Geothermal Resources of Colorado and the Potential for Electrical Power Generation*

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Abstract

Geothermal resources in Colorado are currently used directly for pools, spas, greenhouse agriculture, aquaculture, space heating, and district-wide heating, but not for electrical power- a goal for future alternative energy resources. Several lines of evidence, including geology, groundwater geochemistry, and geophysical data, indicate that Colorado is prospective for geothermal resources suitable for electrical generation. These include:

1) High heat flow - Colorado has the second most aerially extensive heat flow anomaly in the U.S.
2) Quaternary faulting - Colorado has over 90 known faults < 1.8 Ma.
3) Neogene and younger volcanism - Colorado has over 1,200 mi^2 of Neogene or younger (<22.9 Ma) volcanic deposits with five Quaternary volcanoes.
4) Rift zone tectonics - Colorado hosts the Rio Grande rift, which is prospective for geothermal resources. New aeromagnetic studies in the rift by the U.S. Geological Survey are helping to define the character of faulting and volcanic deposits.
5) A low-velocity seismic P-wave anomaly in central Colorado, the Aspen Anomaly, indicates a significant area of relatively low density and hot upper mantle. This could contribute to higher heat flow in the area.

Colorado sedimentary basins also have geothermal potential in the range of existing oil and gas wells. The Denver Basin has bottom-hole temperatures ranging between 200-250°F at roughly 10,000-11,000 ft. The San Juan Basin, south of Durango, has temperatures ranging from 150-250°F at depths between 6,500-9,000 ft. Portions of the Raton Basin west of Trinidad display high geothermal gradients.

Using data from thermal springs and wells, geothermal test holes, mineral exploration holes, and oil and gas wells, the Colorado Geological Survey has constructed statewide maps of heat flow and geothermal gradient to identify the most prospective areas for geothermal resource development. These maps help identify prospective locations for electrical power generation from conventional hydrothermal systems, as well as areas where enhanced geothermal system (EGS) technology can be applied to tap geothermal resources deeper in the earth's crust. A recent EGS study ranks Colorado fifth among the continental U.S. states in total heat energy available below 10,000 ft deep and indicates that Colorado has more heat energy available for EGS systems in the depth range of 10,000-13,000 ft, the shallowest depth range considered by the study, than any other state in the U.S.

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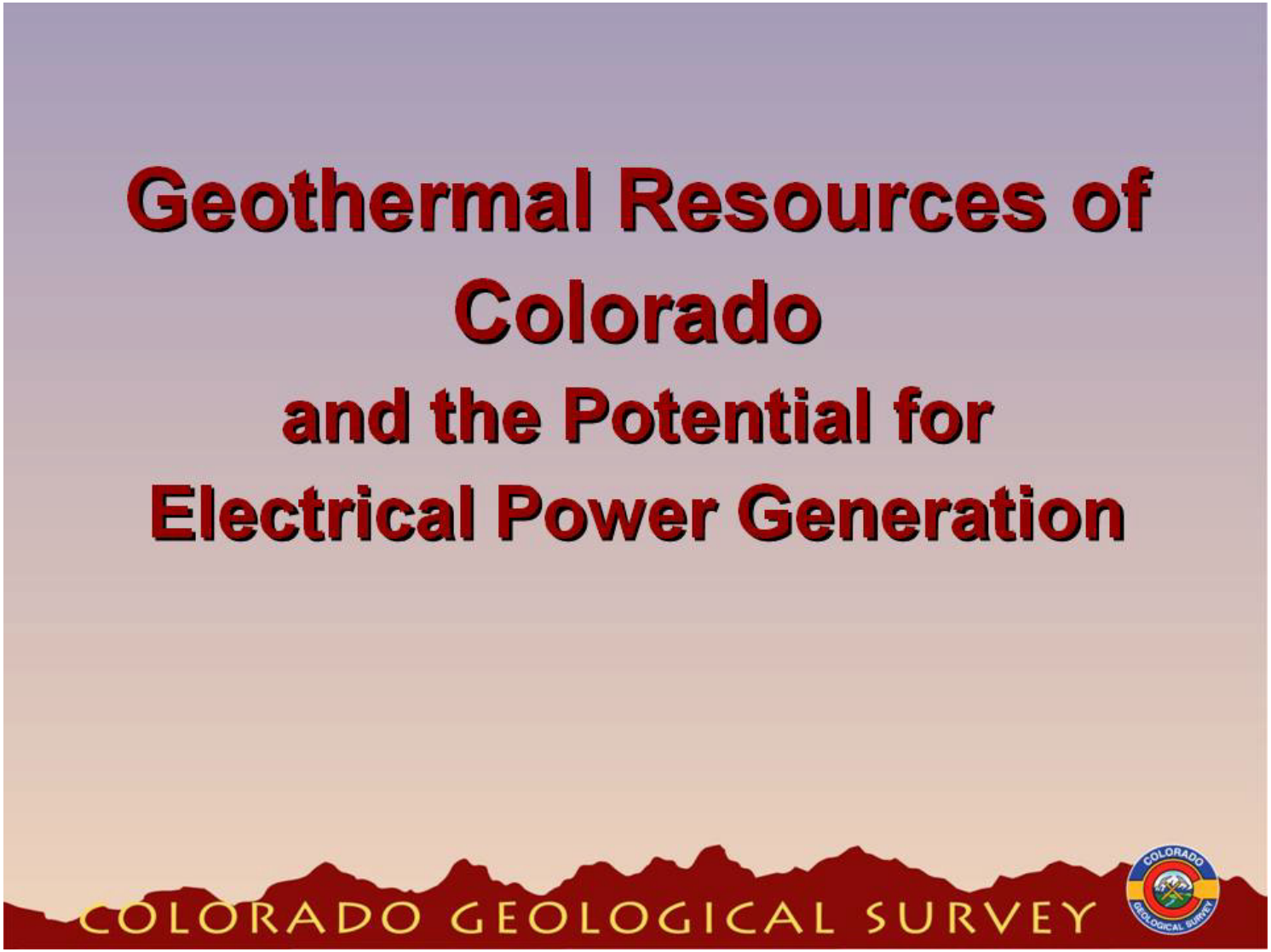

Notes by Presenter:
As of 2005, renewable energy sources supplied almost 9 percent of the electrical power supply in the U.S. Of the total renewable energy sources, conventional hydroelectric energy supplied 80.8 %, biomass 9.2 %, wind 5.4 %, geothermal 4.4 % and solar 0.2 %. Most of the U.S.'s geothermal activity takes place in California and Nevada, but Alaska, Hawaii, and Utah also have some generation. New Mexico, Idaho, and Oregon have new projects underway in various stages of development.

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Currently, geothermal resources in Colorado are used directly for recreation (pools/spas), greenhouse agriculture, aquaculture, space heating, and district-wide heating – but not for electrical power. Several lines of evidence indicate that the geothermal potential for Colorado may be underestimated in regard to electrical generation:

- High heat flow – Colorado has the second largest heat flow anomaly in the U.S.
- Quaternary volcanism (occurring within the last two million years) – Colorado has five such volcanoes
- Quaternary faulting (younger faults have more potential) – Colorado has over 90 such faults
- Rift zone tectonics in the San Luis Valley and upper Arkansas River basin.

A low-velocity seismic P-wave anomaly in central Colorado, The Aspen Anomaly, indicates a significant area of less dense, warmer upper mantle. This could contribute to higher geothermal gradients in the area.

Two sedimentary basins in Colorado indicate potential for geothermal resources at depths in the range of existing oil and gas wells. Oil and gas fields in the Denver Basin and have recorded bottom-hole temperatures that range between 200-250°F at roughly 10,000-11,000 feet. Similarly, bottom-hole temperatures in the San Juan Basin south of Durango have recorded temperatures ranging from 150 – 250°F at depths of between 6,500 – 9,000 feet. Twenty of these wells have temperatures of 250°F or more

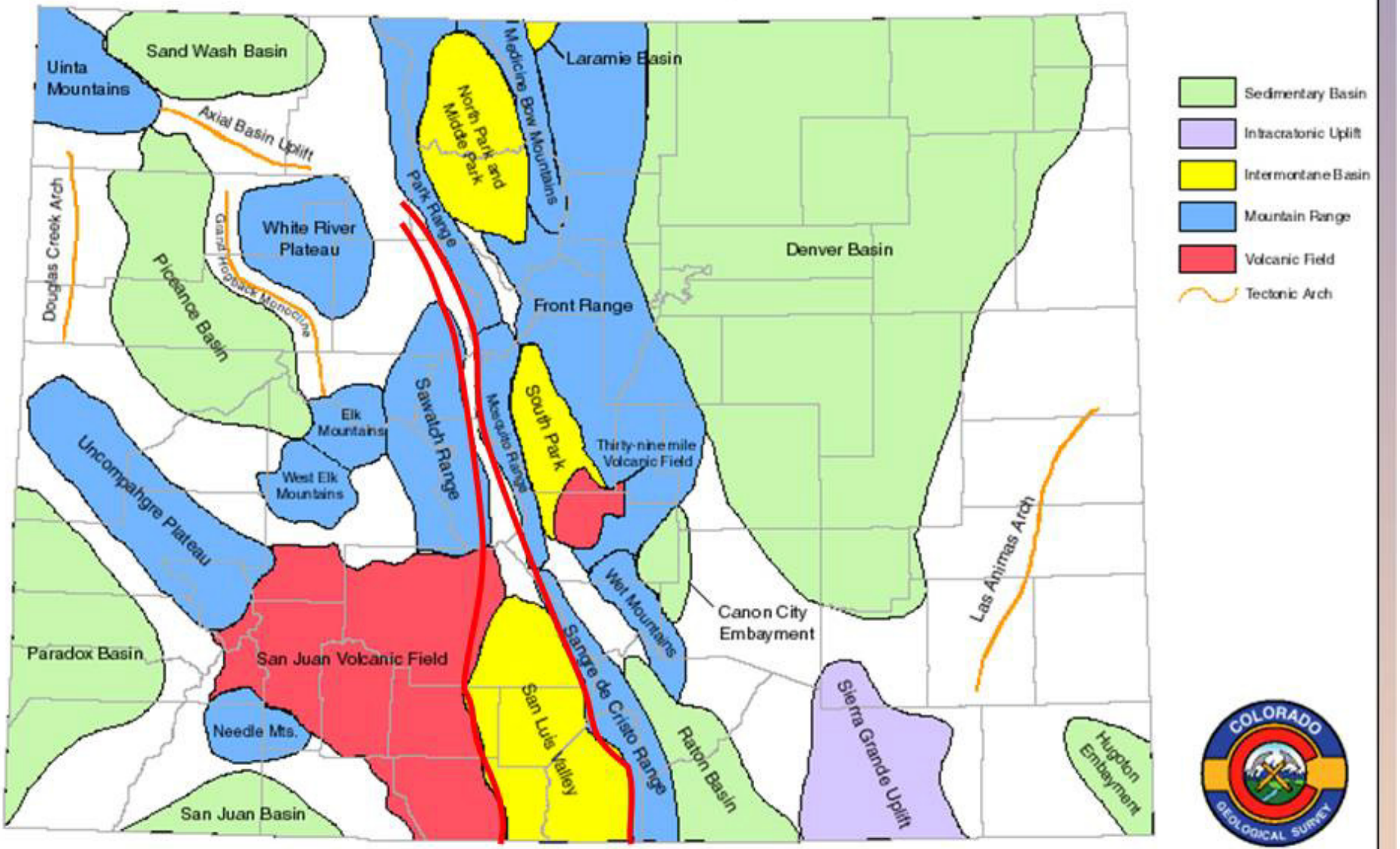
The Colorado Geological Survey, using data from thermal spring and wells, mineral exploration holes, and geothermal test holes, has constructed statewide maps of geothermal heat flow and geothermal gradient to identify the most prospective areas for geothermal resource development. These maps can be used to assist in identifying locations for conventional shallow hydrothermal systems as well as areas where enhanced geothermal system technology can be applied to tap deeper geothermal resources, 10,000 to 30,000 feet deep in the earth's crust.

