Why is Nevada in Hot Water?
New Approaches to Understanding and Harnessing Nevada's Vast Geothermal Resources

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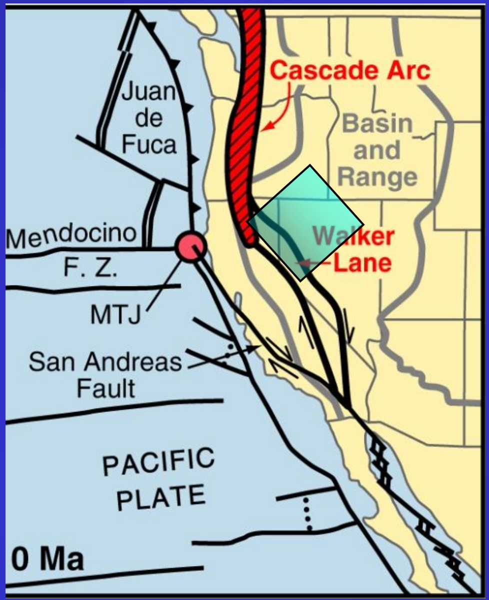
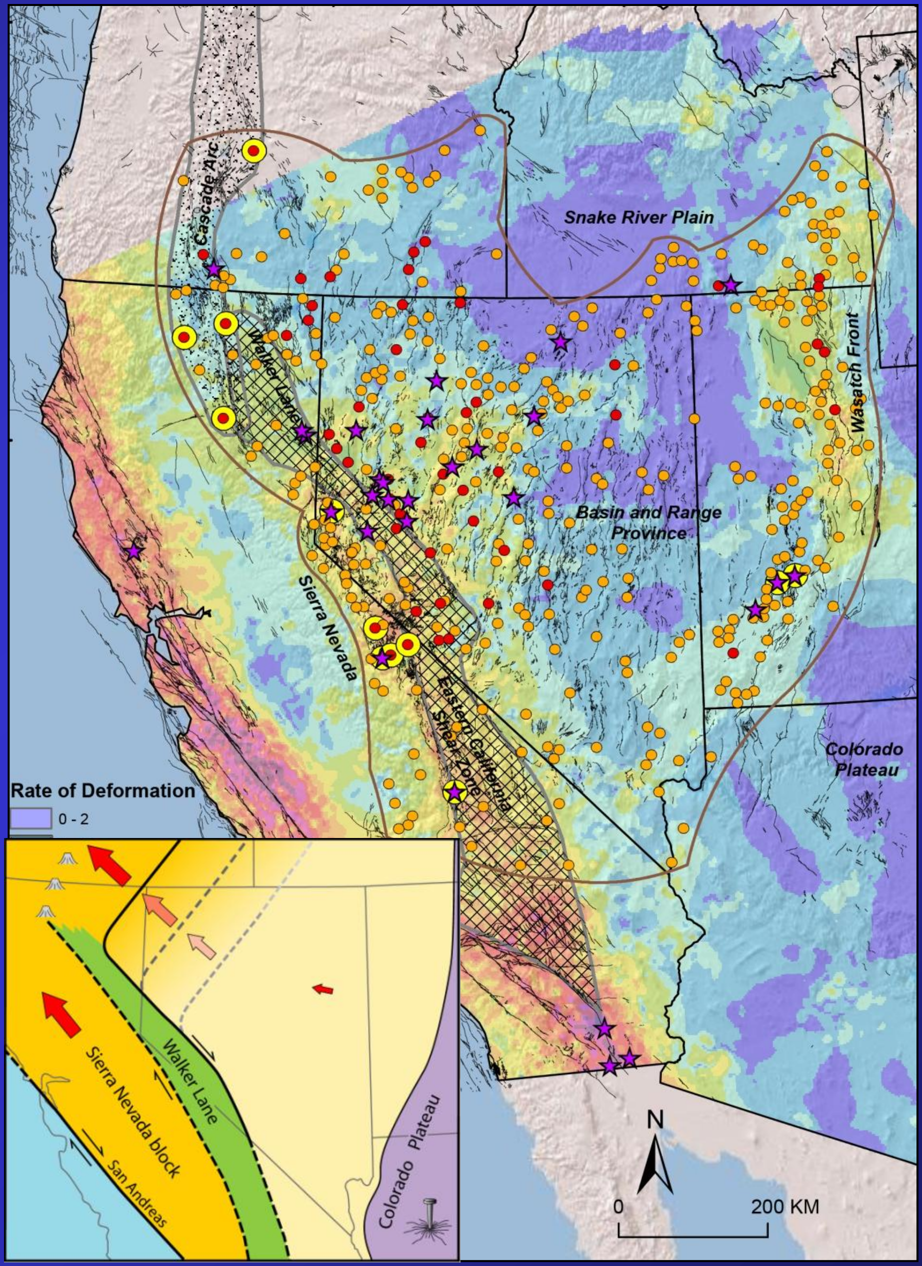
- **Ironic that what little water Great Basin has is hot.**
- **Why is Nevada in hot water?**
- **Difficult to find sufficient fluid flow.**
- **Permeability more important than temperature.**
- **Most geothermal resources are blind, but resources are vast.**
- **New approaches and technologies can facilitate sustainable development.**

Why is Nevada in Hot Water?

