Causes of Geothermal Temperature Anomalies In the Denver Basin: With Application to Petroleum and Geothermal Energy

COLORADO SCHOOL OF MINES
MUDTOC

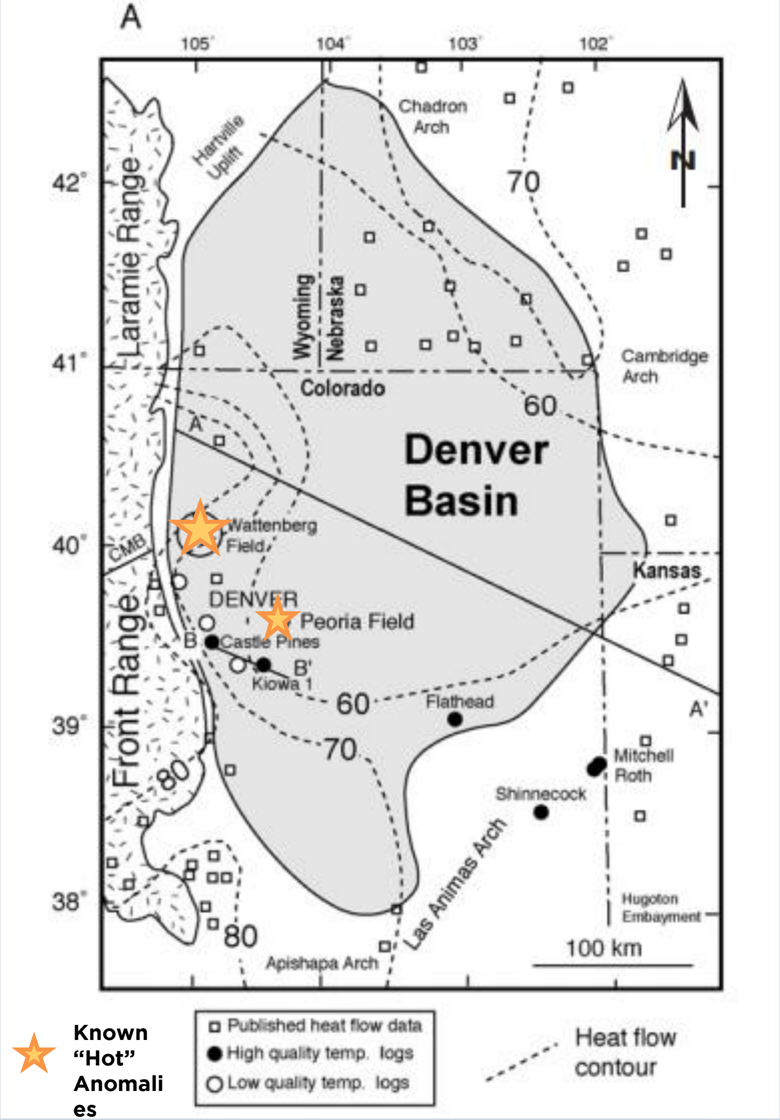
Melia Eaton
M.S. Spring 2024

Outline

I. Introduction & Study Area
II. Hypotheses
III. Objectives and Purpose
IV. Dataset and Proposed Research Methods
V. Geologic & Tectonic Overview
VI. Timeline
VII. Conclusions

Introduction

Study Area: Denver Basin



Modified from Kelley and Blackwell, 2002

- High geothermal gradients associated with immense oil & gas production worldwide
  Ex. Denver Basin & Wind River Basin in the U.S., Anambra Basin & Borno Basin in Nigeria, Ordos Basin in China

- Geothermal highs in the ***Denver Basin*** are associated with productive oil fields & geothermal energy potential
  I. Wattenberg Field: Anomaly of about +10 ^{0}F
  II. Peoria Field: Anomaly of +4 ^{0}F to +6 ^{0}F
  III. Bennett Field: Anomaly of +0.5 ^{0}F

How Do "Hot" Geothermal Anomalies Affect Hydrocarbon & Geothermal Resources?

COLORADO SCHOOL OF MINES
MUDTOC

Hydrocarbon Resources

- Increases rate and controls distribution of organic matter maturity
- Higher gas-oil ratios
- Can increase reservoir porosity over time
- Higher oil gravity
- Can cause thermal cracking, generate pyrolysis gas from crude oil
- Decreases viscosity

= ***Increased Productivity***

Geothermal Resources

- Local "hot" anomalies allow otherwise "cool" areas to produce geothermal energy
- Allows for indirect (electricity) and direct (heating/cooling) uses
- Higher reservoir temperatures = more diverse energy uses, larger areal extent of energy distribution
- Pre-existing hydrocarbon infrastructure in areas of anomaly can be repurposed

