



**Direct Confirmation of Commercial Geothermal Resources in Colorado using Remote Sensing and On-Site Exploration, Testing and Analysis**

Project Officer: Mark Ziegenbein  
Total Project Funding: \$7,582,633

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Hydrothermal Exploration Validation

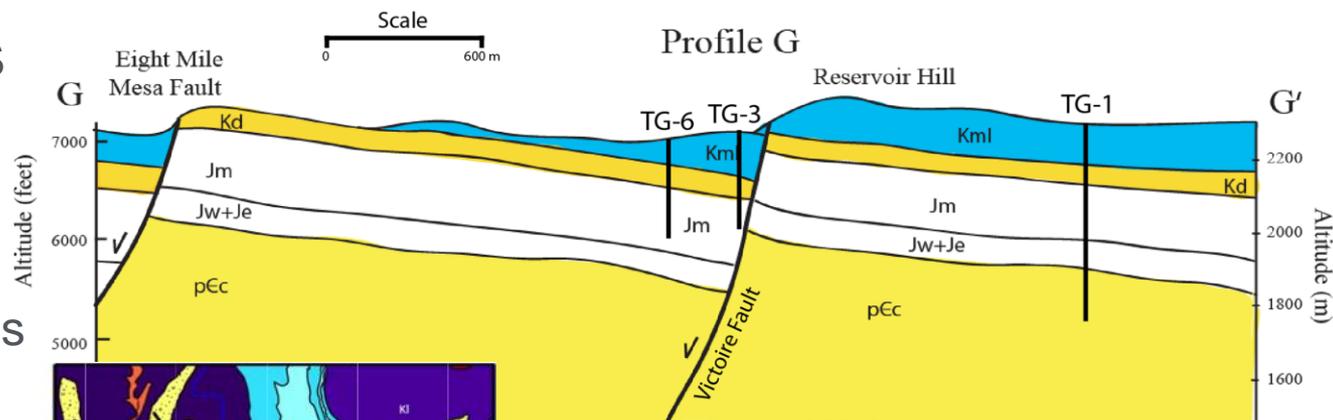
## SOPO Objectives

- Demonstrate communities will support development
- Develop a sequential model for geothermal development
- Demonstrate the validity of remote sensing and other inexpensive techniques
- Demonstrate value of combining community and development techniques

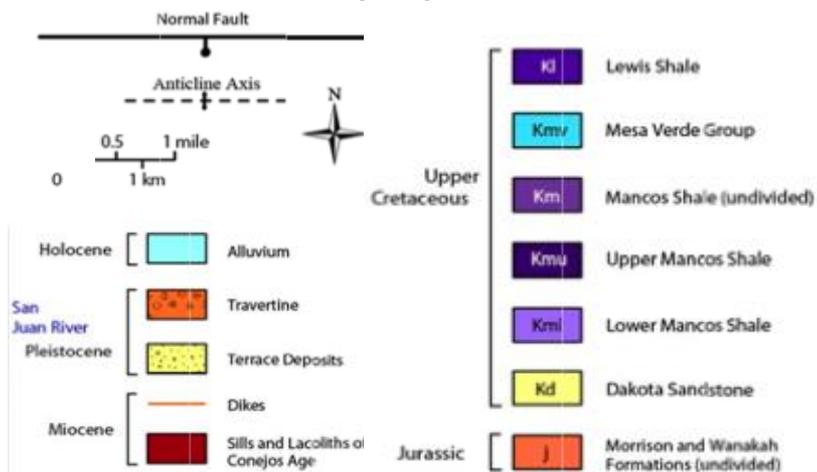
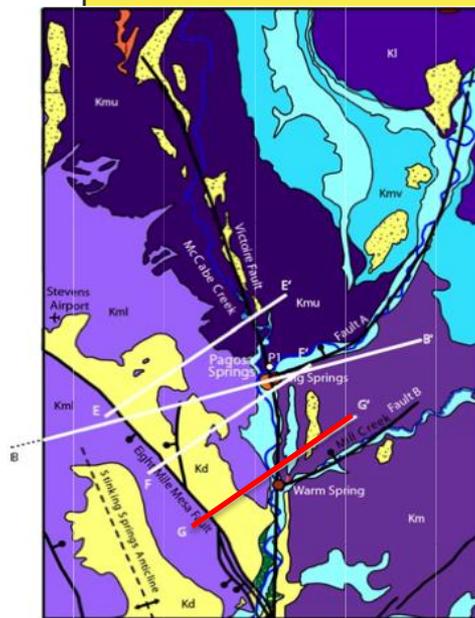
## Impact on GTO Goals

