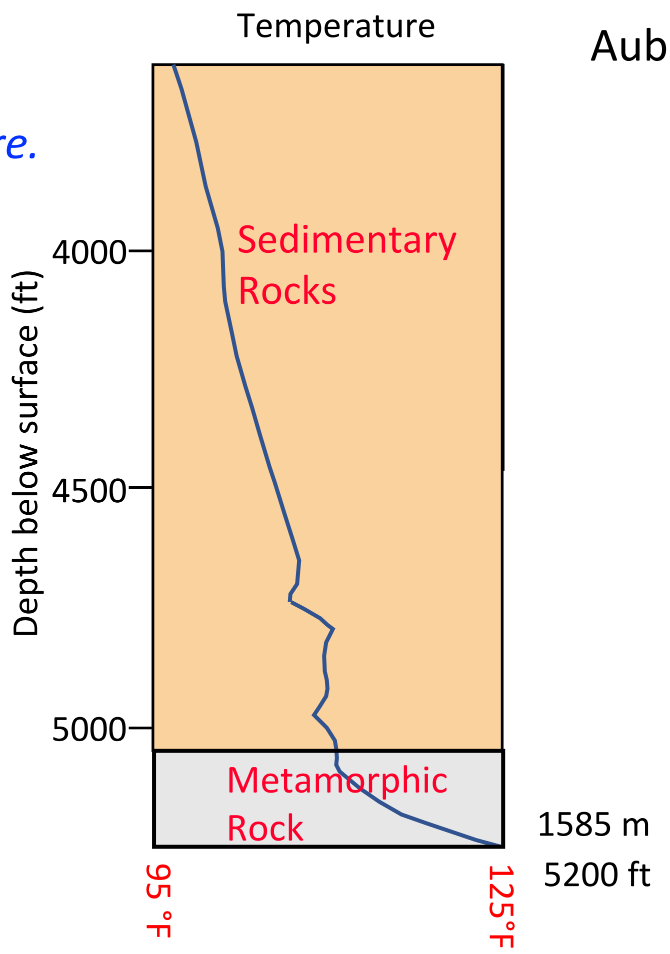
Drilling lubricant ("mud") – it brings "air temperature" down to the bottom of the hole, and carries "drill-generated heat" out of the hole

Mud itself gains or losses heat while
1) going down the well in the middle of the drill stem (frictional heating)
2) coming up the well outside of the drill stream (frictional heating)
3) exchanging heat with the rock walls while coming up: rocks are colder than the mud at shallow depths, and
hotter than the mud in deeper parts of the well

It's complicated!

These data collected 1 day after drilling ceased. The rocks had not regained their natural temperature. It would take months before that would have fully occurred.

→The Equilibrium Temperature is not accurately known.