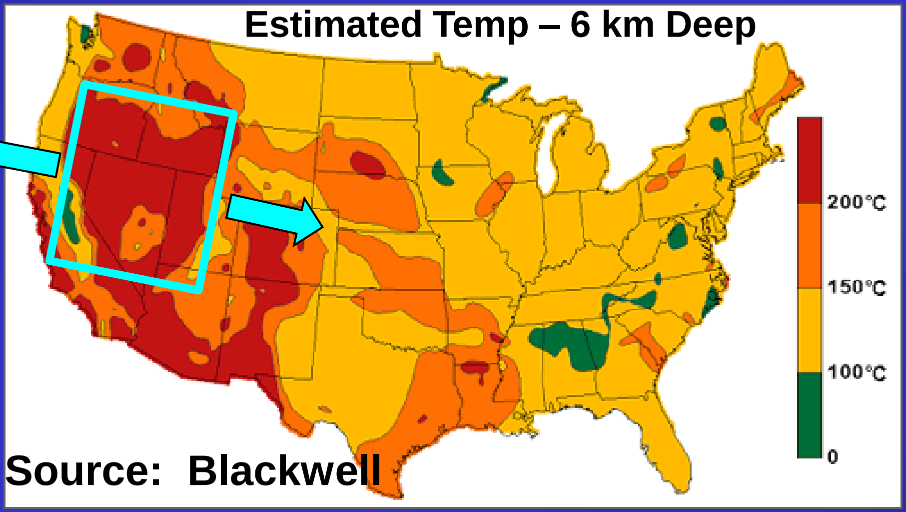
- >400 known geothermal systems
- ~3/4 of resources blind or hidden
- Fields cluster in northern Great Basin
- Strike-slip faulting diffuses into crustal extension inducing dilation on faults

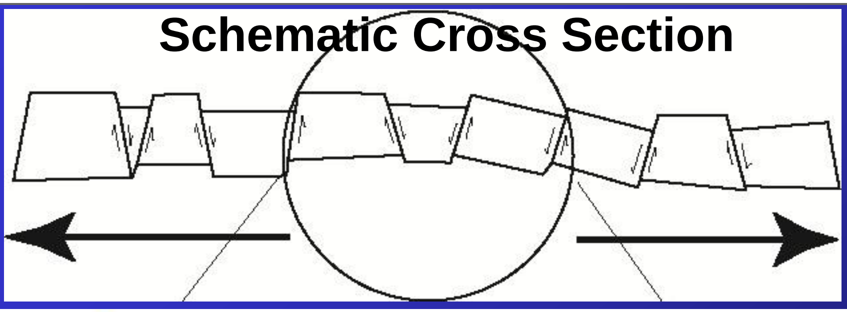


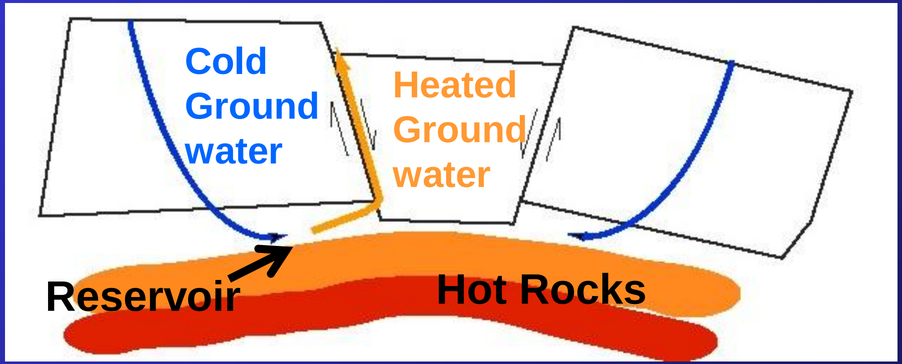


Great Basin Region

- Region of warm crust
- Crust pulling apart or extending
- As crust thins, hot rocks get closer to surface
- Cannot drill 6 km deep (20,000 ft) economically
- Faults allow hot water to reach shallow levels
- Must find hot water pathways using geologic and geophysical techniques