= ***Better Geothermal Reservoirs***

Hypotheses

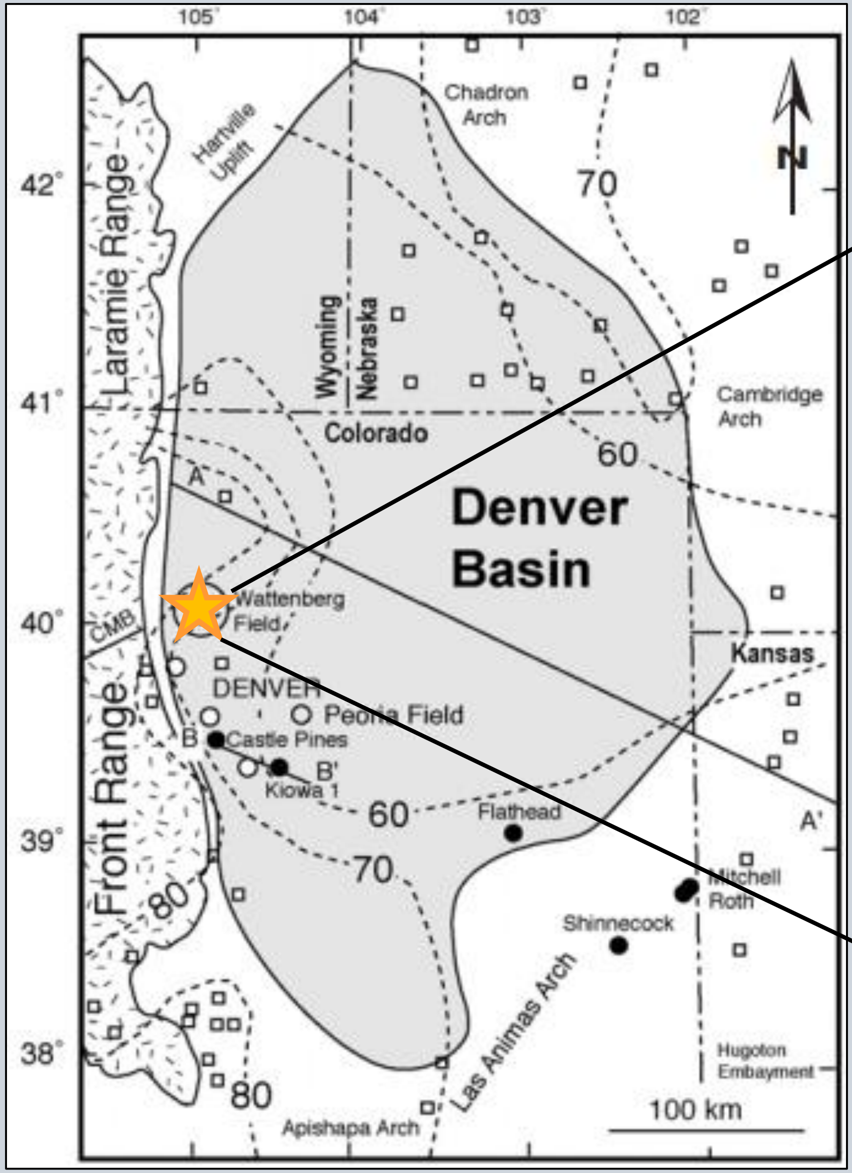
COLORADO SCHOOL OF MINES MUDTOC

I. Upward movement of hot hydrothermal fluids, i.e., saline brines, along faults, fractures, and carrier beds
II. Mineralization of conductive minerals associated with the Colorado Mineral Belt
III. High heat flow from intrusive igneous masses, i.e., magmatic intrusions
IV. Differences in thermal conductivity between rock bodies

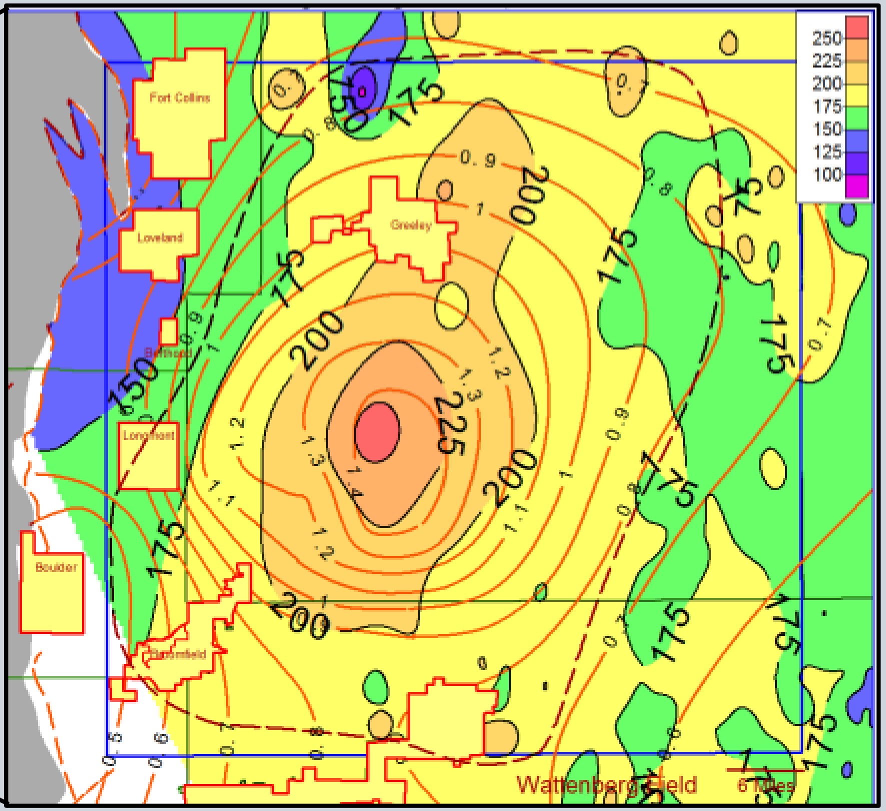
= combination of some (or all) hypotheses?