- Assessed new technologies to lower exploration costs and early stage risk
- Conducted a temperature gradient drilling program in Colorado
- Combined federal, state, and local support for early risk mitigation in low temperature geothermal power exploration

## Regional geologic map and cross section with targeted well sites



NOTE: Cross section colors do not match those of the geologic map



## Innovative aspects

- Initial exploration (Phase 1A)
  - ASTER, Landsat thermal exposures
- Surface testing
- MMR gas samples (soil)
- Geophysical assessment
- Community involvement

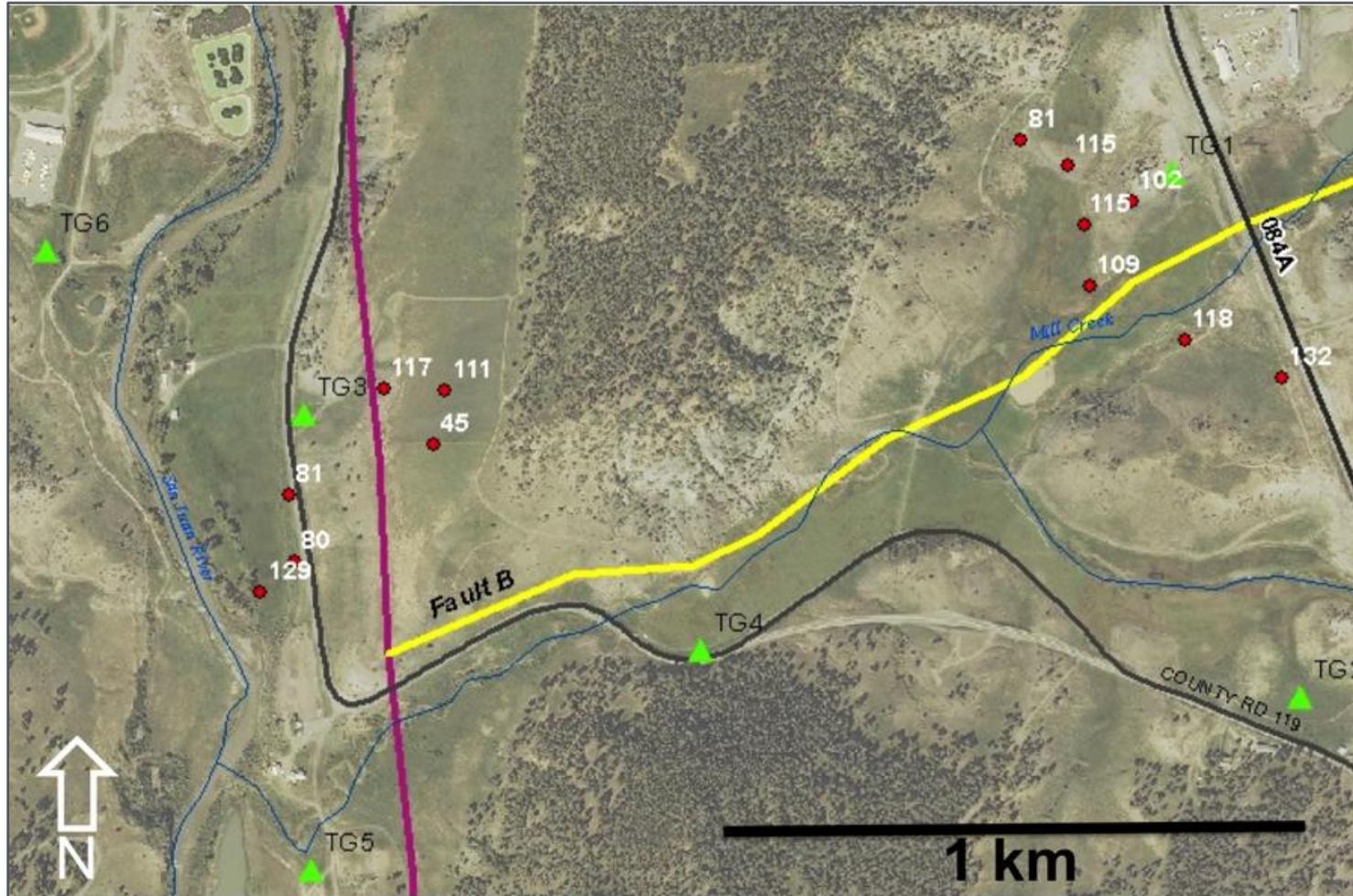
## Scientific Approach

- Initial identification of potential resources through analysis of publically available remote sensing data (Phase 1A previously reviewed)
  - Public data from TM, ETM+, ASTER
  - Land surface temperature
  - 5 broad locations identified
- Field evaluation of prioritized locations
  - Geologic mapping
  - Geophysical surveys (CSM and Revil)
  - MMR soil gas samples
  - Springs and existing wells geochemistry and geothermometry