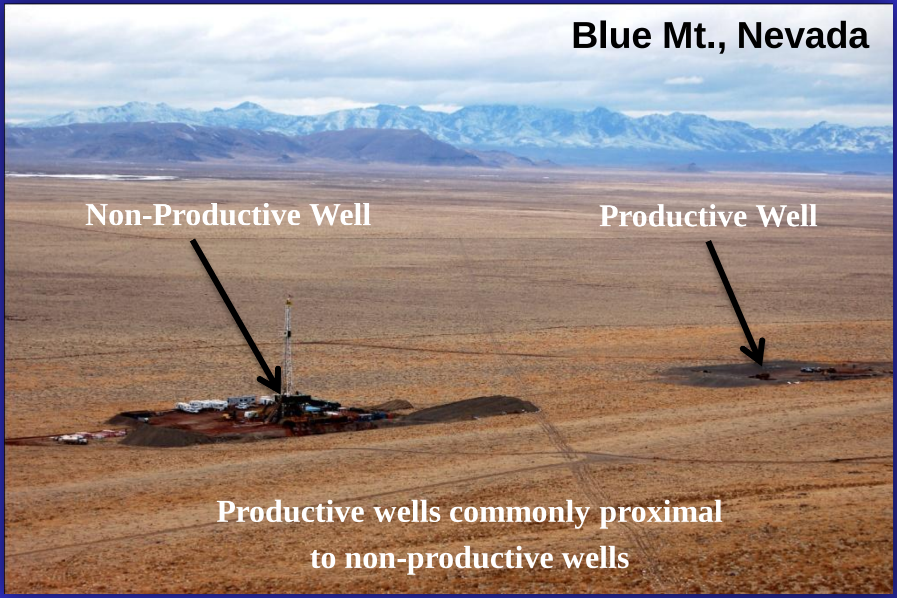


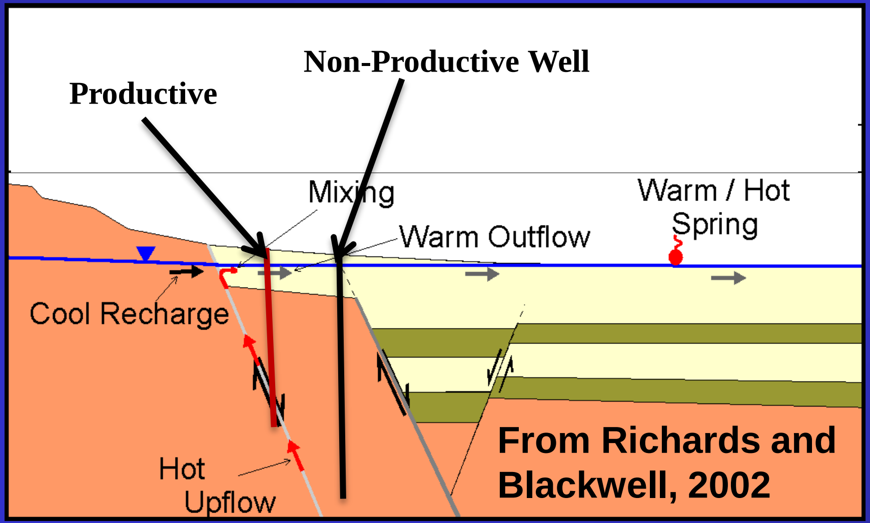


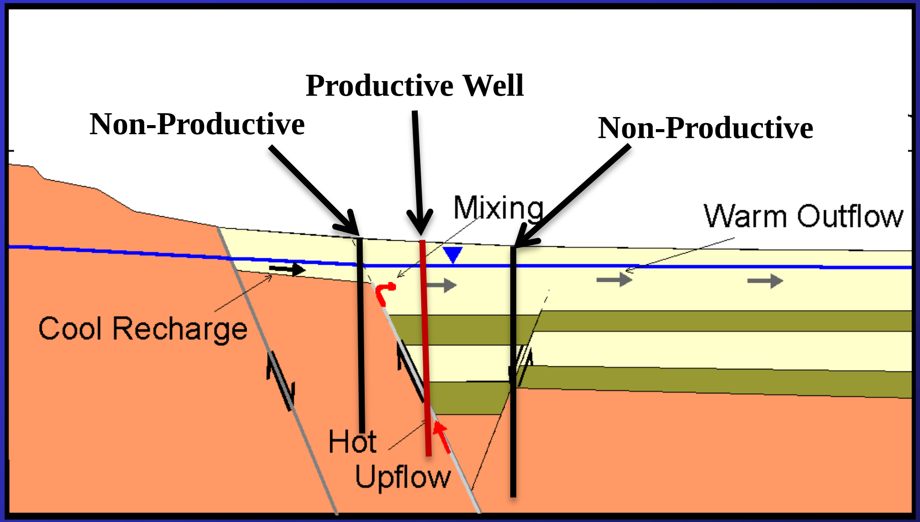


Exploration Challenges

- Exploration Challenges
  - Spring directly above upflow from deep source (uncommon)
  - Outflow from source (common)
  - Hidden or blind systems (common)
- Results – significant drilling risk
  - Hot dry wells
  - Overturn in down-hole temperatures
- Need better conceptual models to:
  - Locate areas of upflow
  - Avoid typically less productive outflow zones