Auburn Geothermal well
Auburn, NY
1983

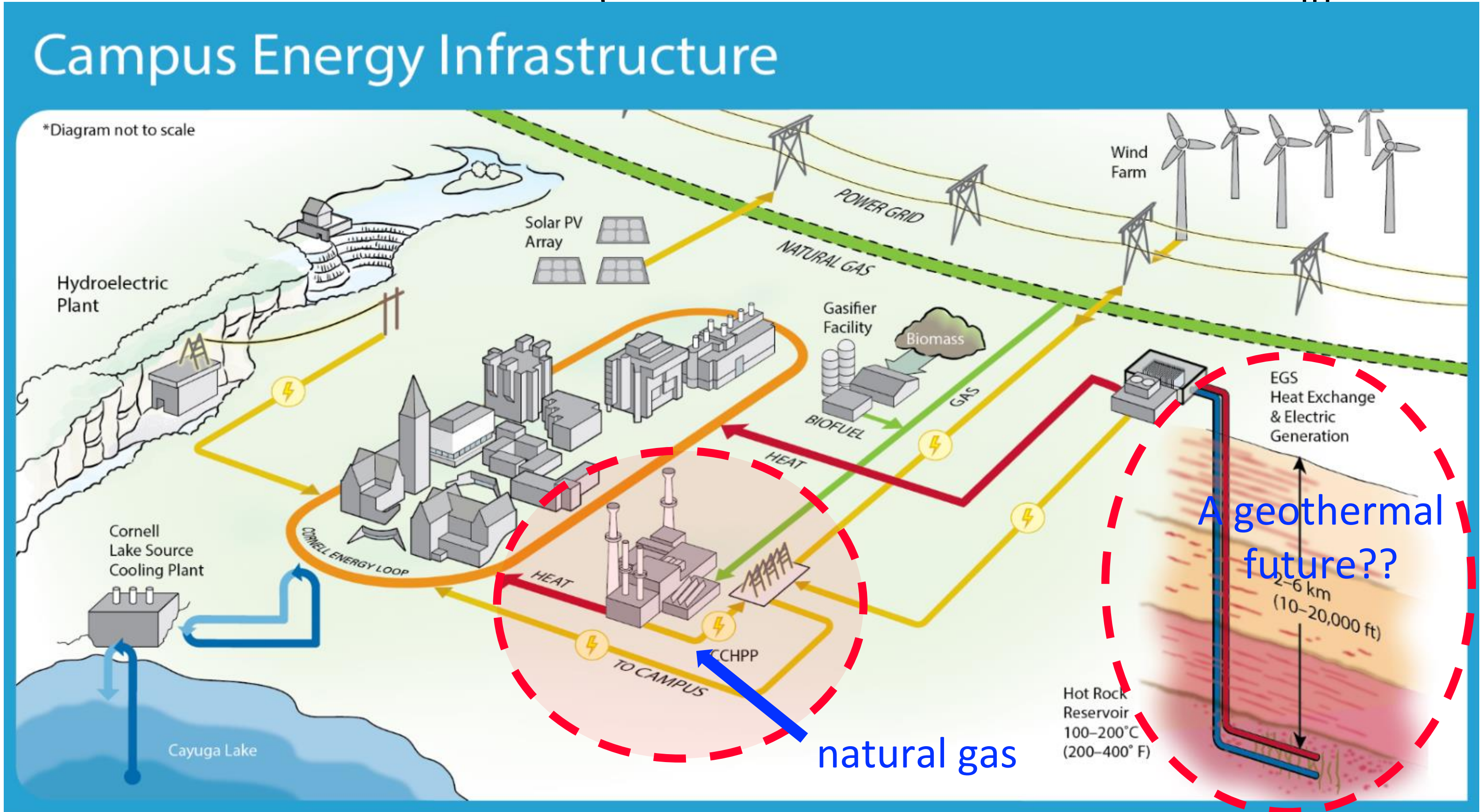
Cornell University's Problem starts with a common situation in northern tier of U.S. states

Located in a cold climate, large buildings need to be heated for

~ 8 months per year

Cornell's Vision to reach Net Zero Energy Campus starts from *current campus annual consumptions of*

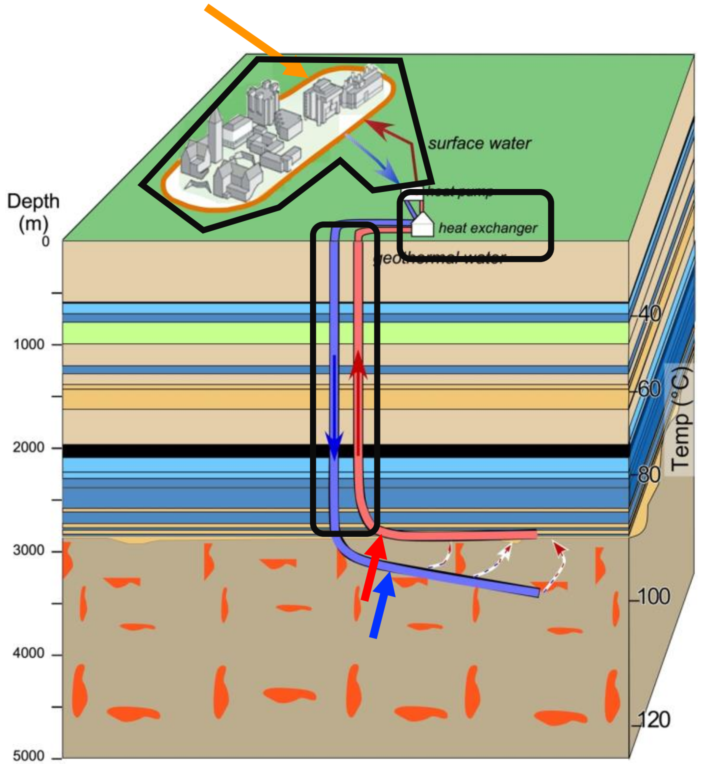
Electric: 250 Gwh_e Heat: 380 GWh_{th}



What is Earth Source Heat?