## Scientific Approach (cont.)

- Identify and drill thermal gradient (TG) wells
  - Fault intersections as potential pathway for up-flow
  - 6 locations identified, 3 drilled
  - Coring for geologic information
  - Order of drilling based on expected value of data
  - Equilibration and temperature gradient measurements
  - Environmental difficulties delayed program
- Identify and drill deep confirmation wells
  - Locations to be based on TG results
  - Not yet identified (TG program still active)

## Initial Exploration Region



- MMR gas sample locations (° C)
- ▲ Planned TG drilling site
- Victoire Fault
- Mill Creek Fault (Fault B)



State of Colorado

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Compile, Analyze & Synthesize existing data for TG targets	Phase 1 report with 6 TG targets identified	Go Approved 10/2014
Complete TG drilling and analysis for exploration well targets	3 TG wells completed, proposal for redirect of TG program.	Redirect Submitted 4/2015

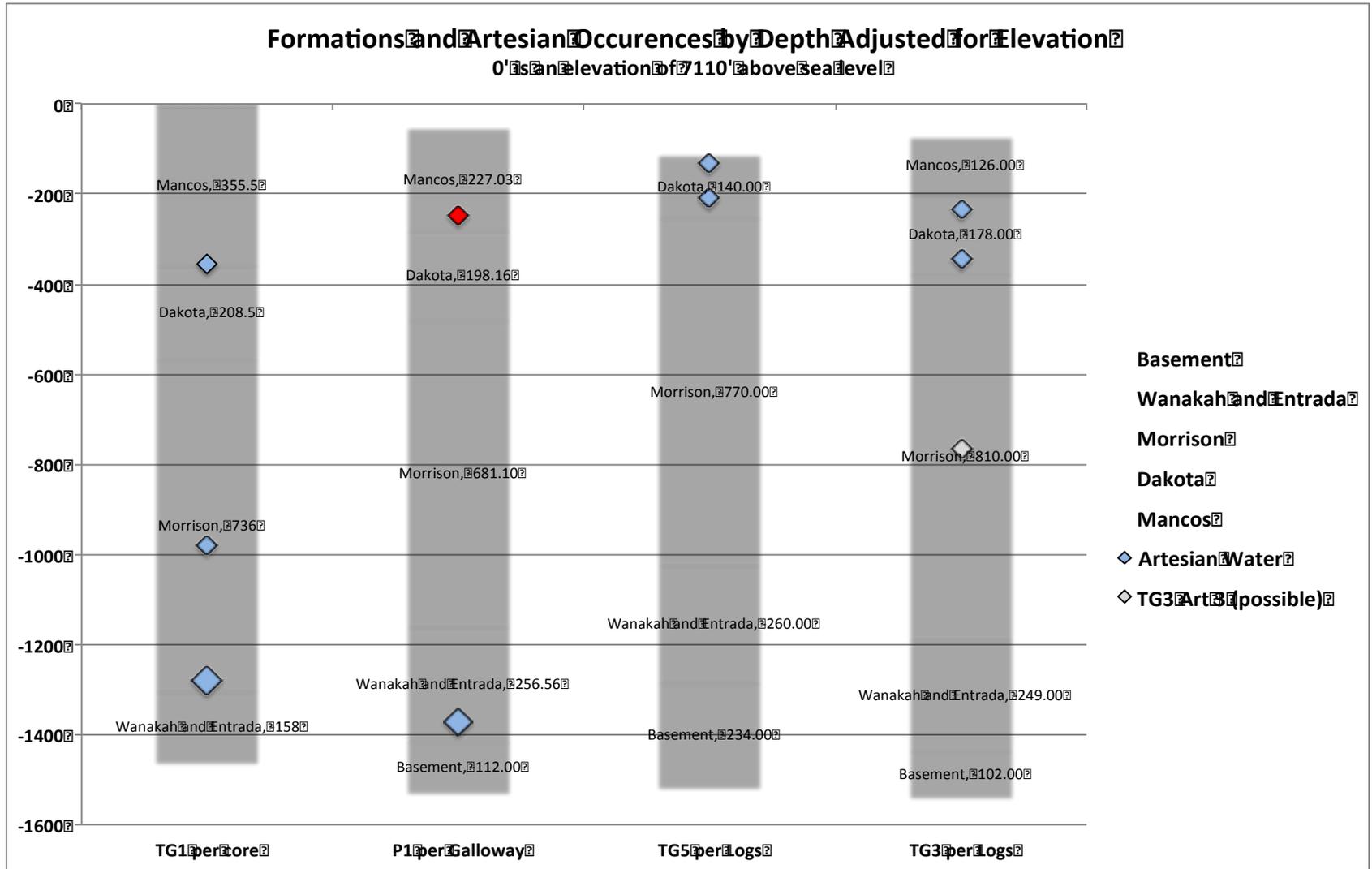
## Compile, Analyze & Synthesize existing data for TG targets