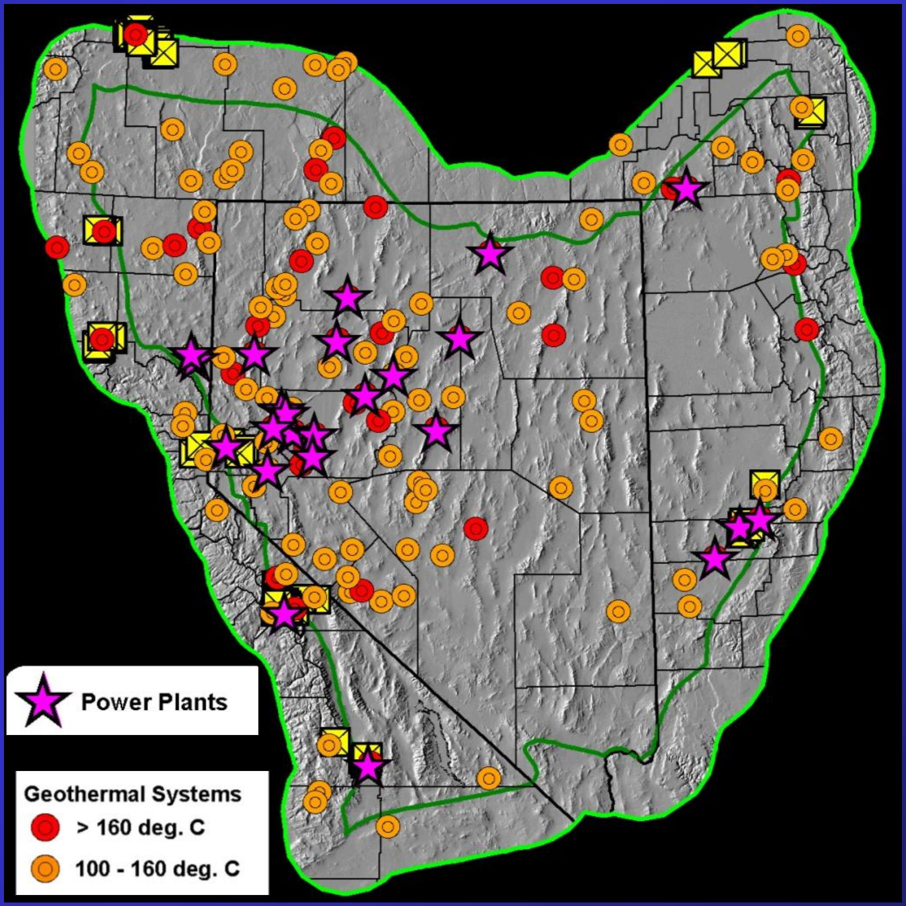






Approach

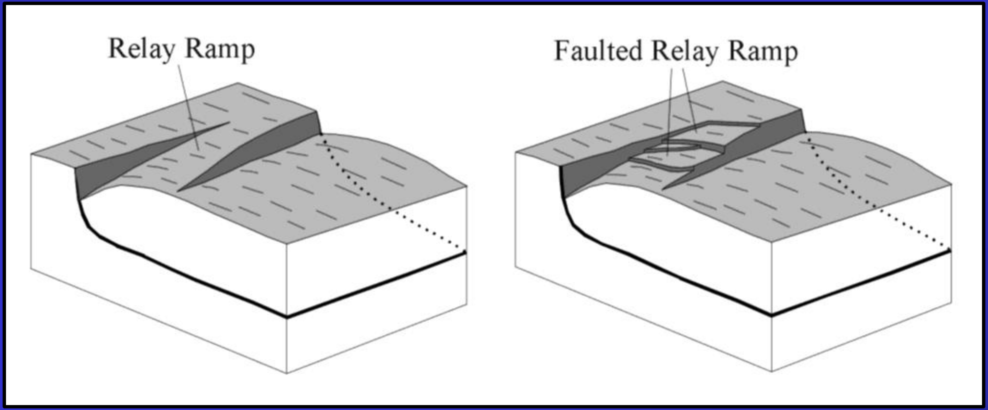
- Characterize structural settings of known systems to better target blind systems
- Approach
  - Develop comprehensive catalogue of favorable fault settings and models
  - 3D modeling of several systems
  - Slip and dilation tendency analysis
  - Synthesize findings
- Combine conventional and innovative techniques to define fluid pathways
- Major impacts:
  - Reduce risk of drilling non-productive wells in conventional systems
  - Exploration for undiscovered blind systems
  - Expansion of conventional systems
  - Balancing production vs. injection