Earth Source Heat is Cornell's vision for a campus-wide geothermal heating system that replaces fossil fuels with renewable heat.

How Does it Work?



- Uses existing **district energy system** with hot water
- **Two (or more) deep wells** are drilled to where rocks are hot (>160°F)
- **Hot water is pumped from one**, and cooled water is returned to the rocks through the other
- **Heat is extracted** from the geothermal water and transferred to surface water via a heat exchanger
- **The heated surface water circulates** through the pipes of the campus heating system

Earth Source Heat

Nice concept. Will it work?

Biggest Challenges:

1) plumbing in the rocks? – will water flow throw the rocks to harvest the heat?

2) money (costly to access the heat)

Earth Source Heat: A Phased Approach

- Preparatory Phase (2009-2021)
- Phase I: Exploration/Test Well Phase
  - Ia: Drill borehole, measure rock + fluid properties

Today (Nov. 2022)

  - Ib: Design demonstration wells, evaluate benefits & risks
- Phase II: Demonstration project
  - IIa: Drill first well, stimulate fracture set, test & analyze
  - IIb: Drill second well, build surface infrastructure, supply heat to east campus
- Phase III: Drill other well pairs and complete surface infrastructure

Earth Source Heat: A Phased Approach

- Preparatory Phase
- **Phase I: Exploration/Test Well Phase**
  - **Ia: Drill borehole, measure rock + fluid properties**
  - **Ib: Design demonstration wells, evaluate benefits & risks**

  2022
- Phase II: Demonstration project
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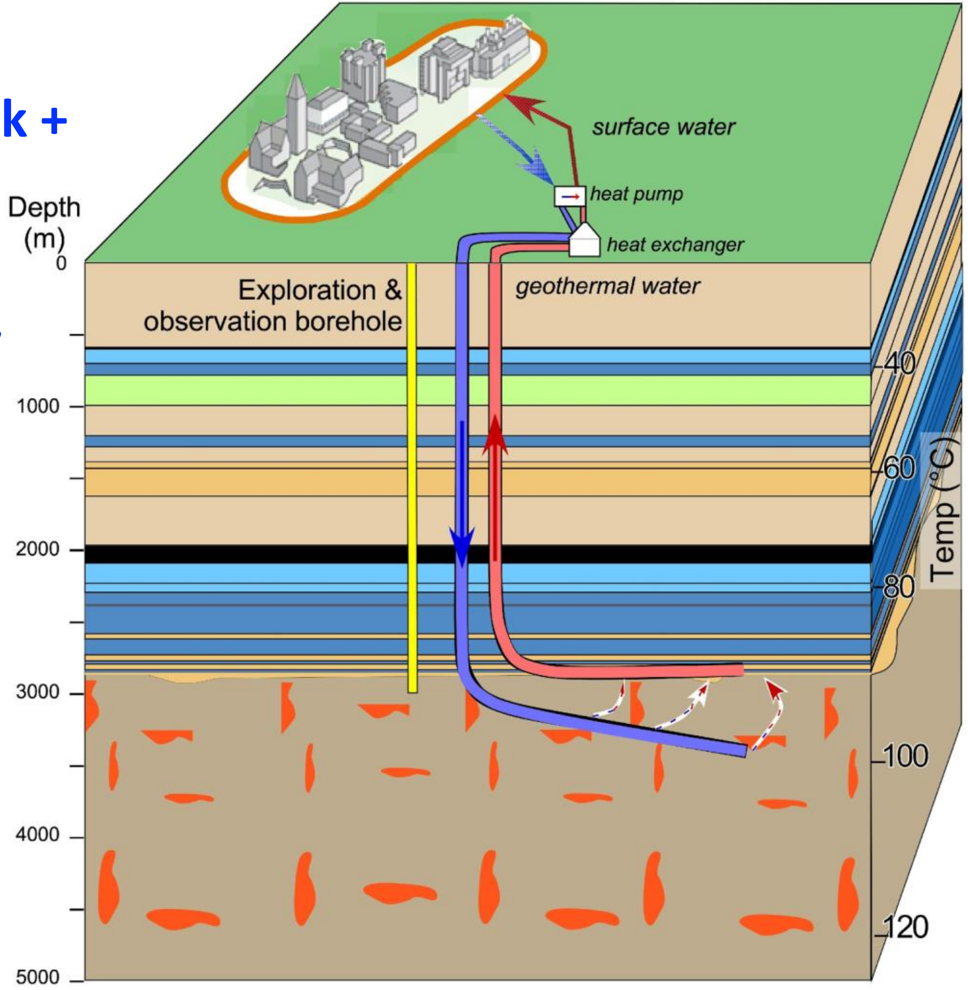
Phase I: Exploration/Test Well Phase