Wattenberg Field

COLORADO SCHOOL OF MINES
MUDTOC



Modified from Kelley and Blackwell, 2002

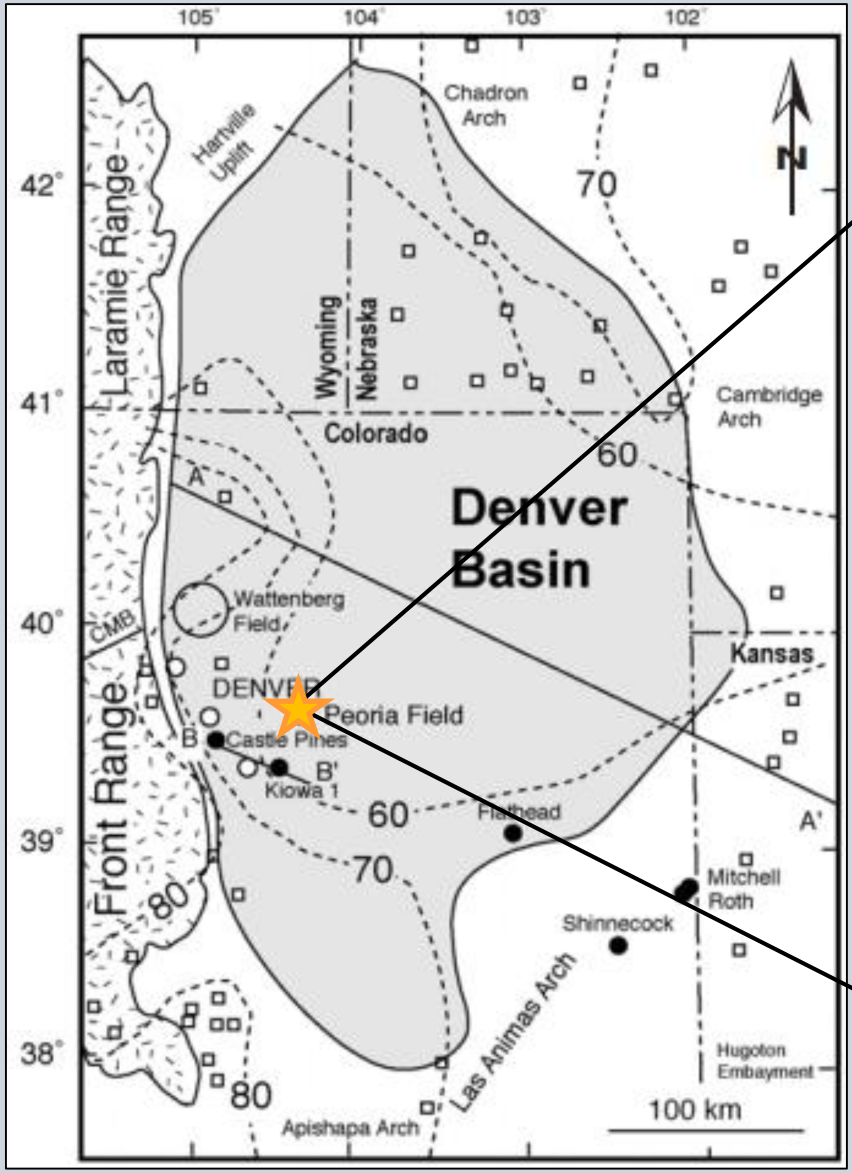


Isotherm map of Wattenberg Field; geothermal gradient map overlain by vitrinite reflectance contours. From Sonnenberg, 2016