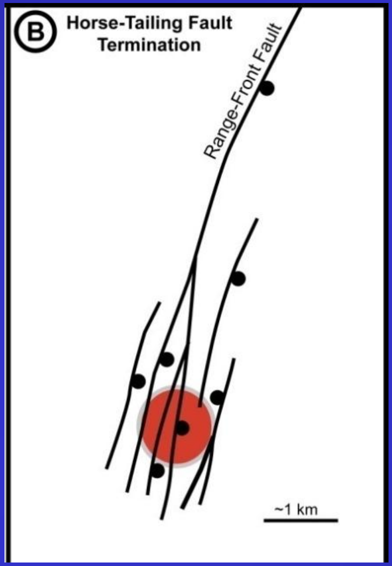
Great Basin Geothermal Systems: Distribution of known systems long established, but structural settings of systems not systematically defined

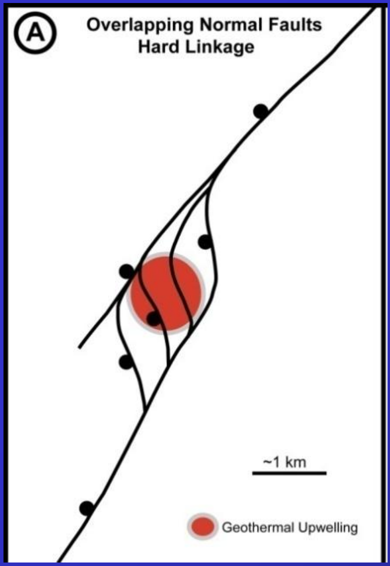
Structural Controls Overview

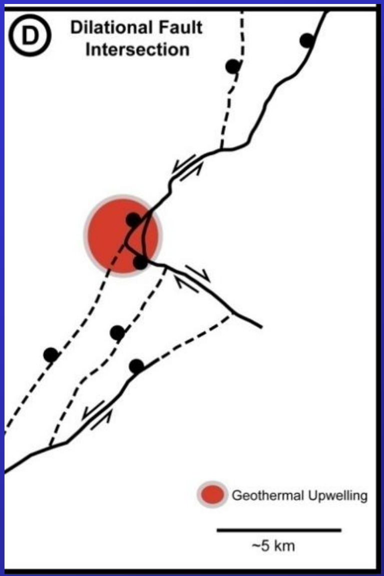
- **Most fields not on mid-segments of major faults**
  - Stress relieved periodically by major earthquakes
  - Clay gouge limits permeability
- **Most on less conspicuous normal faults**
- **Common occurrences:**
  - Fault tips: Terminating, horse-tailing faults
  - Steps or relay ramps in normal fault zones
  - Intersecting faults – dilational quadrants
  - Accommodation zones: Overlapping opposing faults
  - Pull aparts in strike-slip faults
- **Similar findings in other settings - globally:**
  - TVZ of New Zealand (Rowland & Simmons, 2012)
  - Western Turkey (Faulds et al., 2009)
  - Worldwide (Curewicz and Karson, 1997)