- **Ia: Drill borehole, measure rock +**

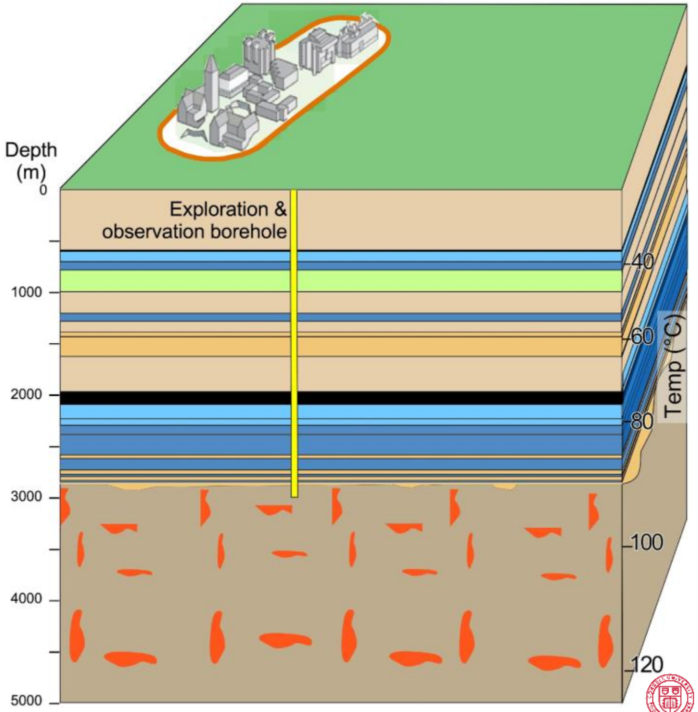
- *ells,*

8 August 2022, Ithaca NY



2022 -- CUBO

Designed to gather data in order to analyze design and risks.
Planned to monitor subsurface conditions later, if ESH moves forward to demonstration.