Presentation Outline:

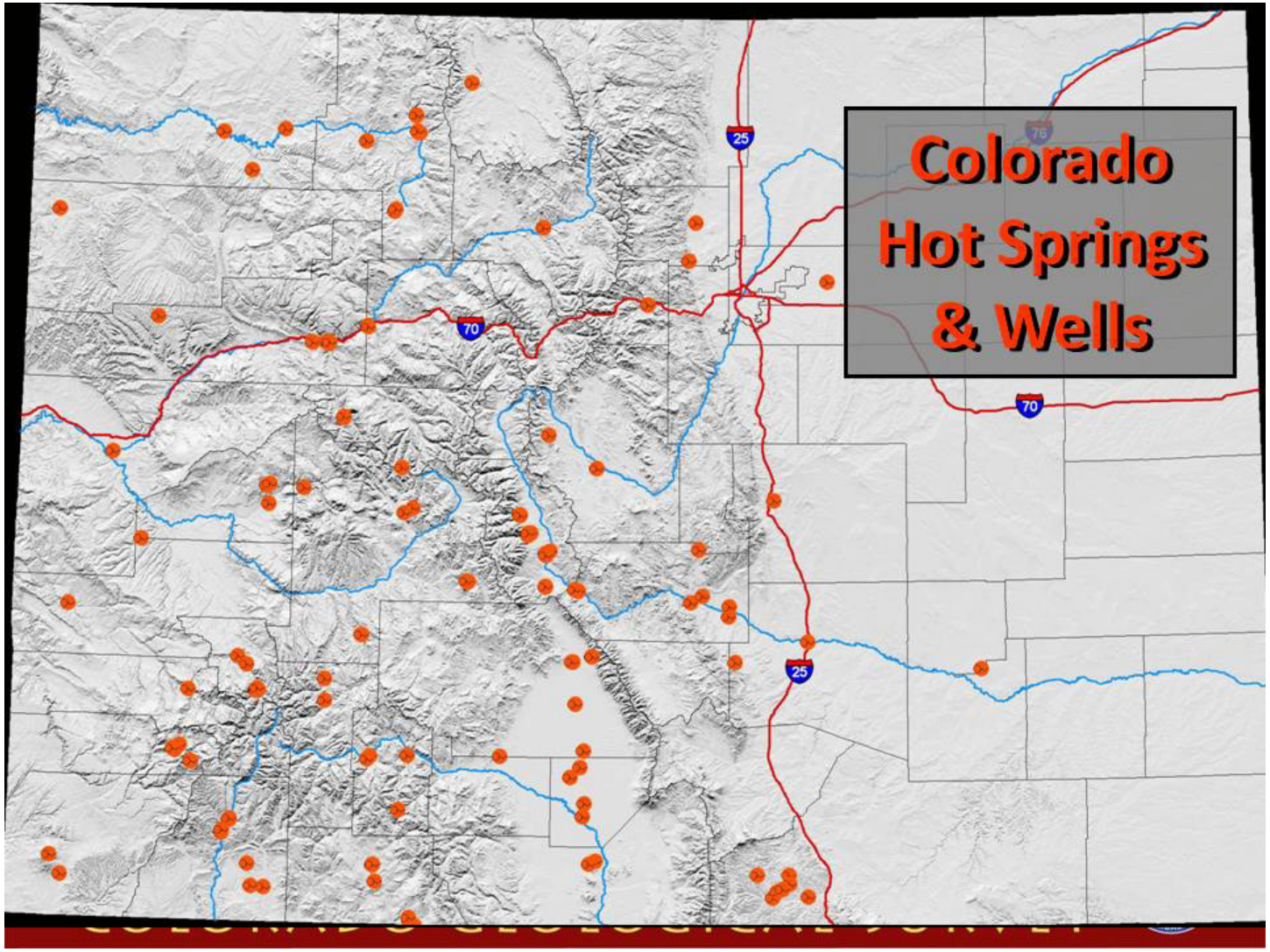
- Colorado Geothermal Background
- Evidence for Electrical Power Potential
- New Data and Mapping

Major Tectonic and Geographic Features of Colorado

modified from Tweto, 1979



COLORADO GEOLOGICAL SURVEY



Notes by Presenter:
The most obvious indicator of geothermal resources at depth are thermal springs:
According to the last inventory done in 1992-93:

- The exact number of inventoried unique hot springs is 111.
- The exact number of inventoried unique geothermal wells is 57.
- Therefore = 168 geothermal features in all.

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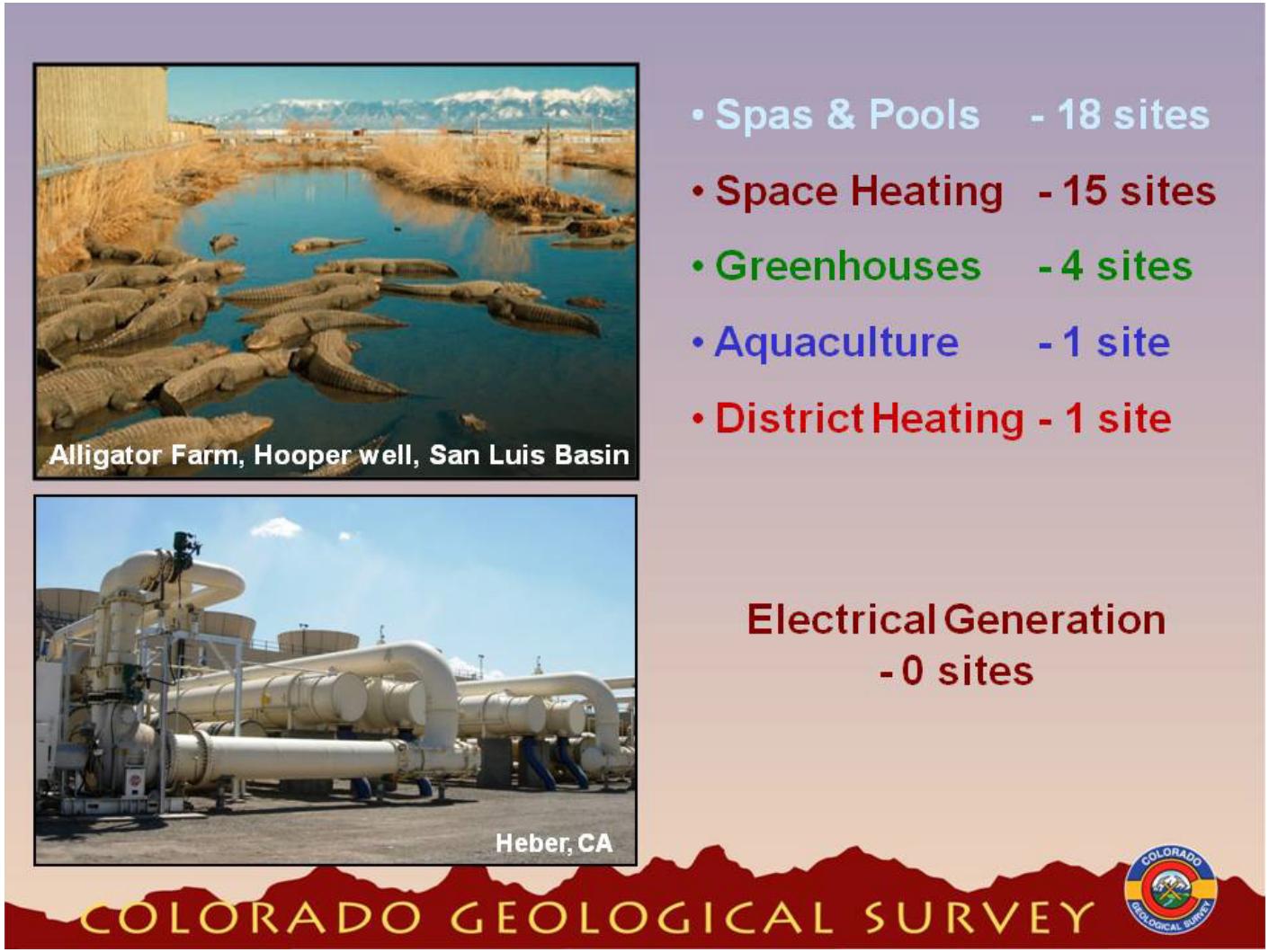
But:

- Some of these hot springs and wells are essentially in the same locality. For example, Glenwood Springs has 8 springs and Pagosa Springs has 1 spring and 2 wells.
- When grouped by locality, Colorado has 93 geothermal spring and well locations

- These springs show the general geographic area of Colorado's geothermal resources - Central Mountains and Western Slope

Geothermal Springs and Wells of Colorado.

- 59 hot spring sites and 34 geothermal wells
- Does not include oil/coal wells or warm household wells
- Geographic area expands as compared to only thermal springs – more to the west of the central mountainous area and a few to the east of the Front Range and Sangre de Cristo Mtns
- How are these geothermal resources currently being used in Colorado?



Notes by Presenter: The Alligator Farm in the San Luis Basin is near Hooper, CO

- Aquaculture is the main business here. They raise tilapia in the geothermal waters.
- The tail water from the tilapia runs is used to produce an alligator habitat as a tourist attraction.

Statistics on direct use of geothermal waters in Colorado:

- Spas & Pools - 18 sites
- Space Heating - 15 sites
- Greenhouses- 4 sites
- Aquaculture - 1 sites
- District Heating - 1 site