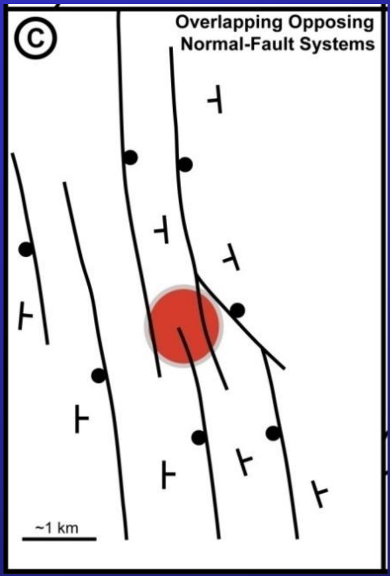


Most Common Setting – Step-Overs or Relay Ramps



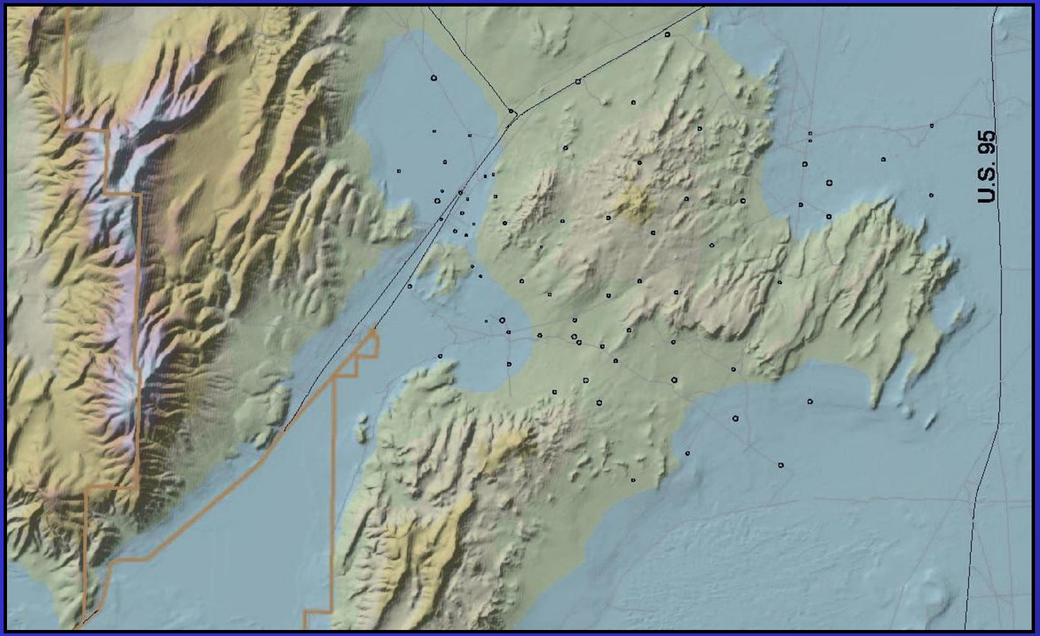


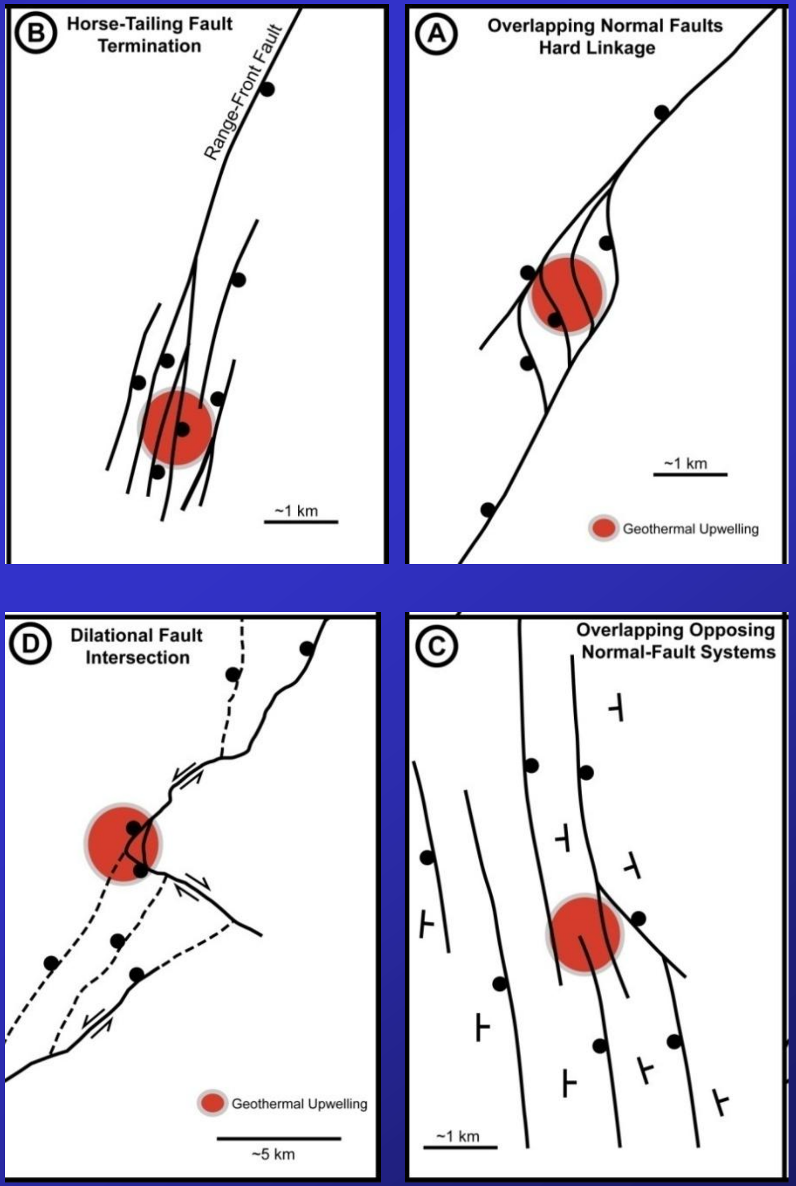




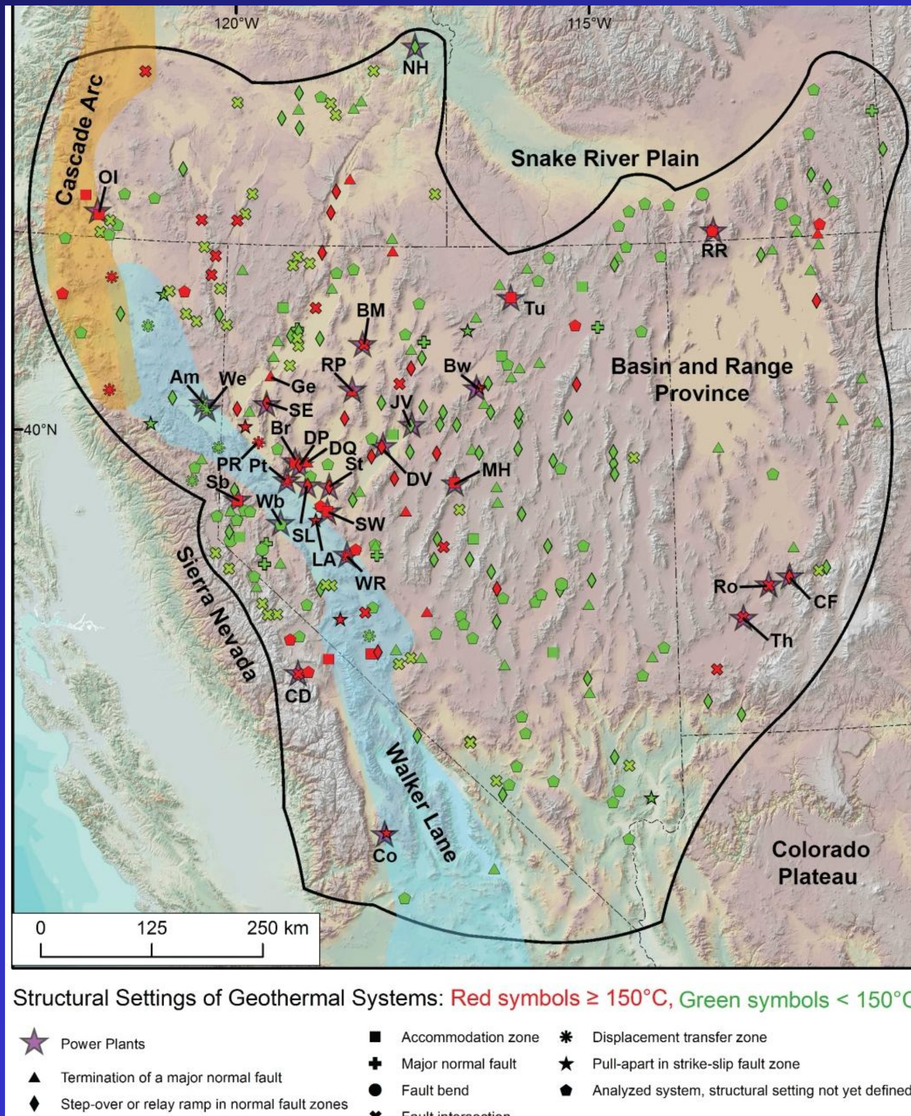
Exploration Applications for Blind Systems

- Indicative features for blind systems
  - Lateral terminations of mountain ranges
  - Steps in range fronts
  - Interbasinal highs
  - Ranges of low discontinuous ridges