- 6 targets chosen
  - Political obstacles overcome
    - Partnership with Town of Pagosa Springs and Archuleta County
    - Supportive landowners
    - Monitoring existing town system (protecting existing businesses)
  - Technical accomplishments
    - Accuracy of remote sensing determined not useful for site selection within broad area
    - Ongoing evaluation of MMR gas sample anomaly data
  - Technical challenges
    - Environmental delays
    - Artesian with core rig
    - Cement

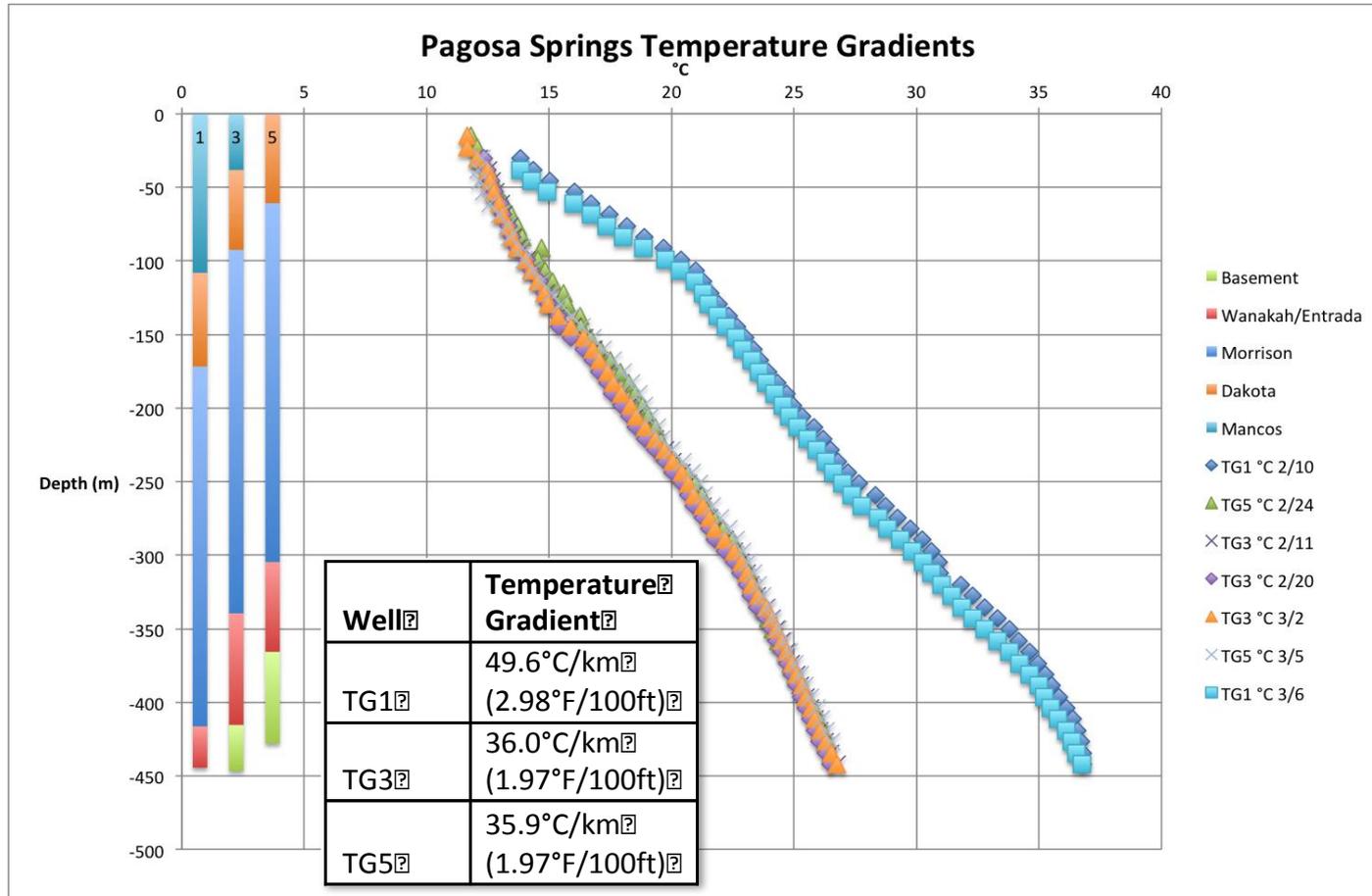
## Complete TG drilling and analysis for exploration well targets

- 3 TG wells drilled
- Thermal gradients measured
- Water chemistry and geothermometry
- Down hole geophysical logging
- Core logging (to be slabbed)
- Technical challenges:
  - Core rig could not handle significant artesian flows
  - Cement interaction with subsurface water (sulfur slowed set time)
  - Significant time and budget cost to water
  - Insufficient oversight once limitations of artesian control with the core rig were reached