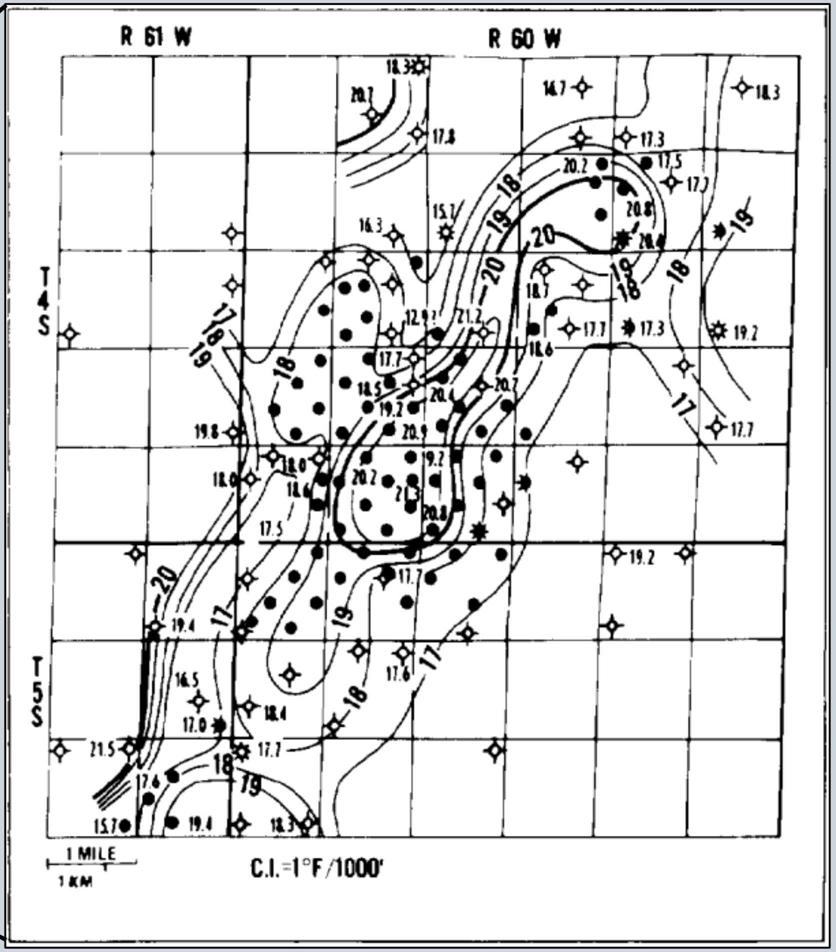
- Productive from the Lower Cretaceous Muddy "J" Sandstone
- Cumulative 812 mmbo, 7.5 tcfg from over 35,000 wells (as of 2019)

= elevated production because of hot geothermal anomaly

Peoria Field



Modified from Kelley and Blackwell, 2002



Temperature gradient map of Peoria Field using BHT values from drilled wells. From Meyer and McGee, 1985

- Productive from the Lower Cretaceous Muddy "J" Sandstone
- Cumulative 47 mmbo in place, about 19 mmbo recoverable

= elevated production because of hot geothermal anomaly

Objectives & Purpose

COLORADO SCHOOL OF MINES
MUDTOC

Discern the cause of "hot" geothermal temperature anomalies in the Denver Basin and assess how anomalies affect hydrocarbon and geothermal energy resources

I. Create correct, comprehensive bottomhole temperature and geothermal gradient maps of the Denver Basin
II. Identify all locations of "hot" geothermal anomalies
III. Create a structural framework map identifying all geologic structures in or around areas of "hot" anomalies
IV. Synthesize all acquired data, maps, and analyses to propose the most likely cause(s) of "hot" geothermal anomalies within the Denver Basin
V. Discuss how the cause(s) of anomalies affect hydrocarbon and geothermal energy resources within the Denver Basin
VI. Suggest world-wide analogues and future work

Dataset

- Denver Basin well logs & associated data
- Well logs & temperature data from White Eagle Exploration
- Hydrothermal fluid samples
- Thin sections & cores
- Magnetic data
- Gravity data
- Seismic data (TBD)

Methods

Temperature Mapping

- Bottomhole temperature (BHT) map of the Muddy "J" Sandstone in the Denver Basin
- Temperature corrections will be applied to temp. data from logs = Harrison Method from Harrison et. al., 1983

$$T_c = -16.51 + 0.018 \times z - 2.3 \times 10^{-6} \times z^2$$

- Geothermal gradient map the Denver Basin
- The Corrigan method for geothermal gradient temp. correction will be used

Structural Framework Mapping

- Geologic structure map of the Denver Basin
- Includes all major faults, uplifts, potential igneous bodies, etc., on or surrounding hot anomalies
- PETRA software will be used
- Locations of structural features, previously processed data will be obtained by project partners and consortium archives

Methods

Thin Section Analysis

- Thin sections from Wattenberg Field Muddy “J” Sandstone cores will be obtained
- Analyzed for potential hydrothermal fluid interactions and Colorado Mineral Belt influence
- Analyzed using a polarizing microscope, XRF spectrometer, and other methods

Core Descriptions

- Visual analysis of Muddy “J” Sandstone cores from Wattenberg Field
- Identifying lithologies that have high thermal conductivity
- Identifying fracture number & dimensions
- Synthesized with thin section analysis to determine thermal properties that influence “hot” anomalies