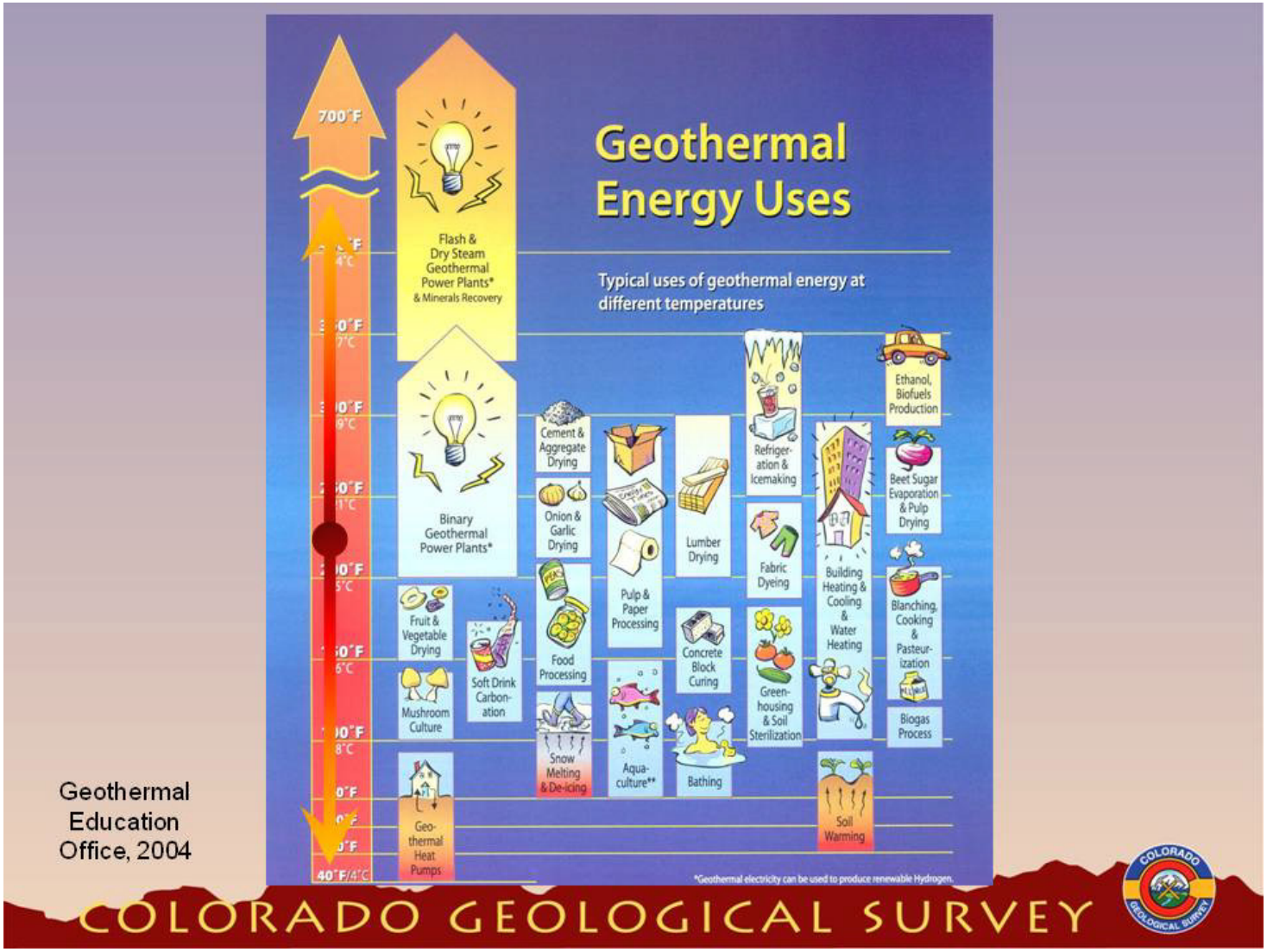
This is how geothermal waters are currently being used for economic benefit in Colorado.

- Electrical generation from geothermal resources is not yet a reality in Colorado.
- The Western Governor's

Association Clean and Diversified Energy Advisory Committee (CDEAC) commissioned a task force to assess geothermal potential in the West. They concluded that Colorado has the potential to produce:

- 20 MW electrical energy in the next 10 years (for cost up to $0.08/kWh)
- 50 MW in 20 years (for cost up to $0.20/kWh)

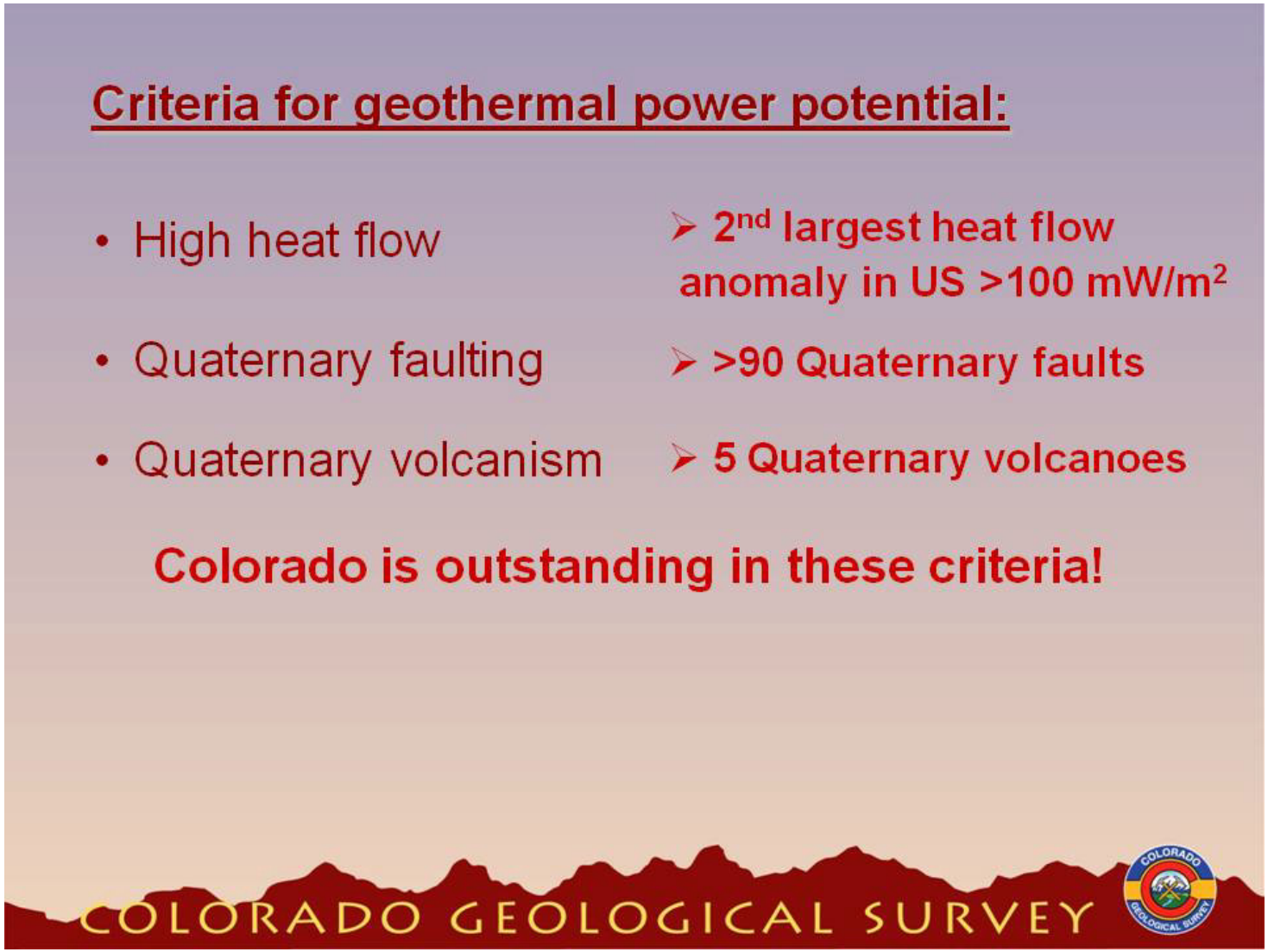
So what kind of temperatures are needed for electrical production?



Notes by Presenter: This chart shows many of the direct uses for geothermal energy. We can make much use of our known geothermal resources at hot springs for many uses.

But, in this talk I am focusing on electrical production

- In the 70s and early 80s one needed temperatures of ~350°F,
- But new binary power plant technology being used largely since the 90s has allowed electrical production from much lower temperatures. In Alaska electricity is being produced with 165F water!
- This technology opens up electrical production potential to many geothermal locations and areas of the country that previously were not able to do so. This alone makes Colorado prospective for geothermal power production.

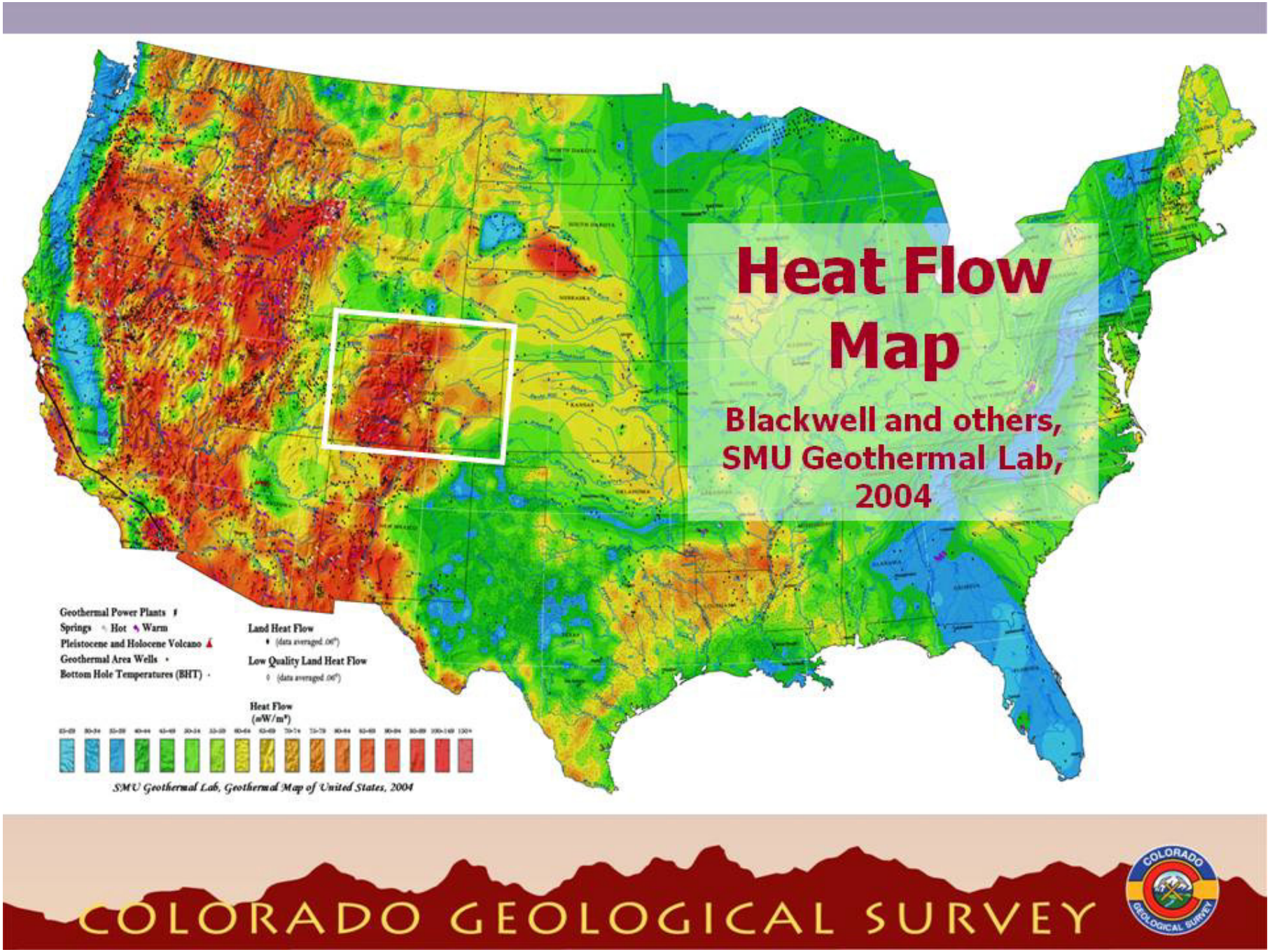


Notes by Presenter : Researchers look for a few primary criteria when exploring for geothermal potential. These include:

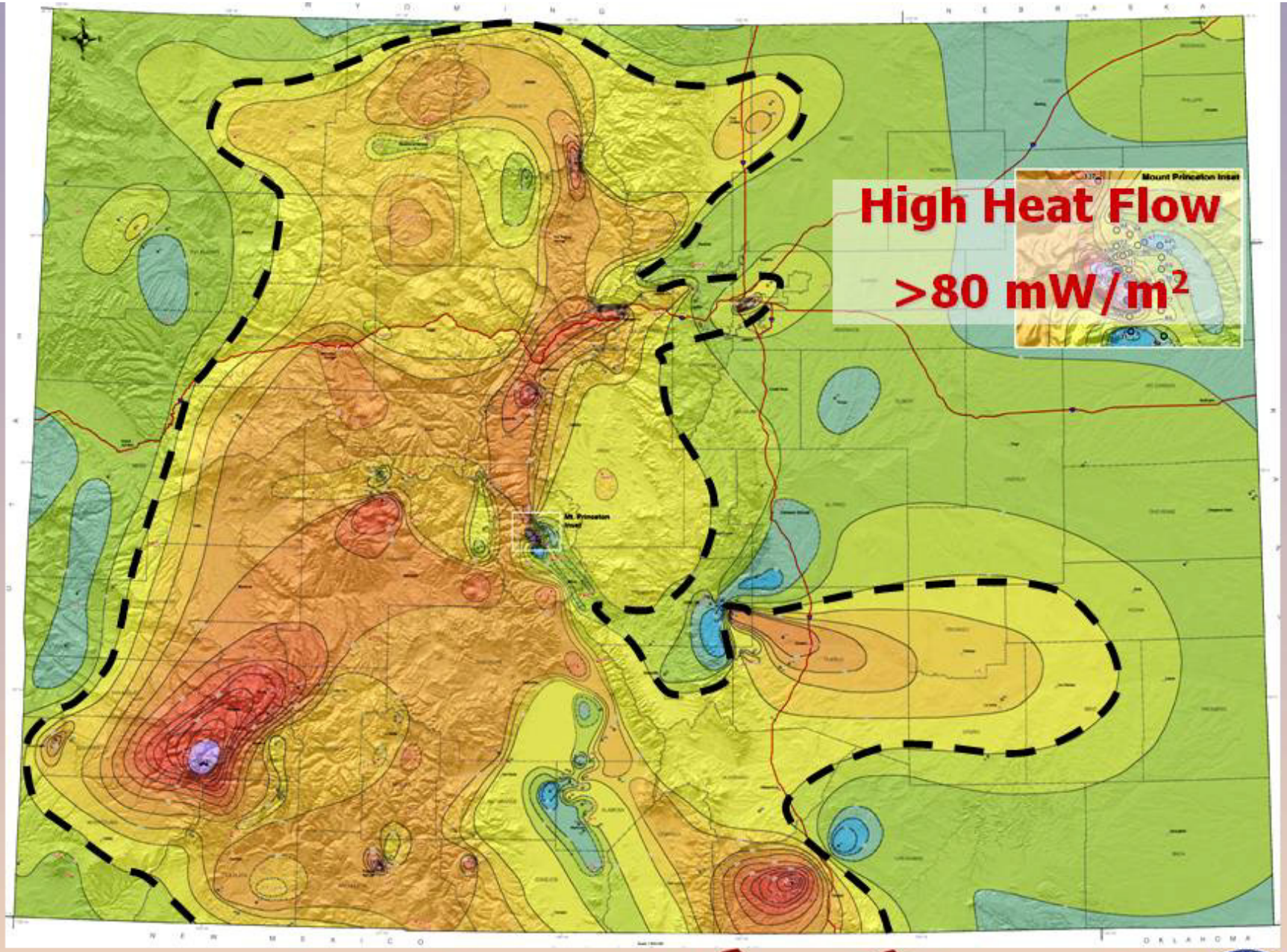
- High heat flow
- Quaternary faulting (<2 million years ago)
- Quaternary volcanism

Colorado is also outstanding with respect to these criteria!

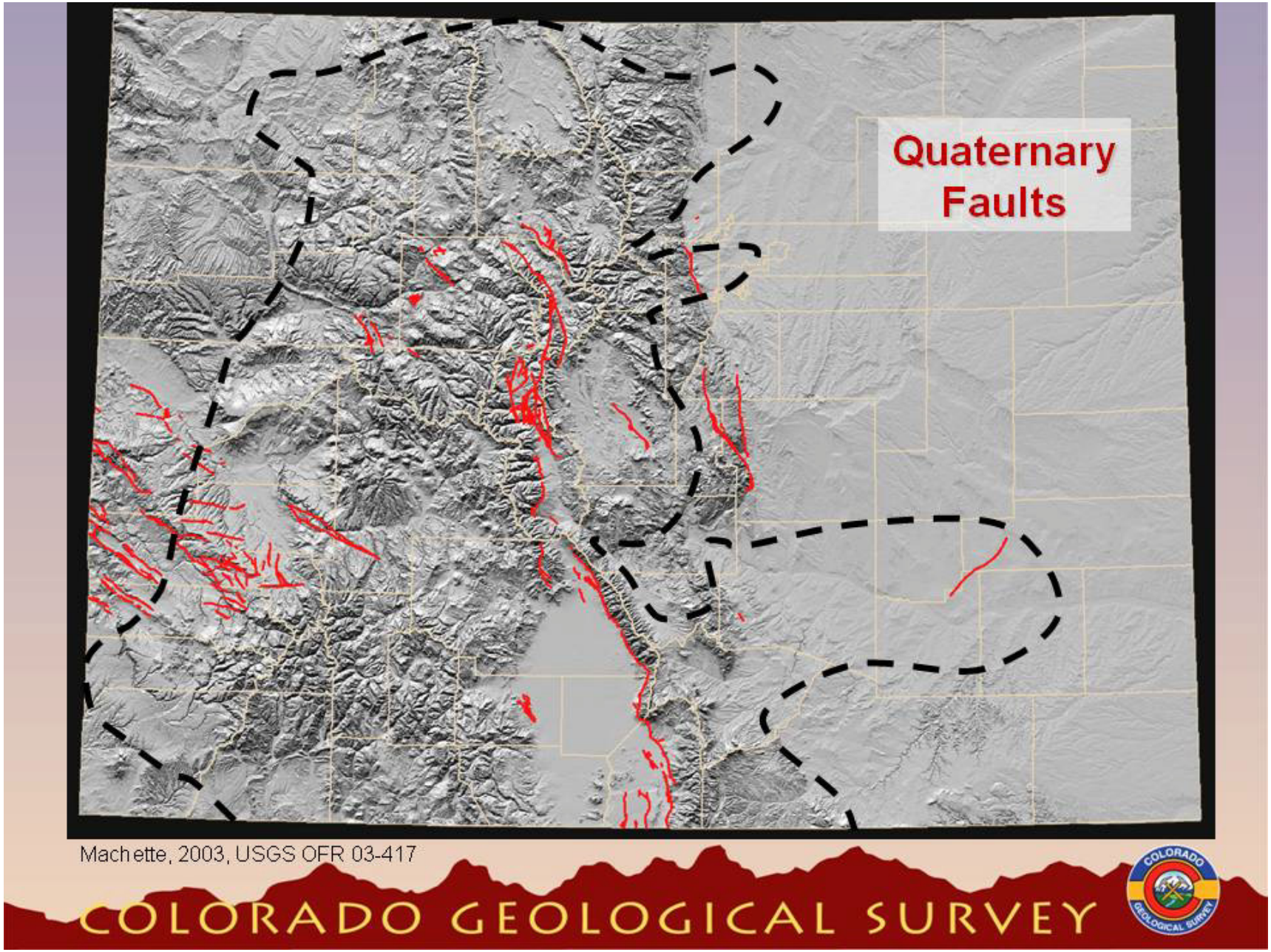
Let's take a closer look at these geologic controls on geothermal potential.



Notes by Presenter: 2nd largest >100 mW/m2 heat anomaly for a state in continental US.

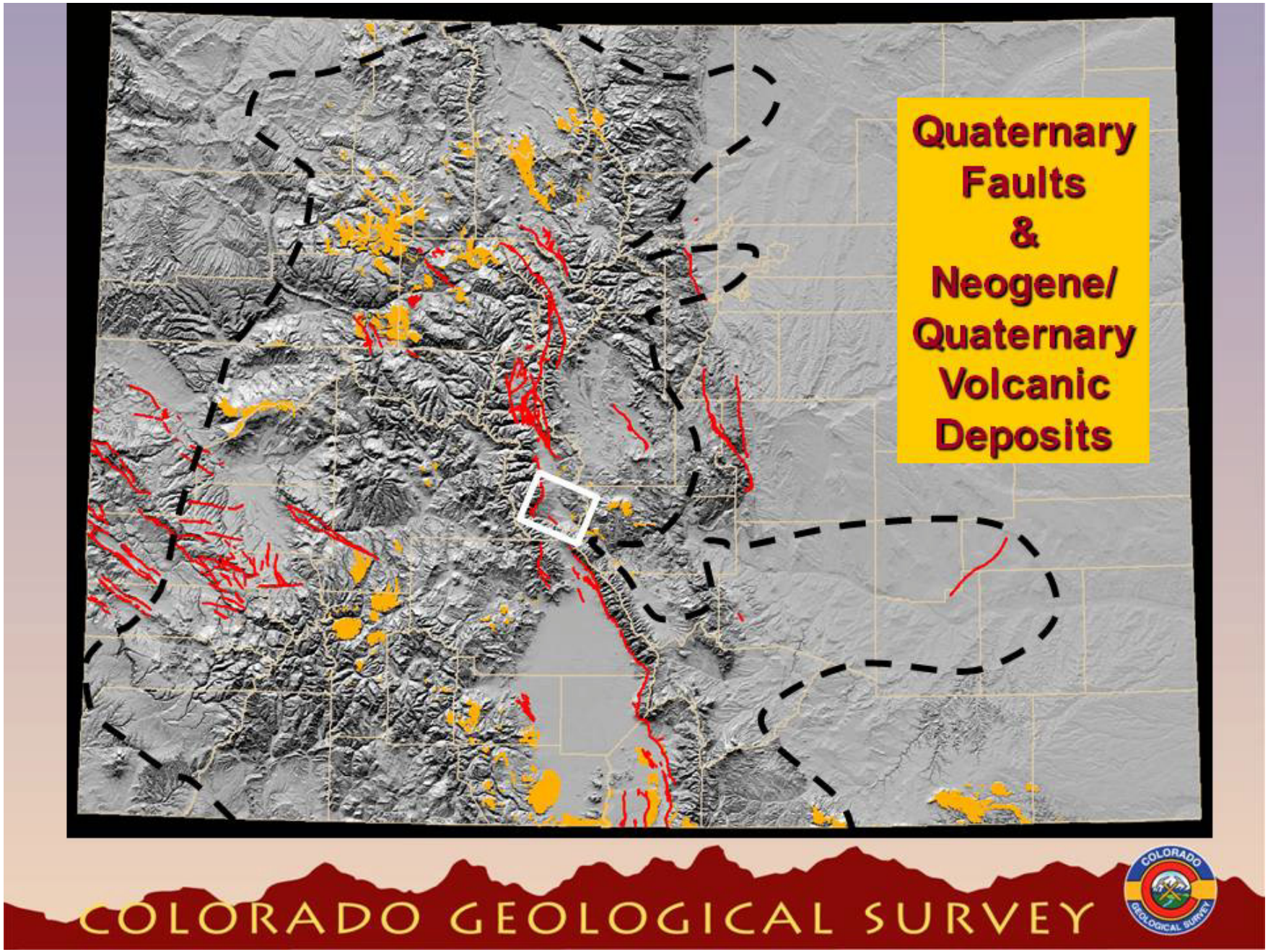


COLORADO GEOLOGICAL SURVEY



Notes by Presenter:

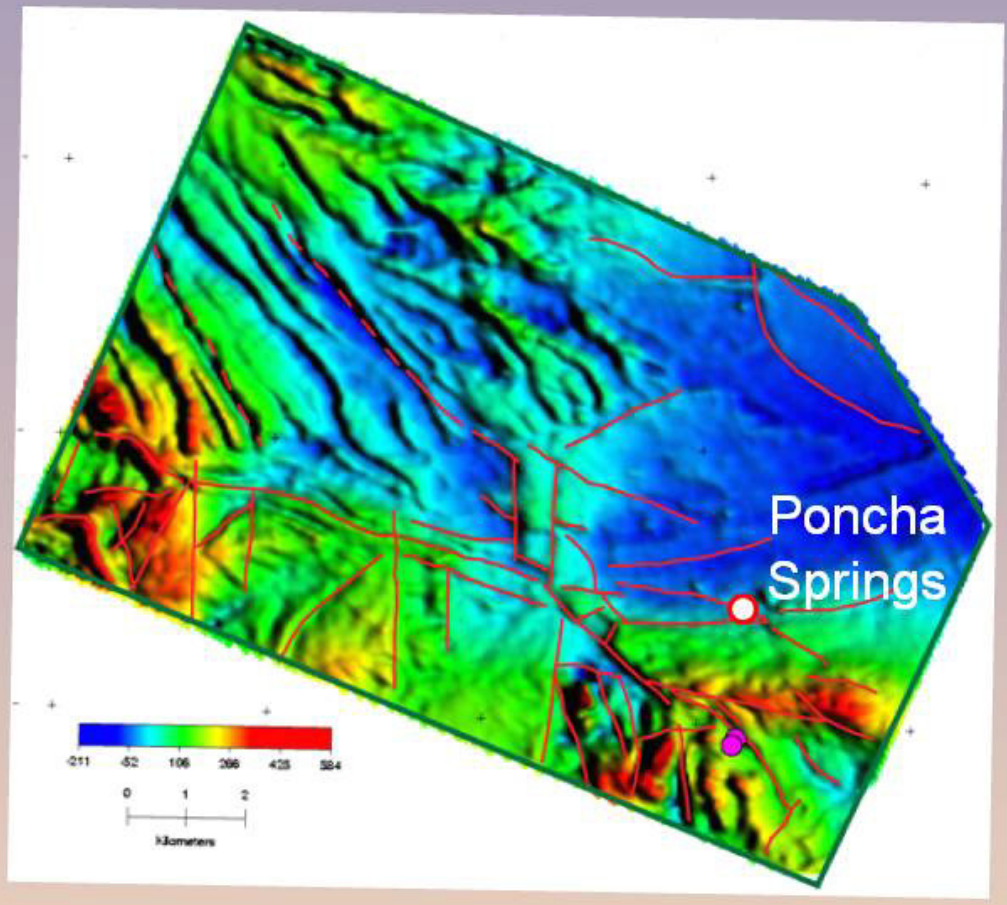
- Best documented young faulting is within the 80 mW/m2 area
- USGS Quaternary (<2 mya) fault database has 92 folds and faults in State (put together by CGS, on our website)
- The best documented Holocene (<12,000 ya) faults are within the high heat flow area.



Notes by Presenter:

- If we add the Neogene and younger (<23 mya) volcanic deposits, we see that most of these also occur within the area of high heat flow.
- These volcanics cover over 816,000 acres or 1,275 square miles

Interpreted Faults on Aeromagnetic Map

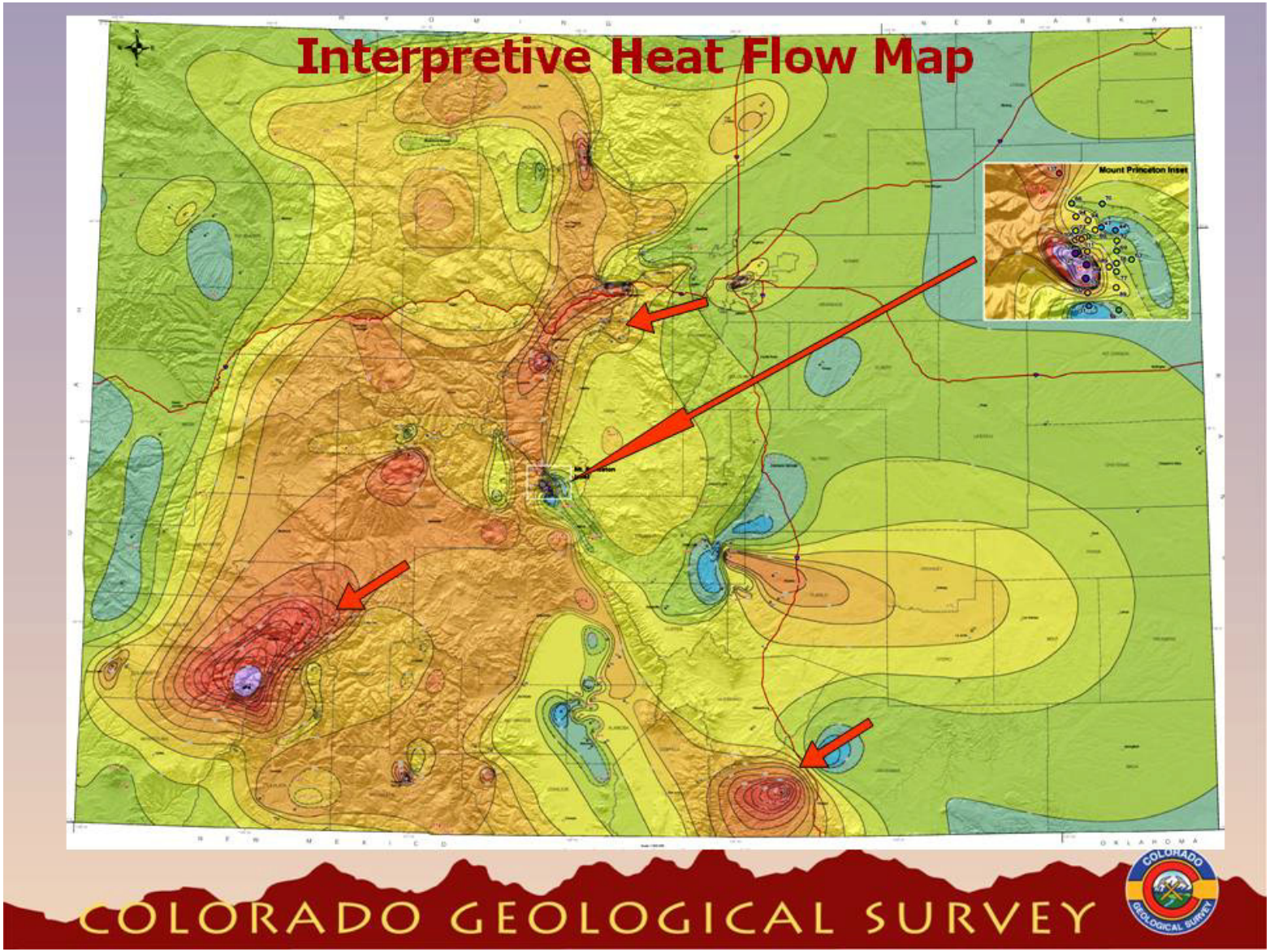


Grauch &
Drenth,
in prep

COLORADO GEOLOGICAL SURVEY

Notes by Presenter:

- In relation to fault identification in Colorado, the US Geological Survey is conducting a multi-year aeromagnetic survey along the Rio Grande Rift.
- This work will identify additional, potentially young faults in the rift area of Colorado
- This is an example from a recent survey in the Poncha Springs-Salida area of Chaffee Co., central Colorado
- Some interpreted faults have been identified in an area of Quaternary cover ~1-2 miles west of Poncha Springs.



Notes by Presenter:

2008 CGS Heat Flow Map-Colorado state map:

- Warmer colors (orange-red-purple) indicate areas with geothermal resources

Indicates areas with high heat flows:

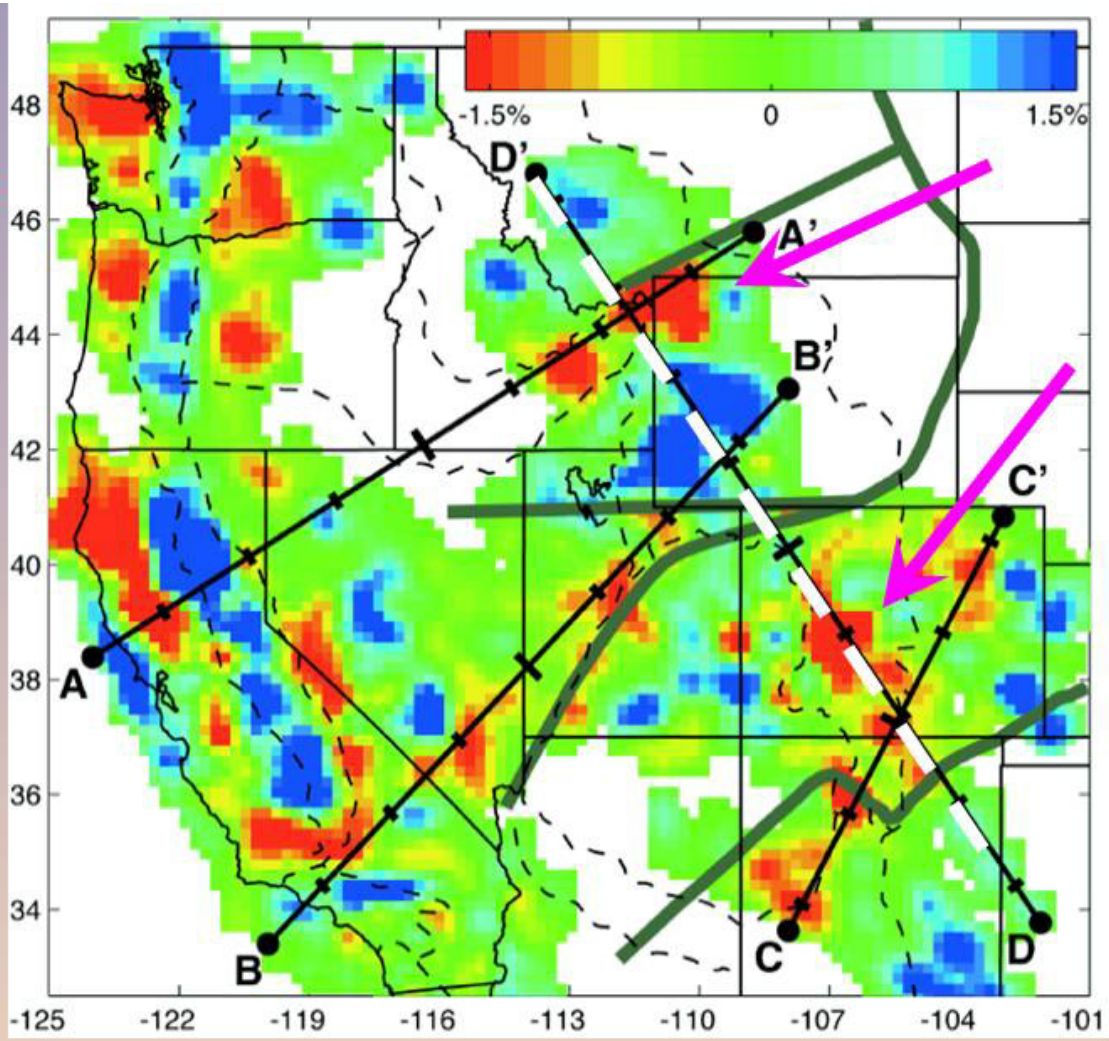
- Rico-Ouray trend (200-300 mW/m2), Trinidad and eastern San Luis Basin area (up to ~200 mW/m2), Leadville-Georgetown area (up to 200 mW/m2), Mt. Princeton-Buena Vista area (300-400 mW/m2),
- Other areas of the state may also have potential