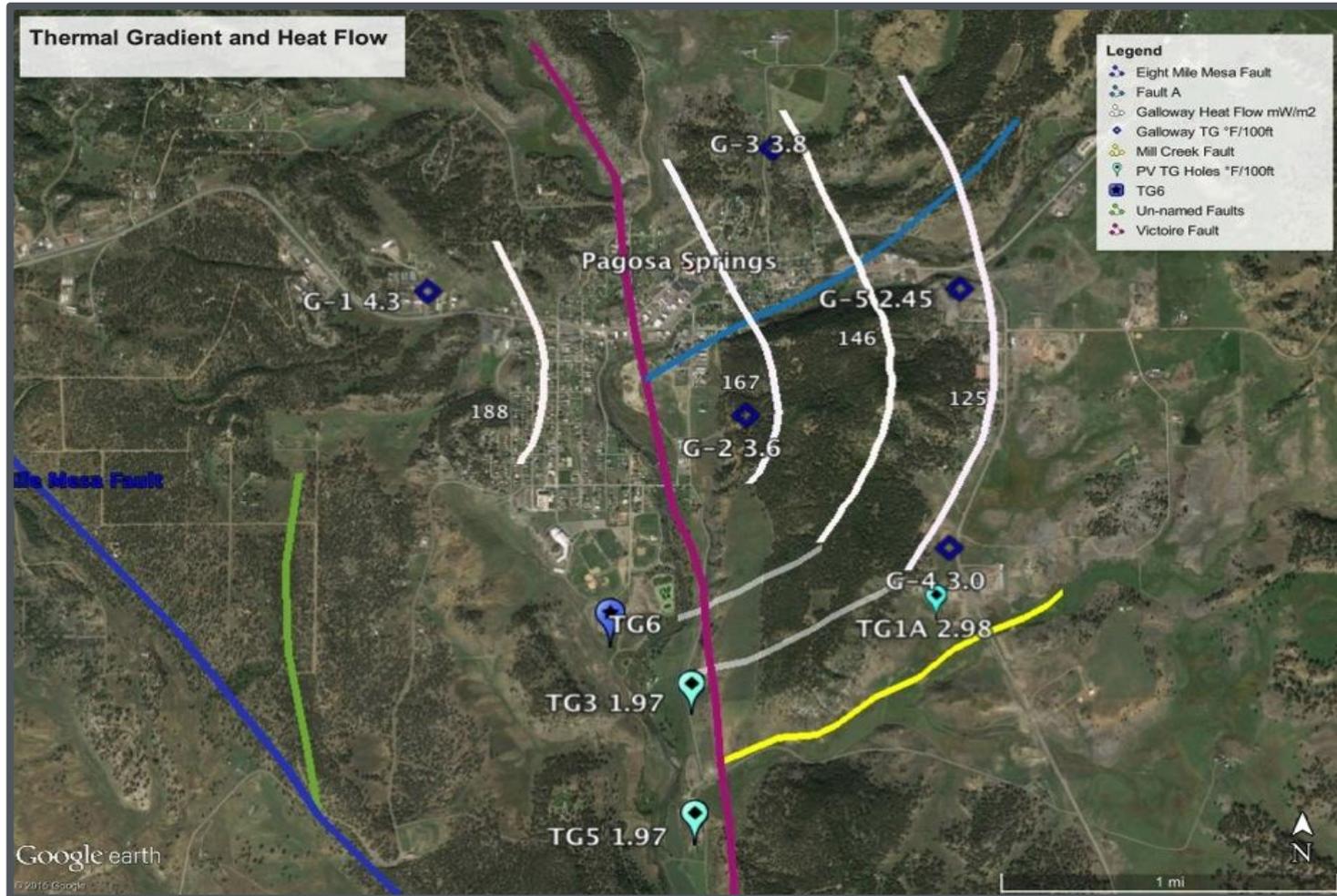




Artesian water diamonds are colored by temperature (red is hot, blue is cold) and sized by flow volume (approximate). TG3 had a potential artesian during rotary drilling but it was not confirmed.



- TG1 would be an acceptable location for a 160° F resource but environmental issues inhibit drilling (Pagosa Skyrocket)