Methods

Seismic, Gravity, Magnetic Analysis

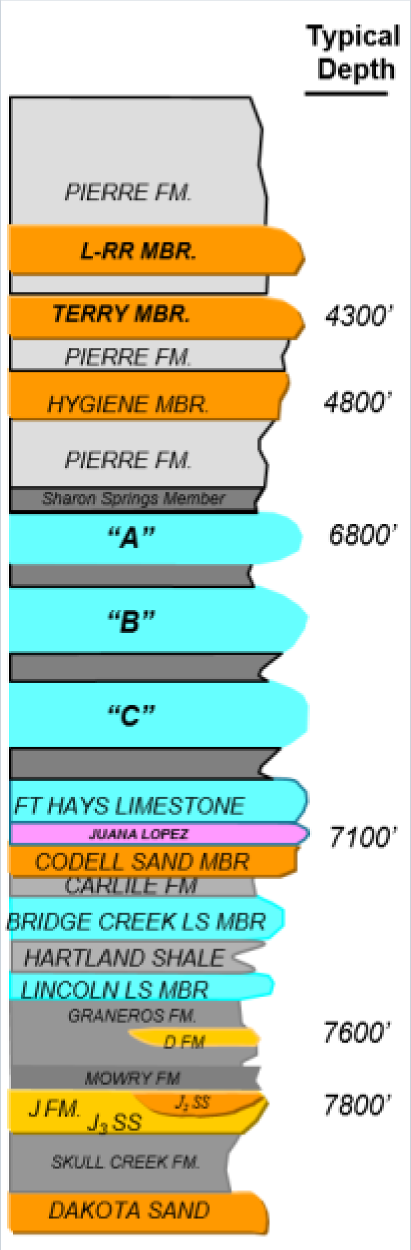
- Visual analysis of seismic data to identify potential igneous bodies, faults, other major structures
- Gravity & magnetic datasets will substitute if seismic data is unable to be obtained
- Visual analysis of gravity & magnetic datasets to identify igneous bodies, other structures around "hot" anomalies

Geochemical Analysis

- Hydrothermal fluid samples from areas of "hot" anomalies will be obtained
- Concentrations of major and minor elements determined via ion chromatography
- Chemostratigraphic logs created via XRD, XRF, and pyrolysis analysis
- Will discern Colorado Mineral Belt influence on geothermal anomalies