Tomographic P-wave velocity variations

Map at 100 Km Depth

Yellow/red = Low Velocity Material

from Dueker, Yuan, & Zurek, 2001



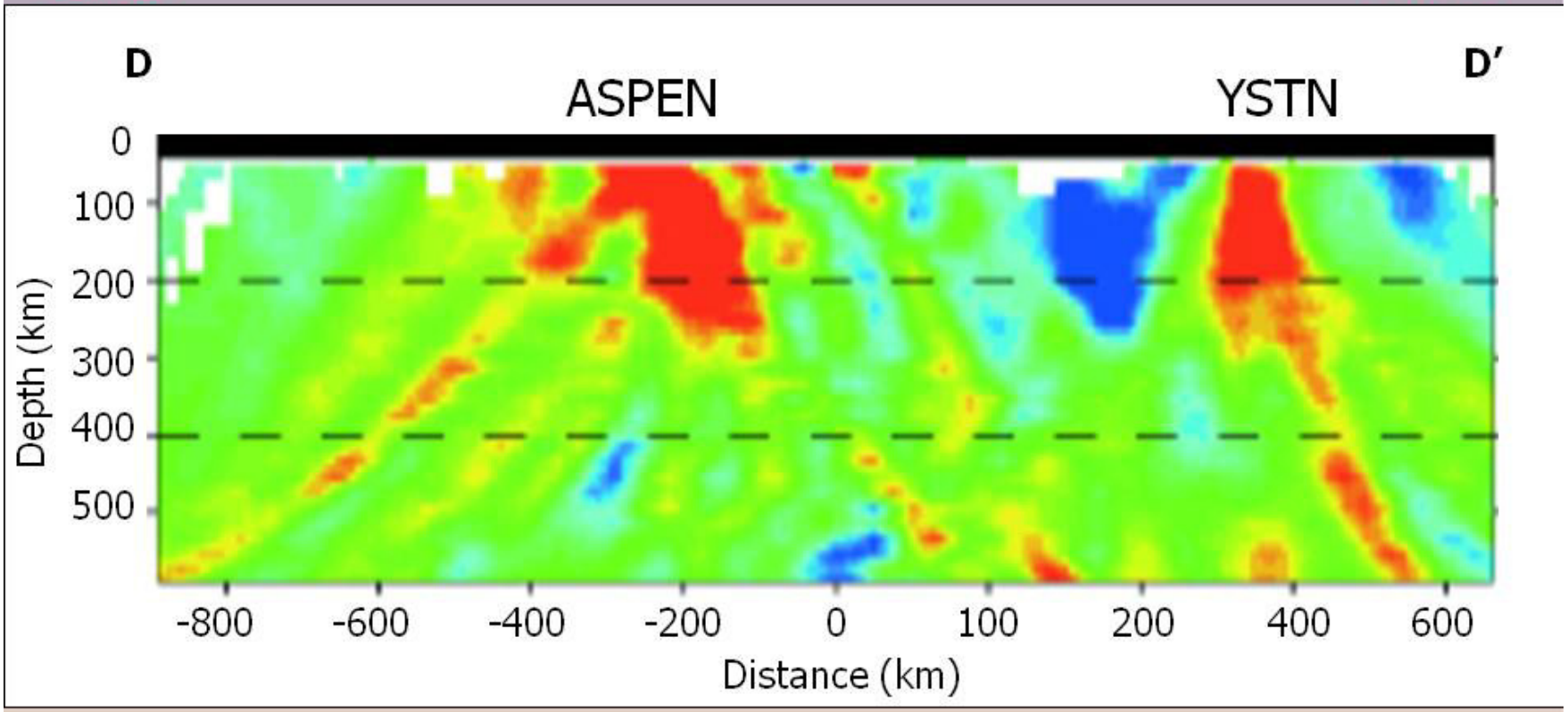
COLORADO GEOLOGICAL SURVEY

Notes by Presenter:
Other evidence indicating geothermal potential includes studies of seismic P-waves
-- Low velocity is indicative of thinner crust areas with warmer upper mantle aesthenosphere
--Here is Yellowstone, a recently active volcanic area. It stands out as an area of low P-wave velocity.
--Note the low velocity area in Colorado = the Aspen Anomaly
--Next we will look at this cross section D-D' from the Texas panhandle NW through Yellowstone

Tomographic P-wave velocity variations

Cross-Section View

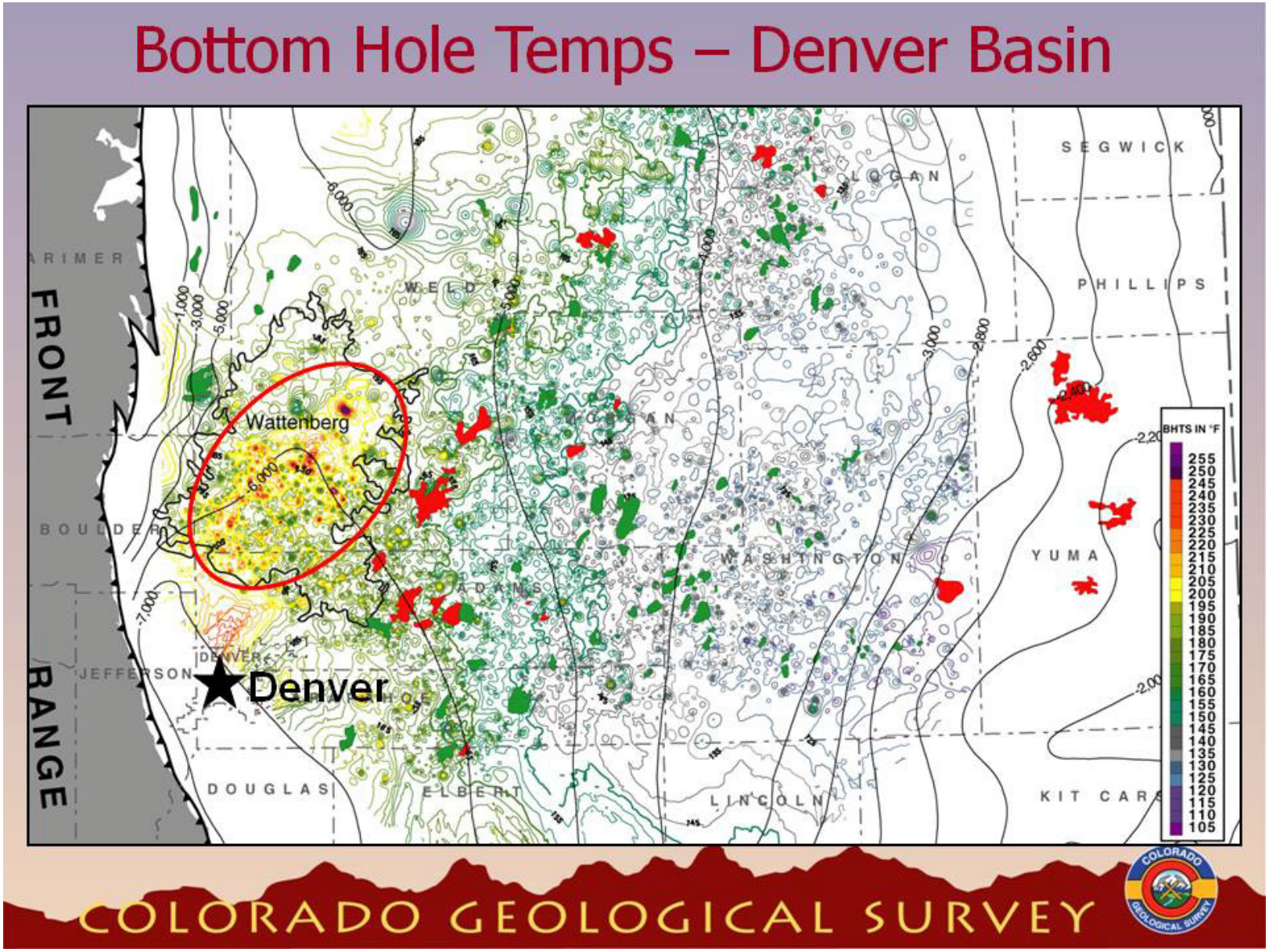
South **North**



from Dueker, Yuan, & Zurek, 2001

COLORADO GEOLOGICAL SURVEY

Notes by Presenter:
The Aspen Anomaly is comparable in size to the Yellowstone Trend
It also appears to have deep roots, as does Yellowstone.

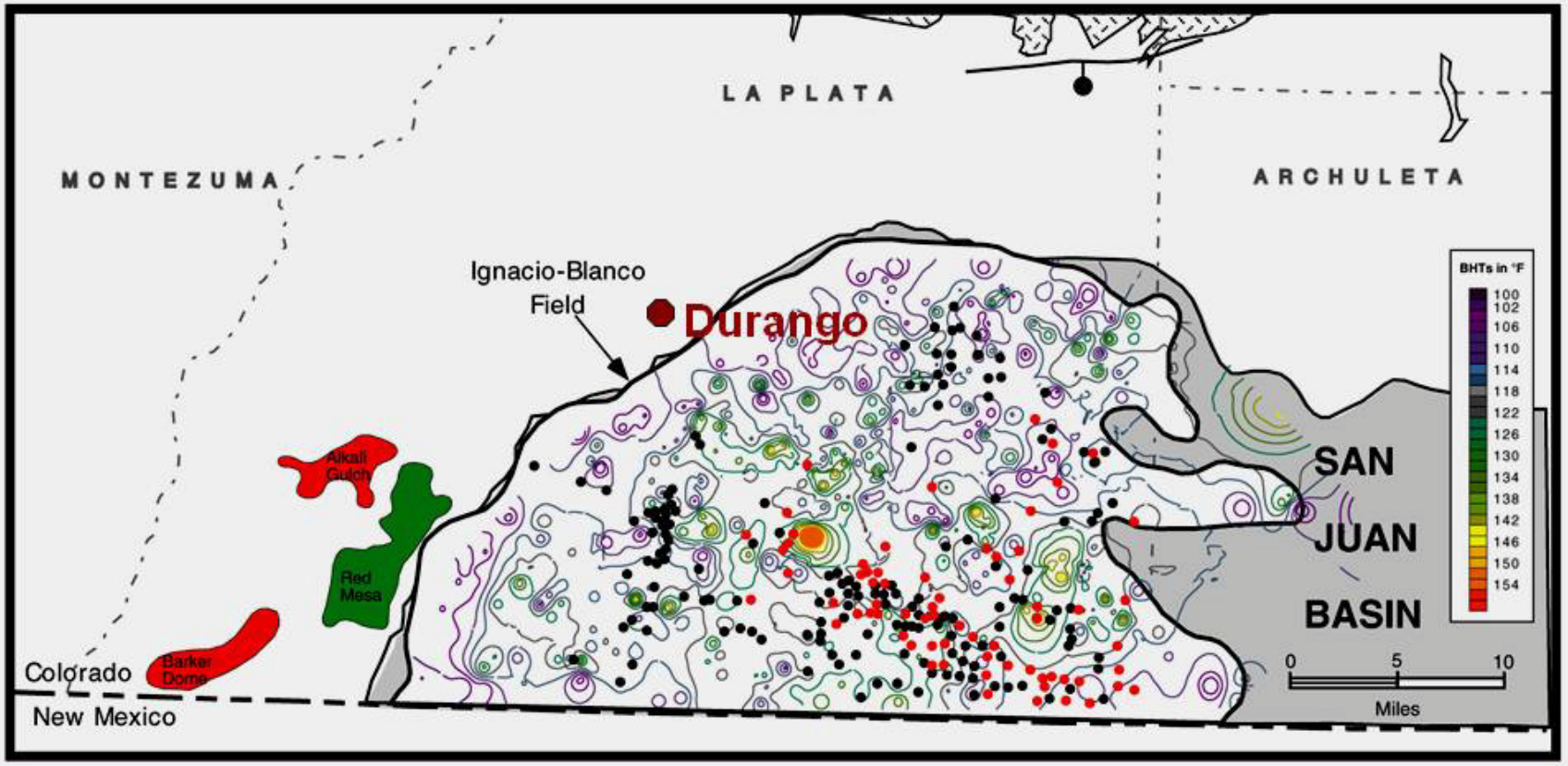


Notes by Presenter:

There is significant potential for geothermal development in Oil & Gas fields

- This figure exhibits bottom hole temperatures (BHT) in the Denver Basin, Dakota Fm
  - --Note the high temperature trend in the Wattenberg Field
  - -- 200-250F
  - -- roughly 10,000-11,000 ft deep

Bottom Hole Temps – San Juan Basin

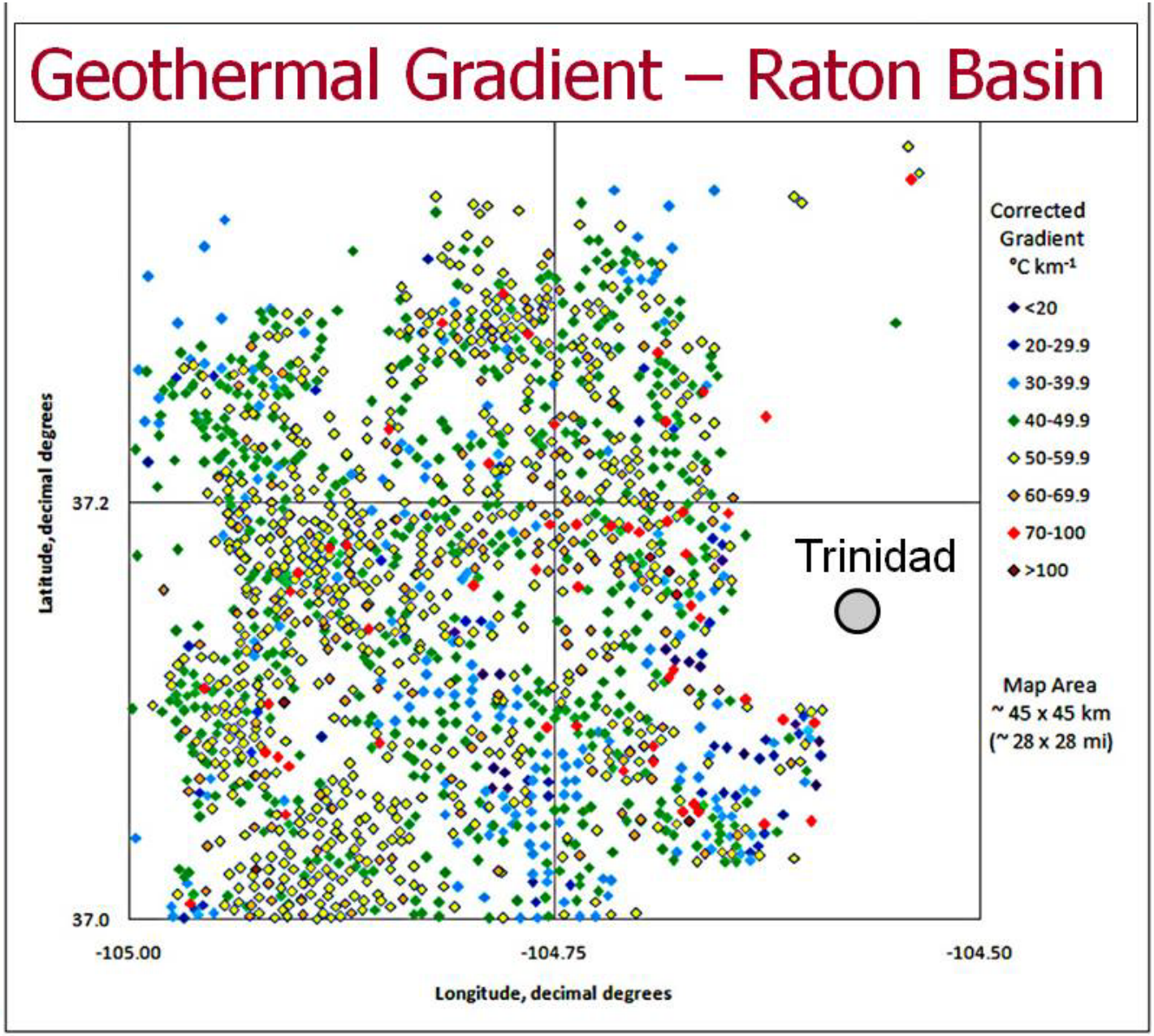


COLORADO GEOLOGICAL SURVEY

Notes by Presenter:

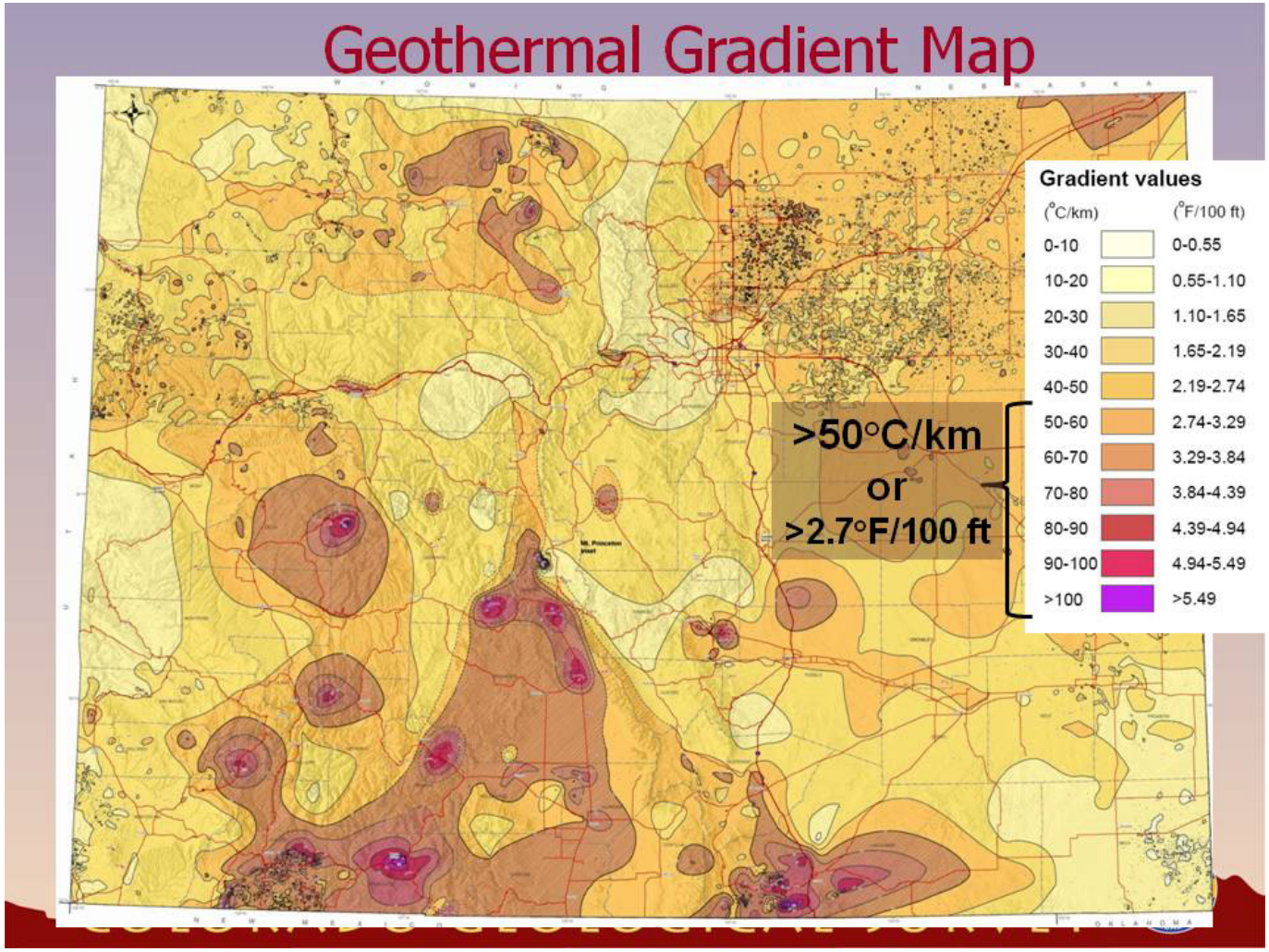
Dakota Fm BHT are indicated by dots: red>230F; black<230F

- 20 wells in the San Juan Basin have temperatures of 121°C (250°F) or more between 7,000-9,000 feet deep.
- One well has a temperature of 150°C (302°F) at a depth of only 7,400 feet.



Notes by Presenter:
Geothermal gradient (corrected) in the Raton Basin

- Can see that most of the wells in the basin are >50°C/km (yellow, orange, red, purple).
- There is a concentration of these wells in the SE quadrant of the field.