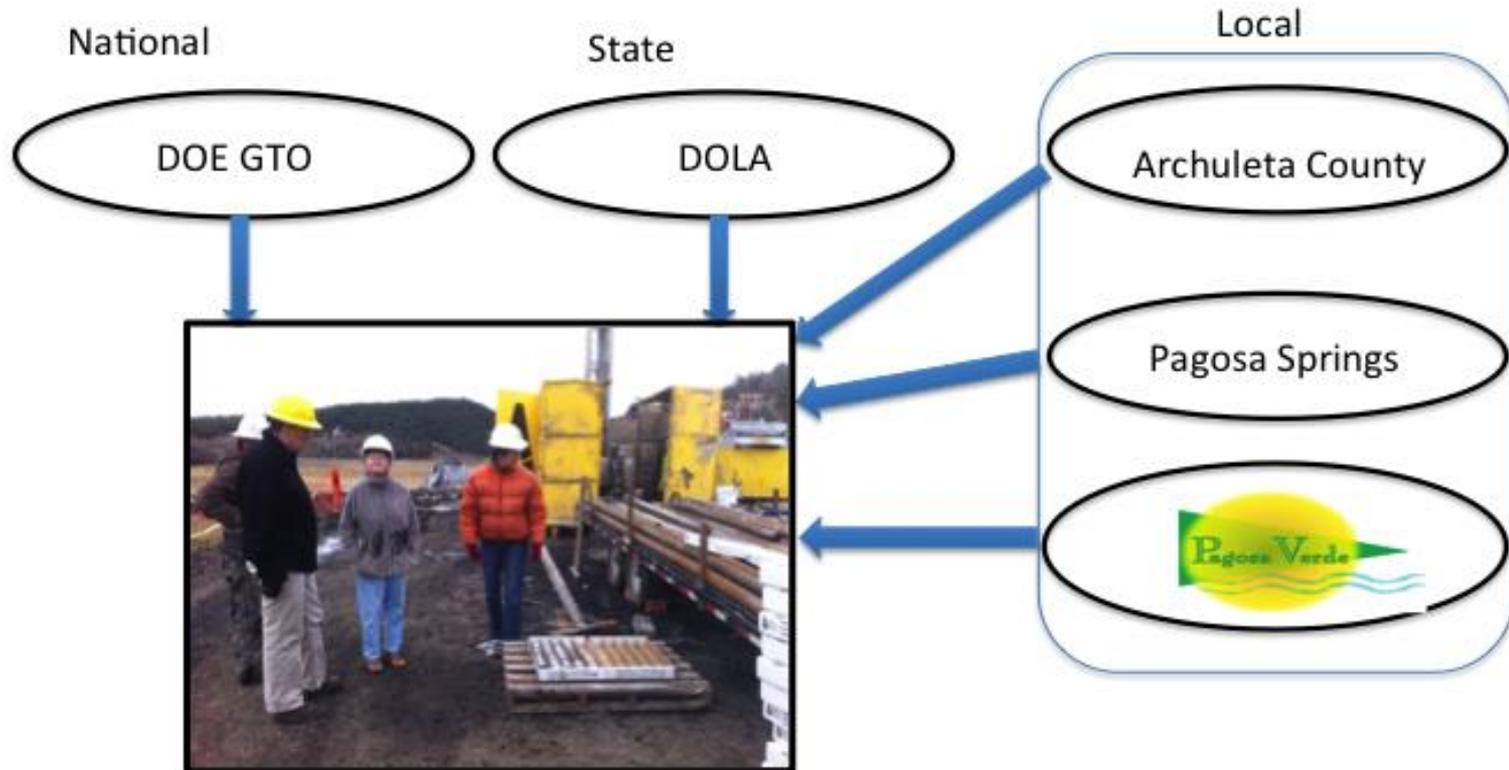


White lines are heat flow contours ( $\text{mW}/\text{m}^2$ ), gradients reported in  $^{\circ}\text{F}/100\text{ft}$

- Lack of elevated gradient at TG-3 and TG-5 limits the southern boundary of the heat flow anomaly
- Geophysically indicated plumbing exists but there is not hot water at an economic depth for TG-3 and TG-5
- Ongoing evaluation of the MMR soil gas data value to the drilling program
- Validates gradients from shallow (300ft) wells drilled by Galloway in 1980 by colocation with a deeper thermal gradient well (TG1, 1458ft (444m)) when accounting for thermal conductivity variance between the Mancos shale and underlying sediments (Dakota, Morrison, Wanakah)
- Increasing heat flow anomaly to the west provides guidance for future exploration activities
- Down-hole geophysical logging allows for improved unit correlation between core and rotary drilled sections of well
- Addresses political difficulties regarding regional development of geothermal resources

Milestone or Go/No-Go	Status & Expected Completion Date
Redirect Proposal Go/No-Go	Submitted, Go/No-Go expected 4/2015
Complete Initial TG Analysis/Documentation/Core Lab/NGDS	Ongoing: Logging Analysis Complete, TG Collection complete, Thin Sections Ongoing, Heat Flow analysis ongoing, Core Slabbing and Storage in Process, MMR Analysis and results ongoing, NGDS not begun June 2015
Complete Redirect	Pursuing water chemistry and gradients of existing wells; Drill 5 new TG Holes; MT if BA allows: On hold awaiting redirect approval. June 2015

## Community involvement



- Increased understanding of the Pagosa Springs geothermal system
- Model of community support and involvement
- Surface exploration techniques and subsurface imaging are necessary to identify a drilling location
- Full time project manager, geologist, a drill crew with rotary experience, and a capable drill rig for artesian management are necessary for cost control in an artesian environment
- Thermal gradient drilling program occurred in Colorado