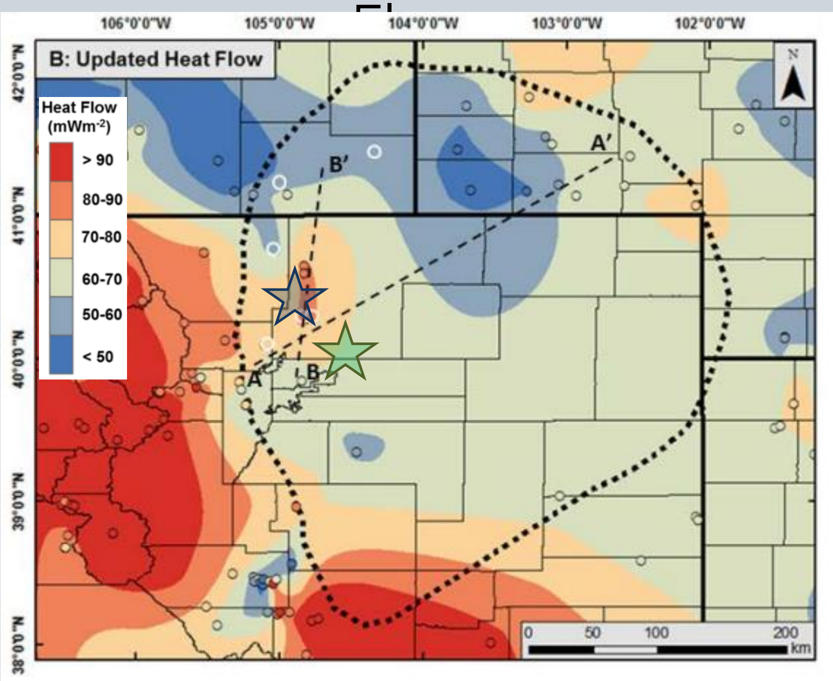
Geologic Setting

COLORADO SCHOOL OF MINES MUDTOC



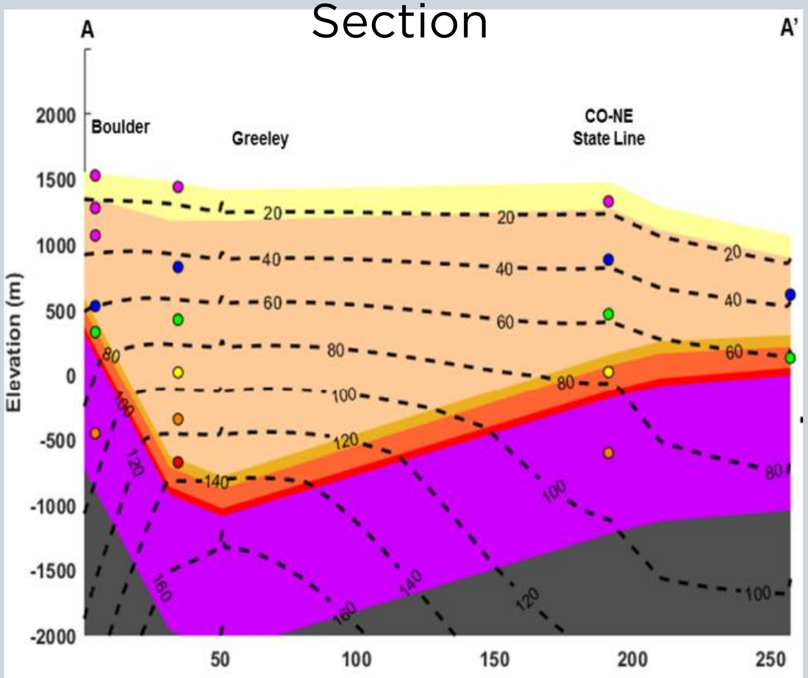
From Sonnenberg, 2016

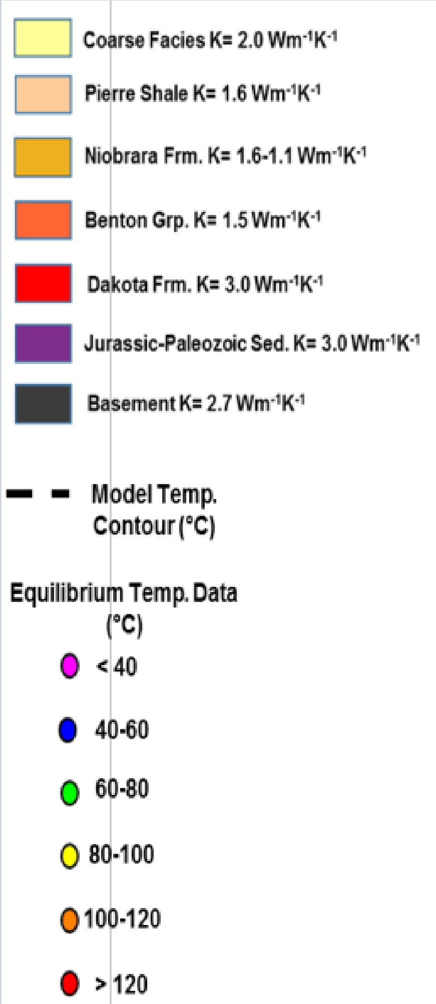
Denver Basin Heat Fl



Heat flow contours derived from well log data. Location of Wattenberg Field denoted by the blue star, location of Peoria Field denoted by the green star. Modified from Brokaw, 2017

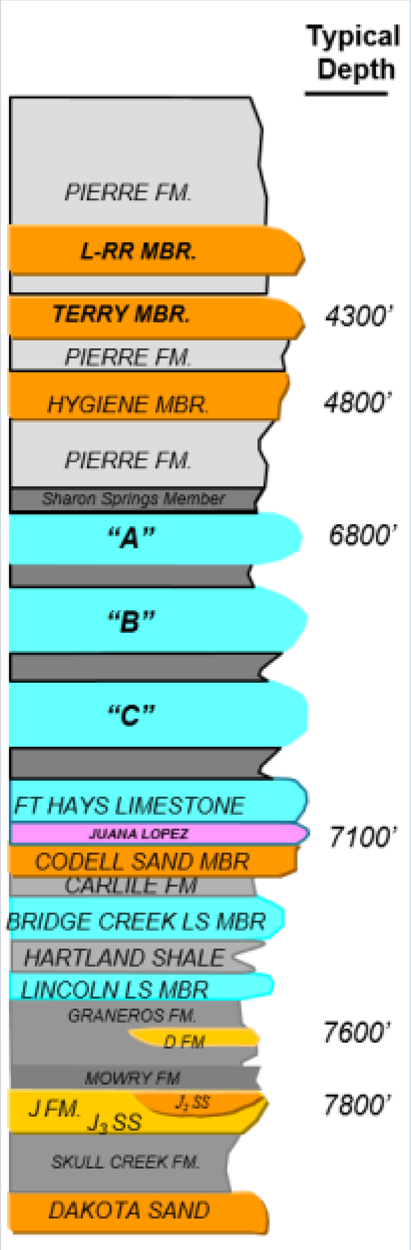
A-A' Heat Flow Cross Section





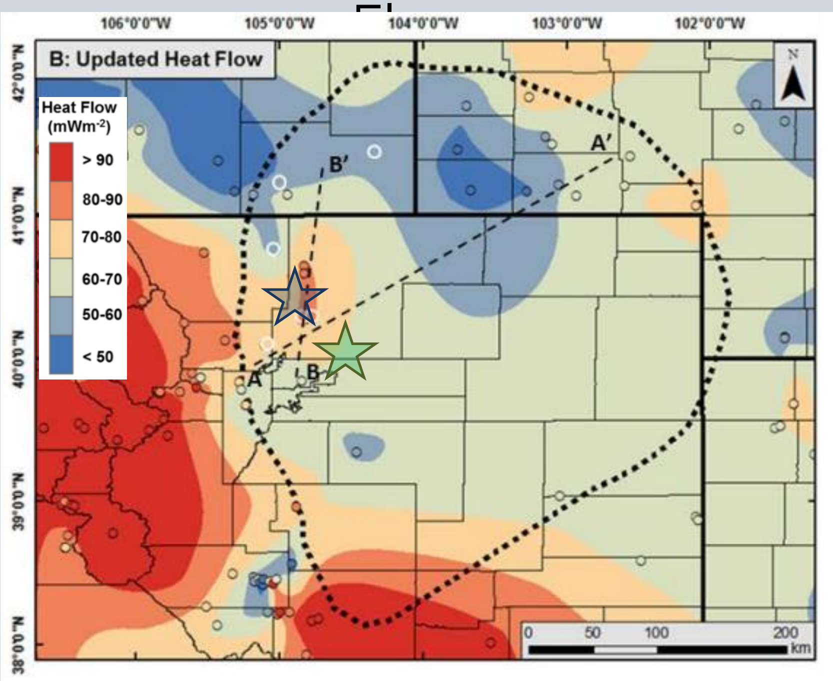
Subsurface heat flow values derived from well log data. Highest heat flow values found in the Dakota Group (includes Muddy "J" Sandstone). From Brokaw, 2017