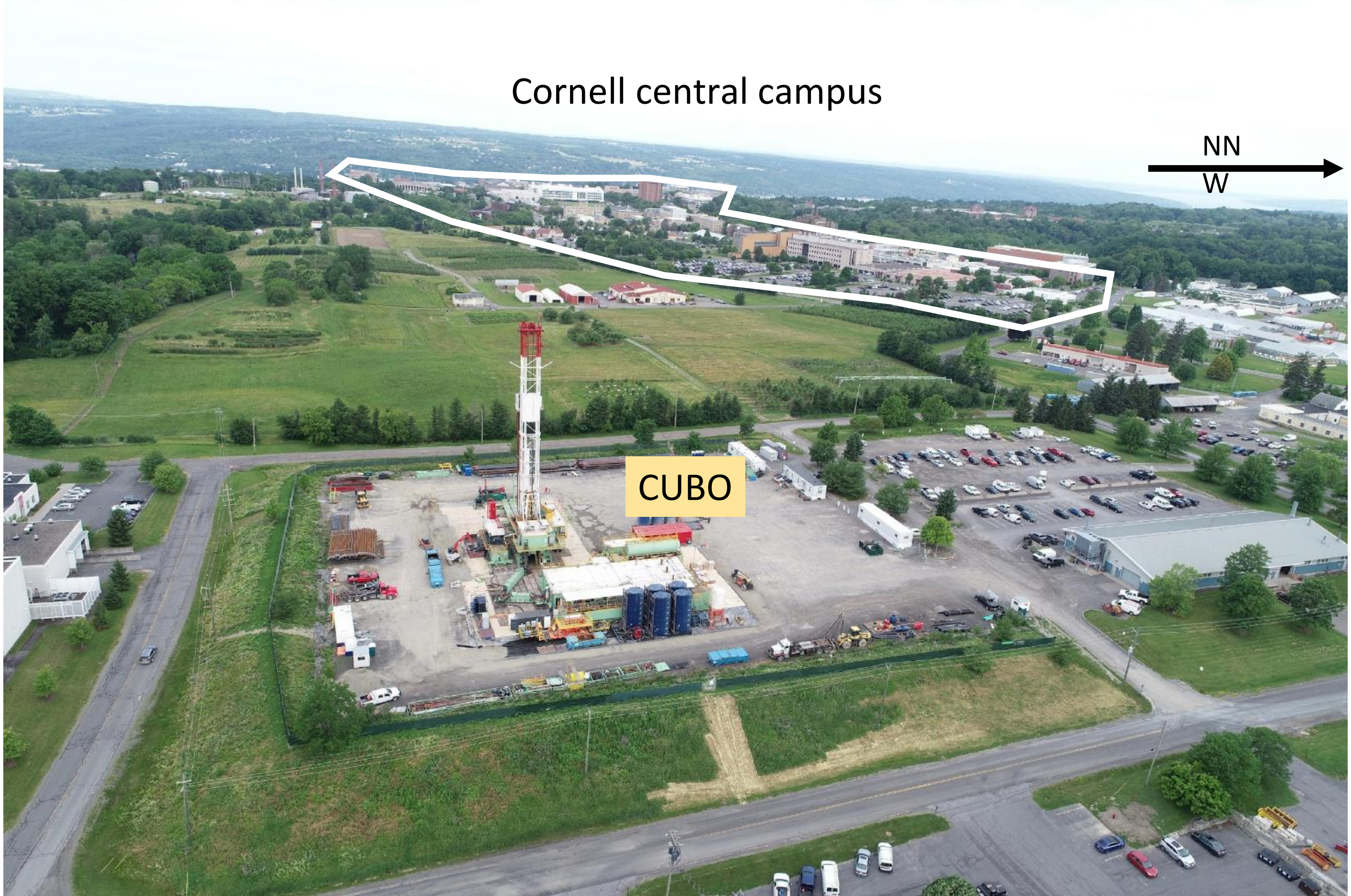


Drilling Phase

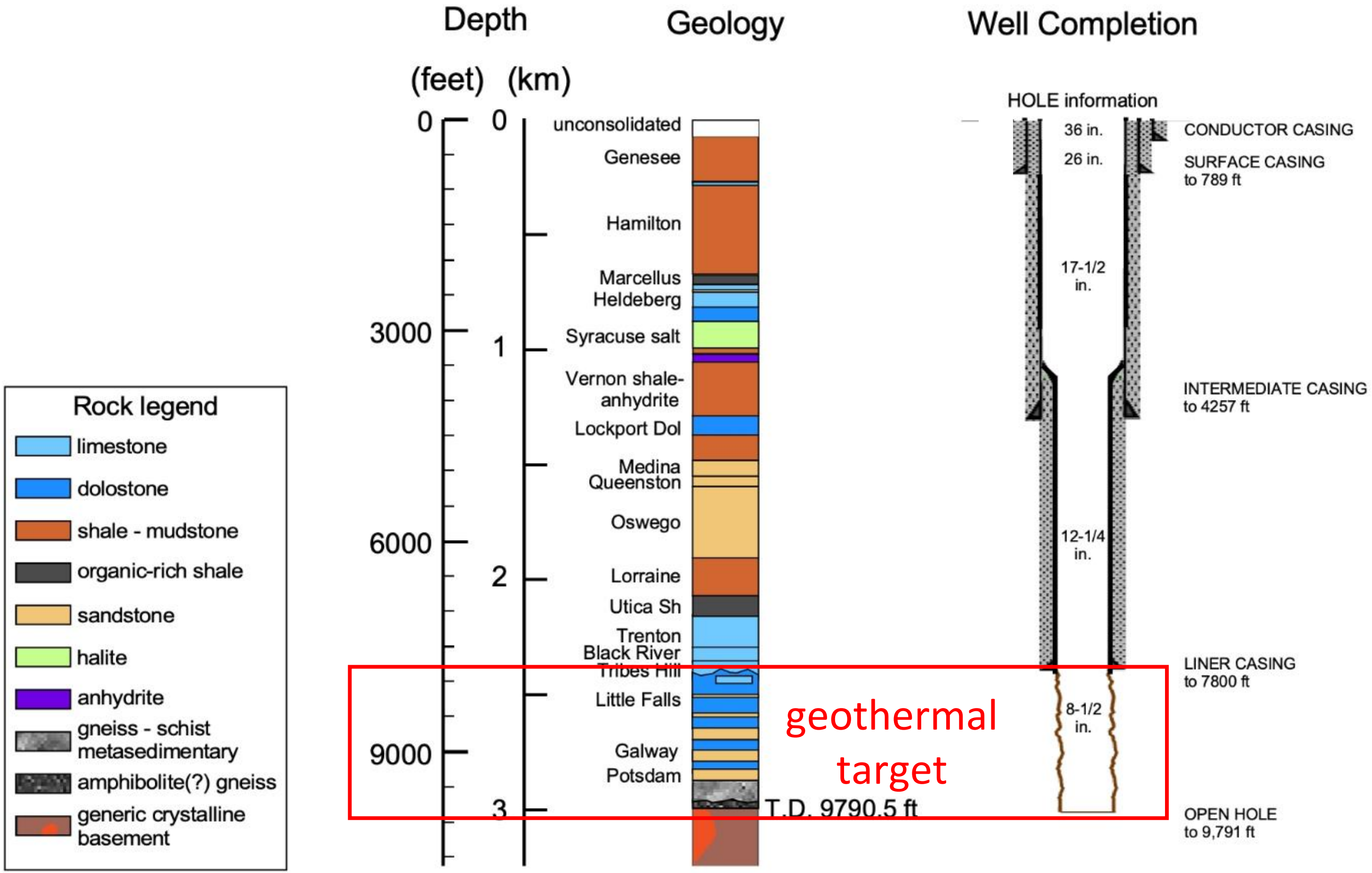
- Geophysical rock properties
- Temperature
- Fracture characteristics
- Rock samples
- Fluid samples
- Hydrogeologic tests
- Stress tests