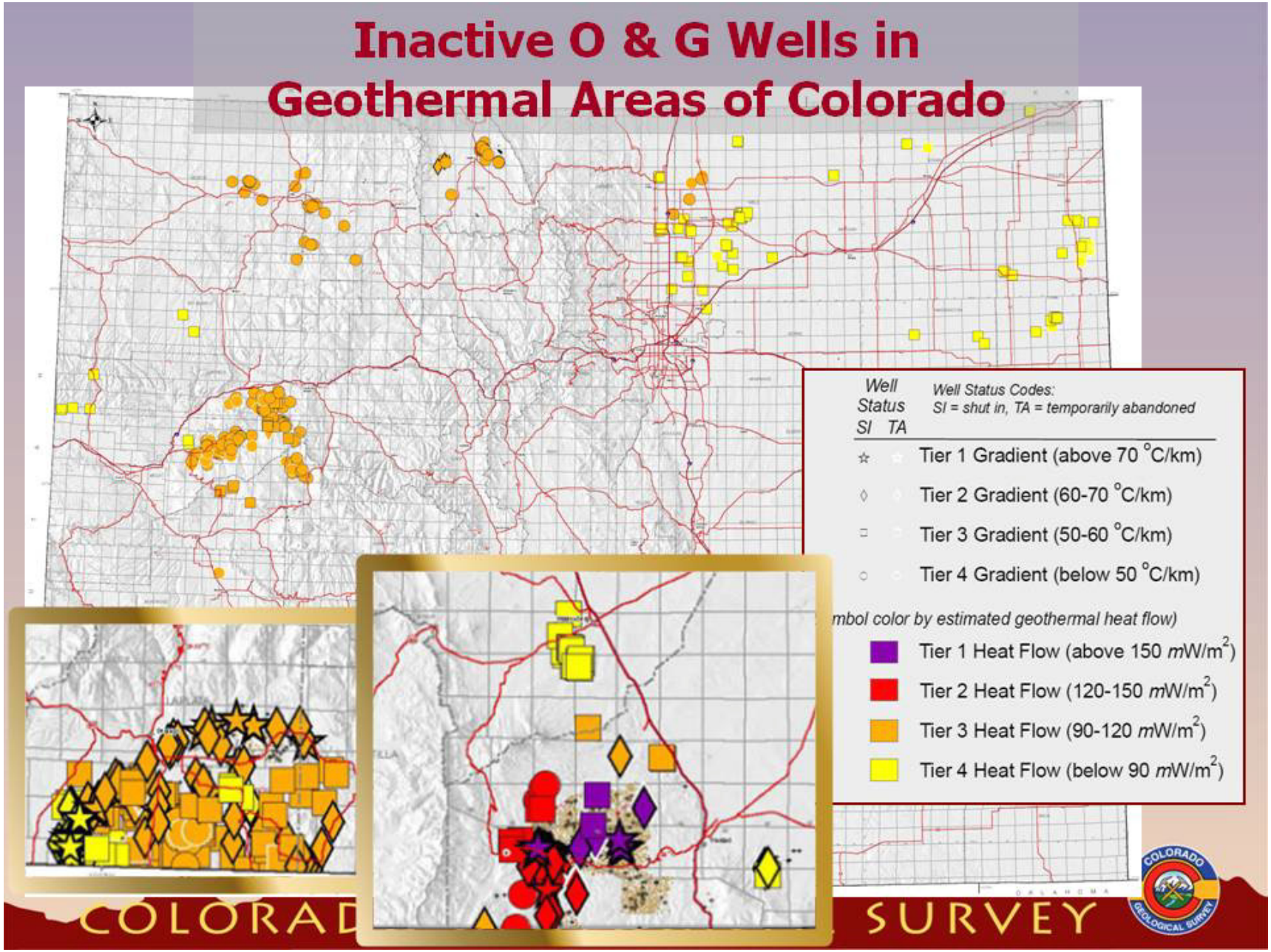


Notes by Presenter:

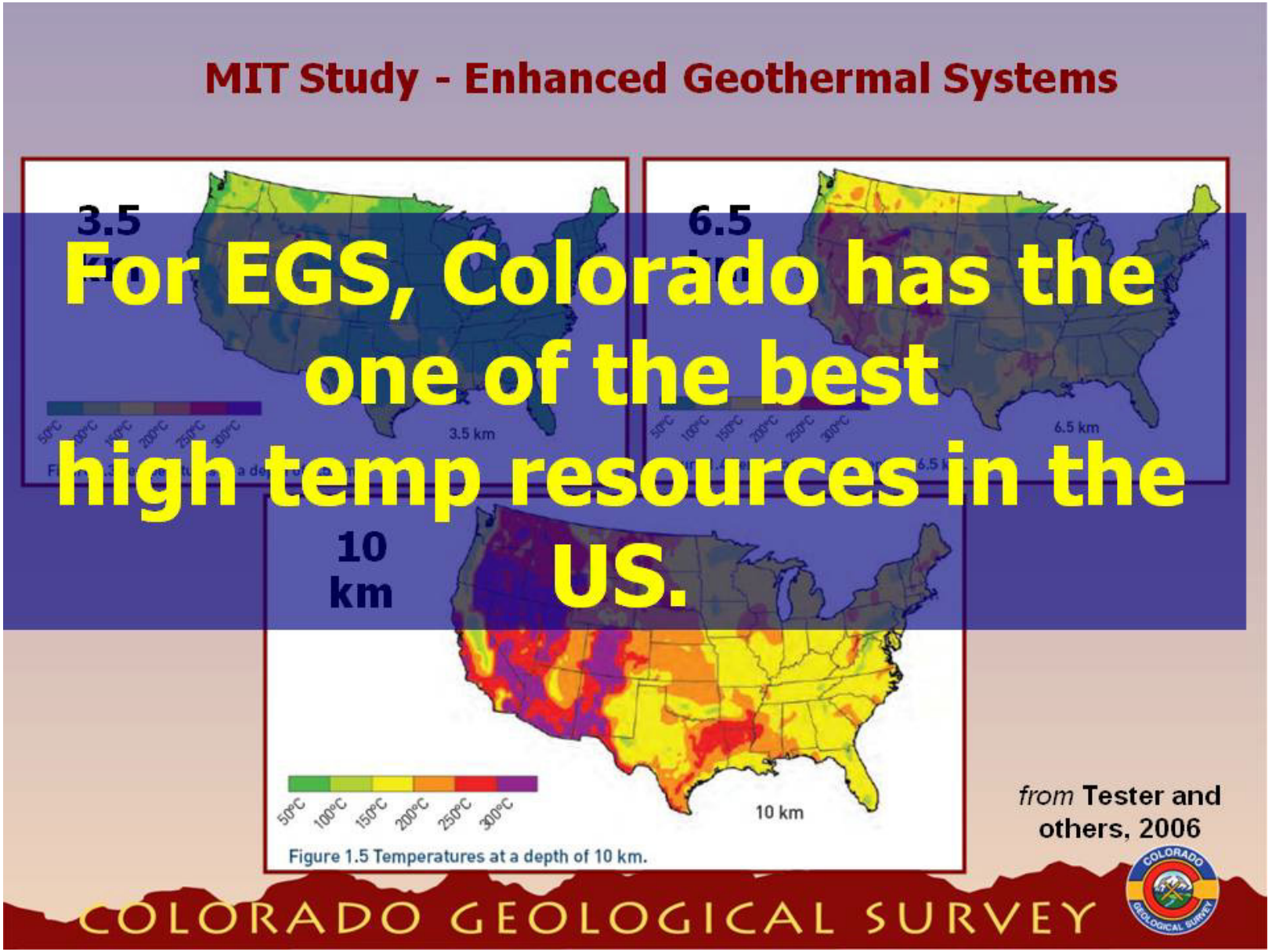
- We have combined the Heat Flow dataset. BHT dataset for major Oil and Gas Basins, and O&G Drillstem Test temperature data to produce this map.
- Corrections were applied to calculated gradients from BHT and DST data to allow it to be used with gradients from the Heat Flow data.
- Warmer colors = higher geothermal gradient
- Areas outlined have gradients at or above 50°C/km. These areas potentially have boiling water within 2 km (6500 ft) of the surface.
- These maps help identify prospective locations for electrical power generation from conventional shallow hydrothermal systems, as well as areas where enhanced geothermal system (EGS) technology can be applied to tap geothermal resources deeper in the earth's crust.

There is a caveat…

- The data points are often clustered with wide areas of sparse data. More research/exploration drilling is needed to further define these high gradient areas.

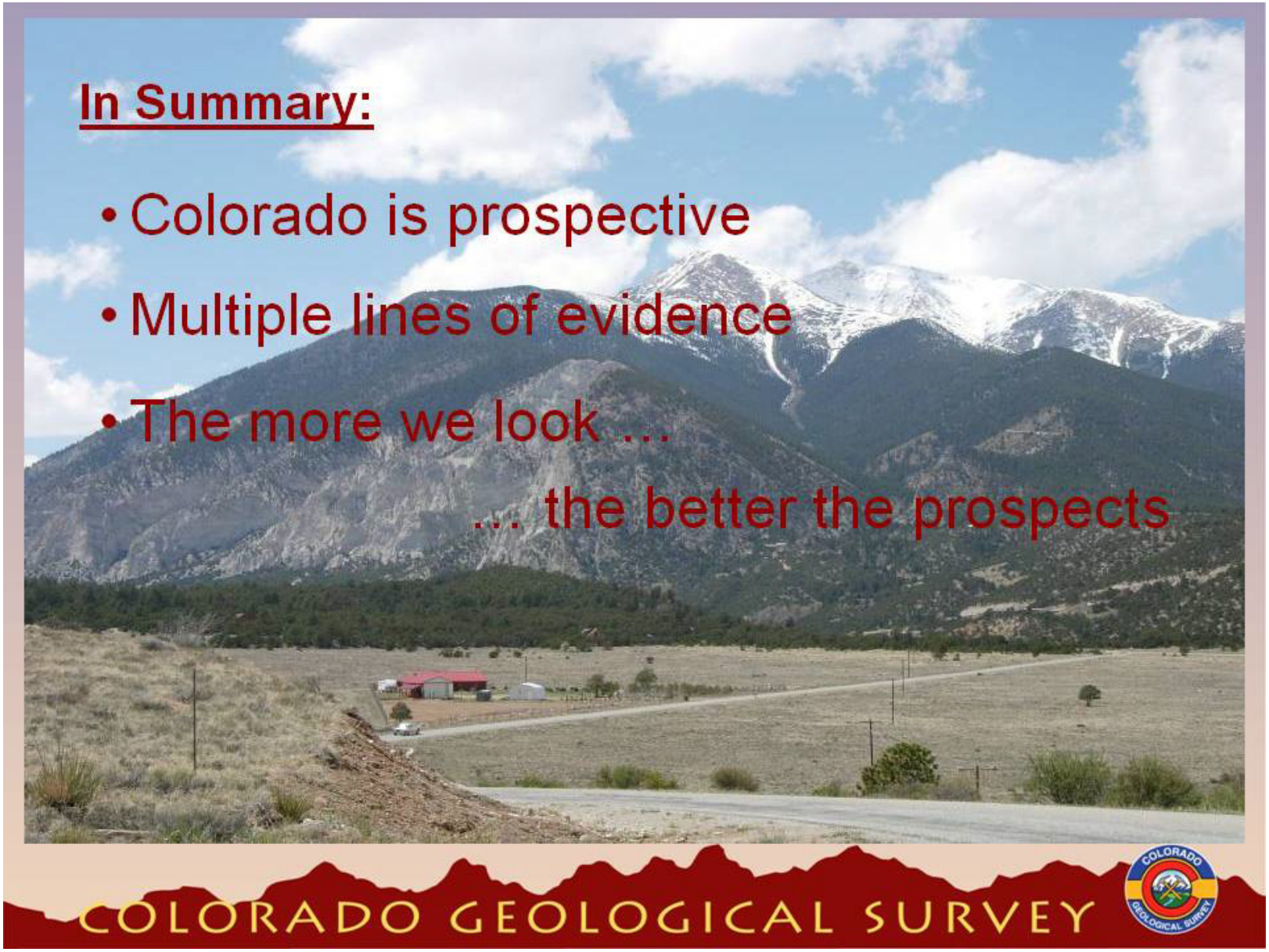


Notes by Presenter:
Inactive wells on this map are those that are temporarily abandoned or shut-in.
Database includes all 87,000 wells in Colorado and they have been assigned gradient and heat flow tier rankings.



Notes by Presenter:

- Tester, J.W. and others. 2006, The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century: Massachusetts Institute of Technology, INL/EXT-06-11746.
- For Enhanced Geothermal Systems (EGS), Colorado has one of the best high temperature resources in the US.
- Best heat resource in the 3-4 km range (10,000-13,000 ft)
- Colorado ranks 5th among the continental U.S. states in total heat energy available below 10,000 feet



Notes by Presenter:
In Summary:

- We believe Colorado is prospective for geothermal energy development

– both conventional hydrothermal systems and enhanced geothermal systems

- Multiple lines of evidence indicate that Colorado's potential is greater than has been thought in the past
- The more we look, the more data we have, the better the prospects