Geologic Setting



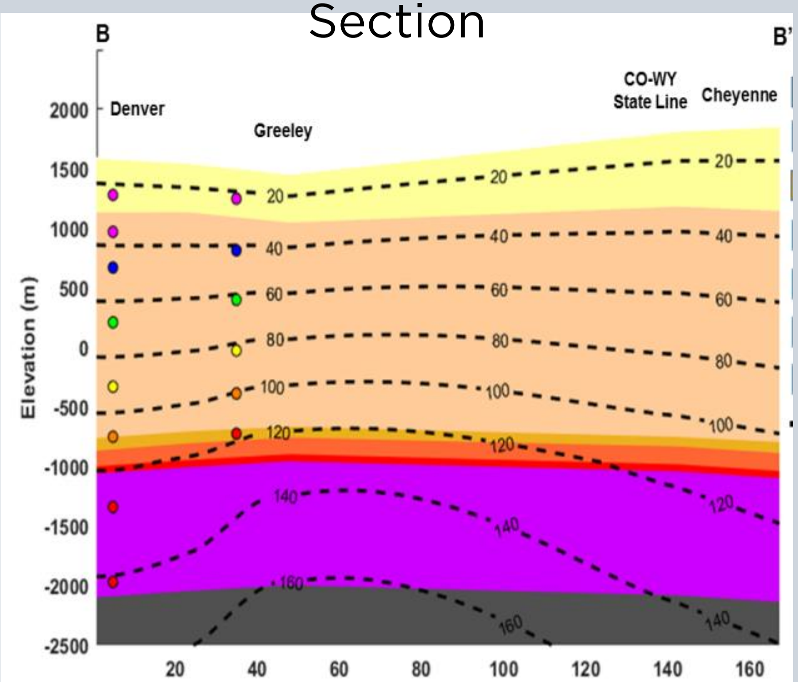
From Sonnenberg, 2016

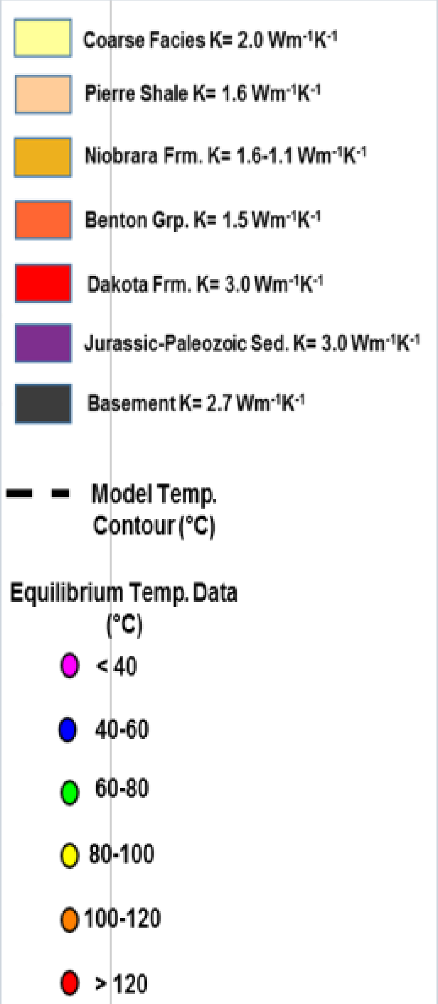
Denver Basin Heat Fl



Heat flow contours derived from well log data. Location of Wattenberg Field denoted by the blue star, location of Peoria Field denoted by the green star. Modified from Brokaw, 2017