Observatory Phase

- Fiber optic temperature profiler
- Borehole seismometer

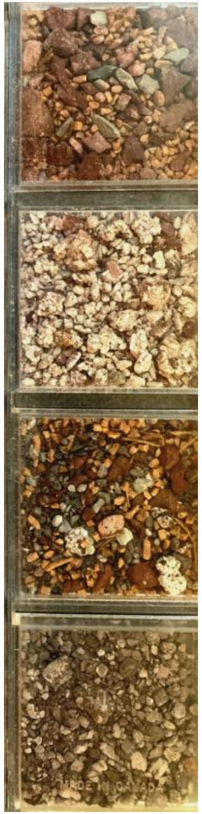

Cornell central campus
NN
W
CUBO

Cornell University Borehole Observatory

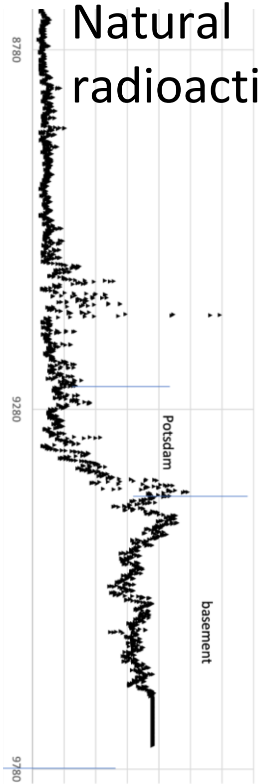


Ready for Geological Analysis: Data sets are not as simples as an outcrop, yet reveal compositional change and the organization within the rocks

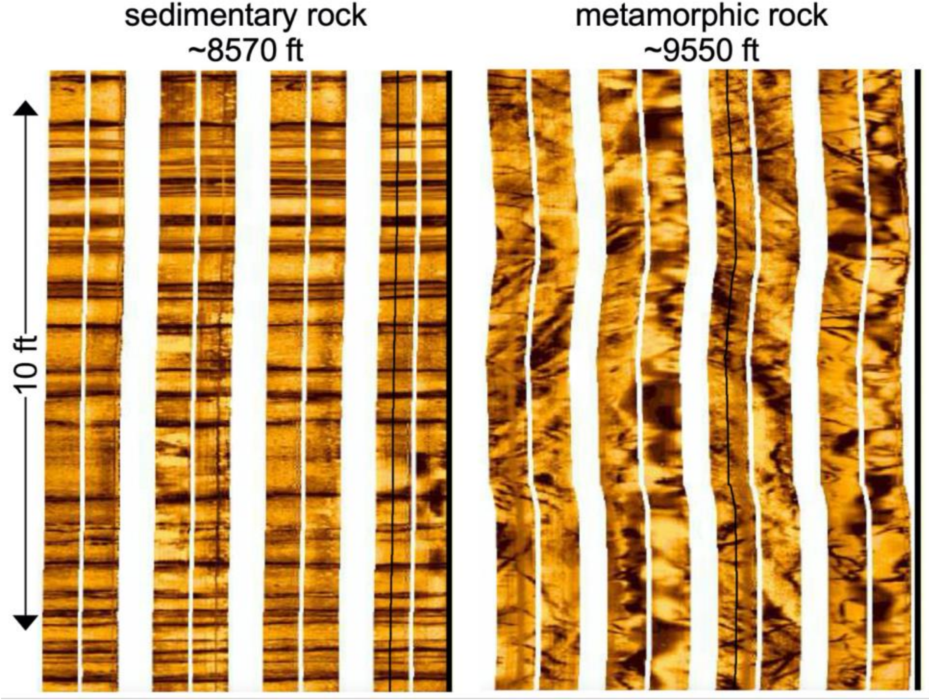
Physical samples of drilled rock



Natural radioactivity

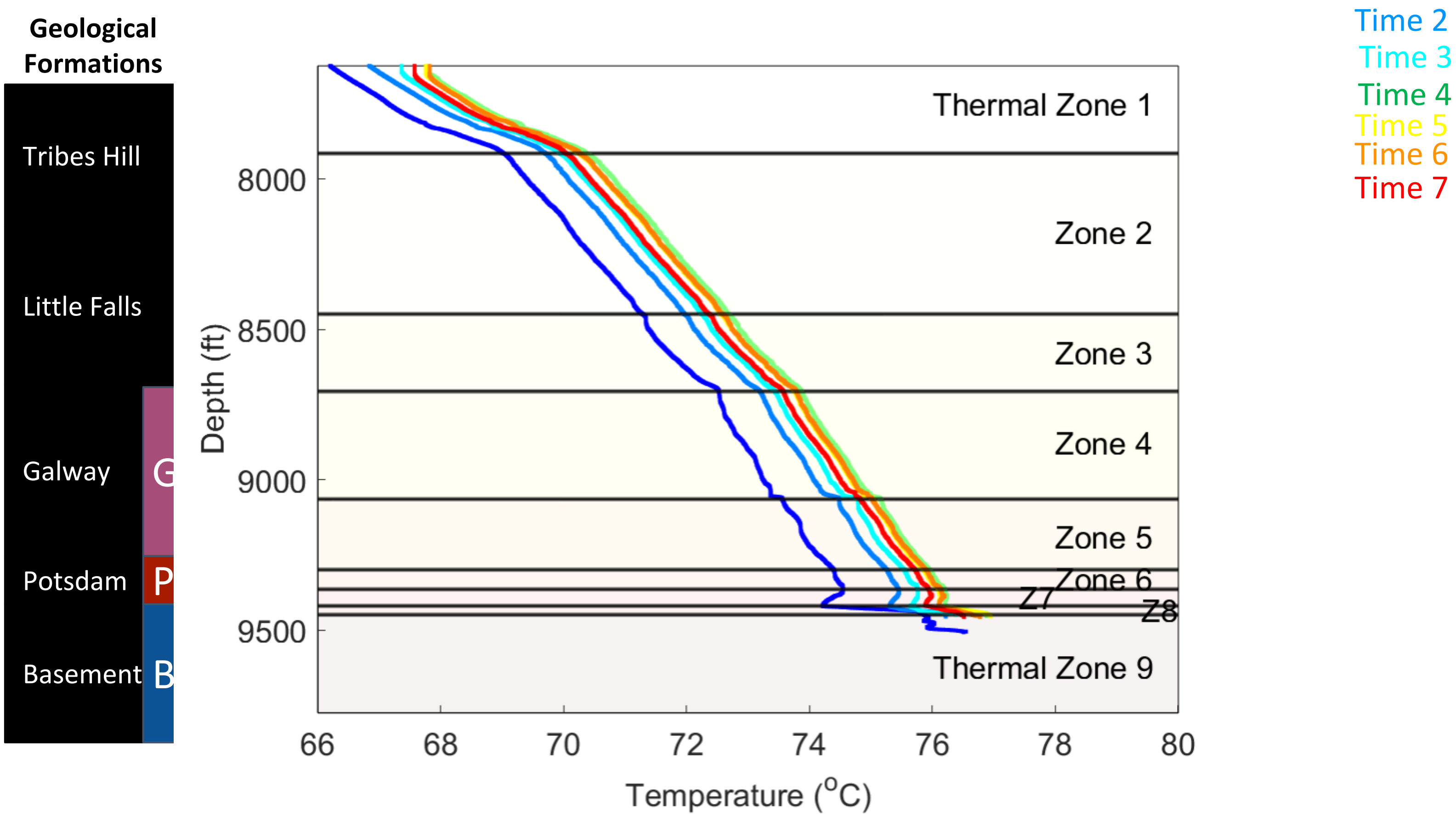


Images of Resistivity Variation



What will be the Equilibrium Temperature after more time passes?