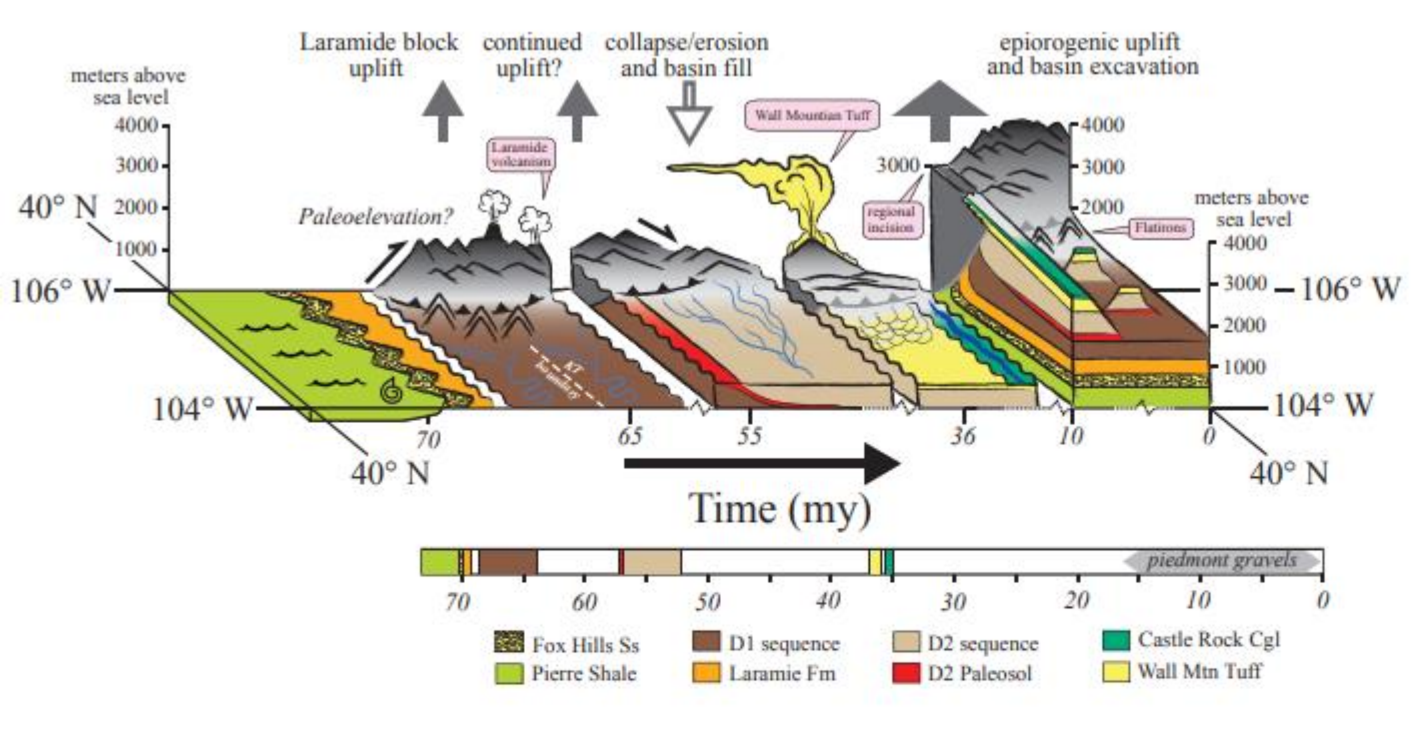
B-B' Heat Flow Cross Section





Subsurface heat flow values derived from well log data. Highest heat flow values found in the Dakota Group (includes Muddy "J" Sandstone). From Brokaw, 2017

Tectonic Setting



Evolution of the Colorado Front Range and Denver Basin. From Raynolds et al., 2007

Time	Major Tectonic Events
Precambrian	Major fault systems and shear zones formed via tectonic adjustments
Cambrian - Ordovician	Transcontinental Arch & Sierra Grande uplift controlled deposition
Silurian – Permian	Uplift of the Ancestral Rocky Mountains & Amarillo Mountains Alliance Basin and Sterling Basin form
Triassic - Cretaceous	Western Interior Seaway formed Laramide Orogeny began in Late Cretaceous
Paleogene	Laramide Orogeny formed the modern Rocky Mountains and associated mountain ranges Uplift caused tilting of the basin, solidifying the structural configuration seen today

Timeline

COLORADO SCHOOL OF MINES MUDTOC

Fall, 2023

- Gather data to create the BHT and geothermal temperature maps of Denver Basin
- Develop structural framework map of Denver Basin
- Visually analyze seismic, gravity, & magnetic datasets
- Obtain hydrothermal fluid samples and begin analysis
- Begin to synthesize all findings

Spring, 2024

- Wrap up any unfinished data analyses
- Synthesize all maps and data to propose most likely cause(s) of "hot" geothermal anomalies
- Write thesis
- Defend thesis
- Finish all necessary thesis paper edits and submit final draft to CSM library

Conclusions

COLORADO SCHOOL OF MINES
MUDTOC

I. In almost every case, hot geothermal anomalies are proven to enhance oil & gas production worldwide

II. In every case, hot geothermal anomalies enhance geothermal energy production and allow for varied applications

III. Multiple hypotheses have been proposed to explain the cause of local geothermal anomalies

IV. When the cause(s) of geothermal anomalies in the Denver Basin are determined, answer(s) will aid hydrocarbon & geothermal exploration worldwide

Thank you to our Sponsors!

COLORADO SCHOOL OF MINES MUDTOC

Sponsoring Member Companies

Antero Resources

Boomtown Oil

HELIS OIL & GAS, L.L.C.

Chevron

CIVITAS

FUNDARE RESOURCES COMPANY, LLC

GMT Exploration Company LLC

COTERRA

HALLIBURTON

OXY

Red Willow Production Company

TGS

EOG Resources

In-Kind Supporting Companies

GeoMark

IHS

Mike Johnson & Associates

MJ LOGS

PRA Platte River Associates, Inc.

Schlumberger

ENVERUS

COLORADO SCHOOL OF
MINES
MUDTOC