CUBO Borehole Temperature Data Immediately After Drilling



Cornell Mission alignment

(Education, Research, Extension)

achieved in part through **student participation in the 2022 CUBO operations team**

Environmental monitoring

Eric (and George)

Zachary

Sample catching/management

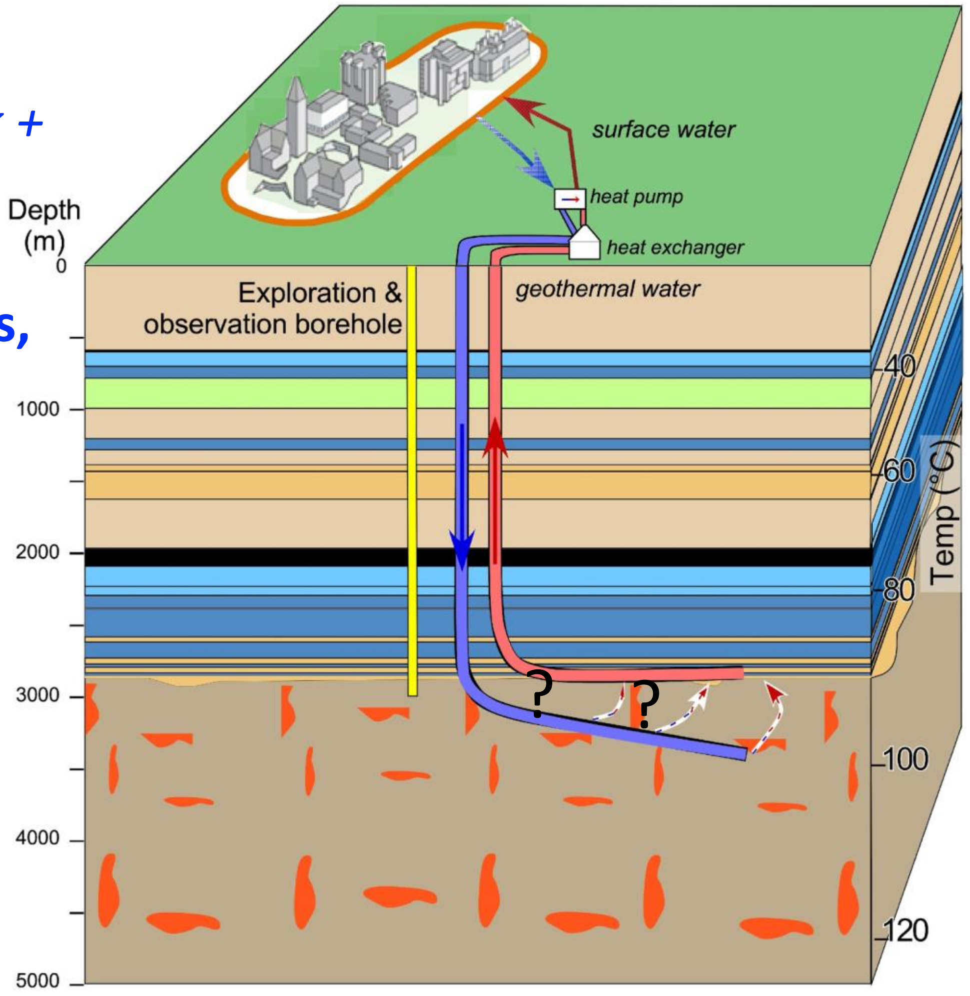
<u>Students</u>
Roberto
Reeby
Daniela
Madeline
Sean
Ivan

Juliette

Phase I: Exploration/Test Well Phase

- *Ia: Drill borehole, measure rock + fluid properties*
- **Ib: Design demonstration wells, evaluate benefits & risks**

coming soon…



Careers

Geothermal career possibilities

- ~50 contractors with a wide range of kinds of educational preparation
  a. From completing formal education at 9th grade to PhDs
  b. (I'll be adding more here!)
- The example of drillers
  a. See clip P1000604 for the voice of one driller
- The broader context