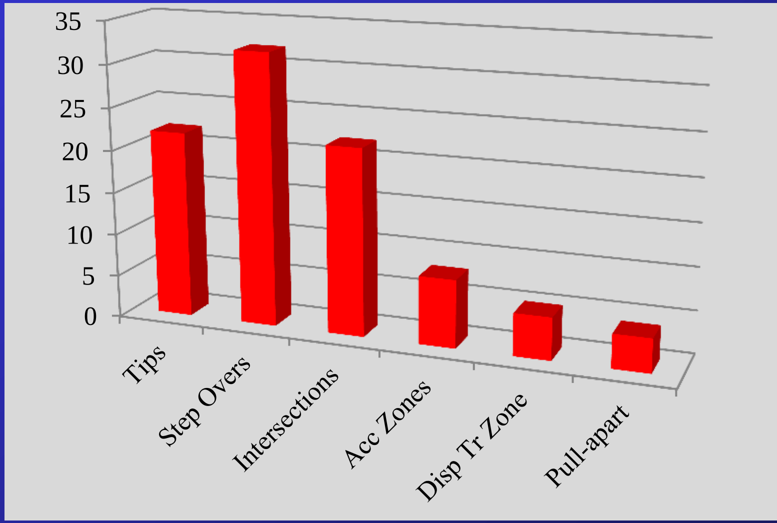


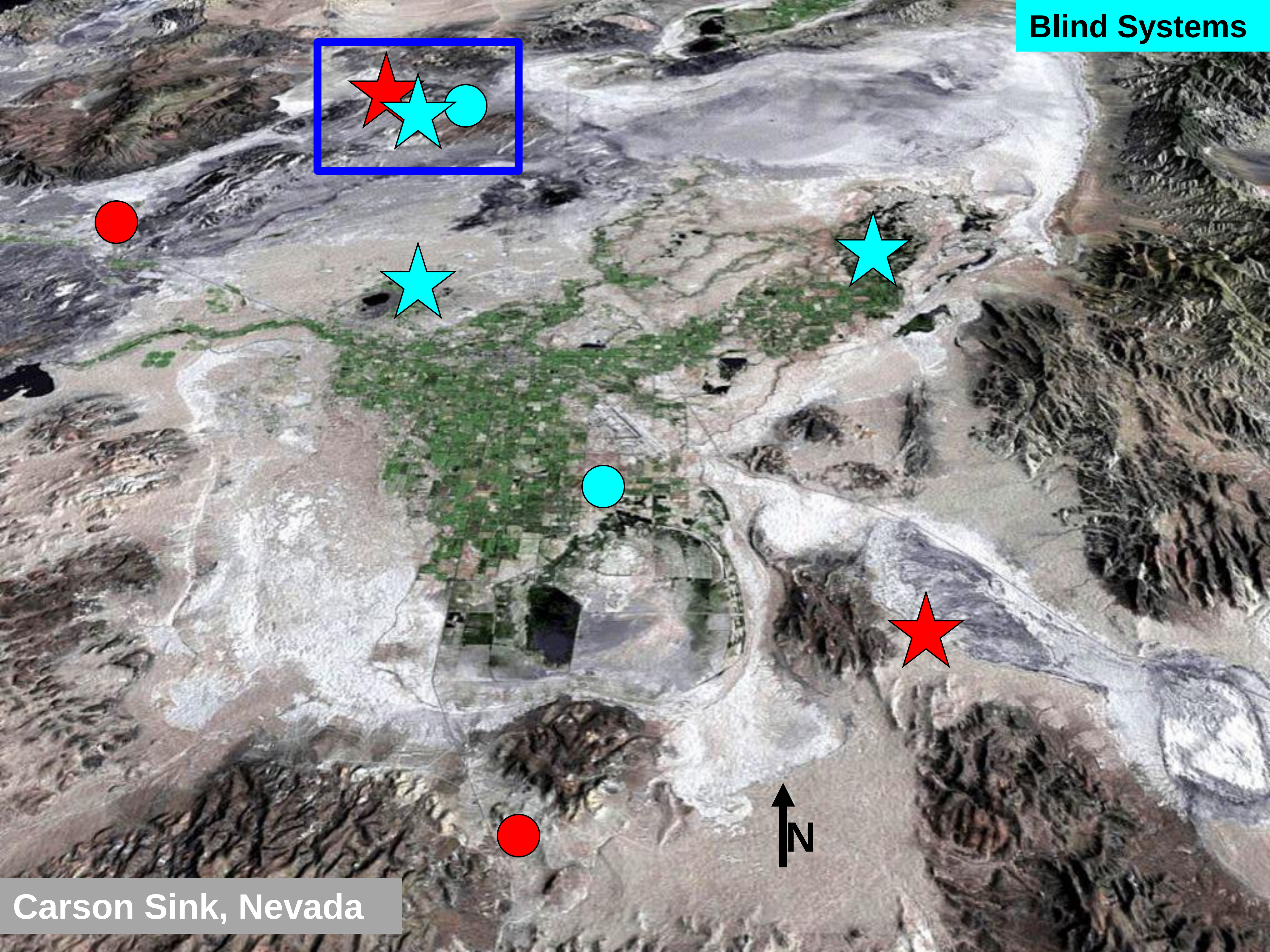
Structural Inventory: Major Findings



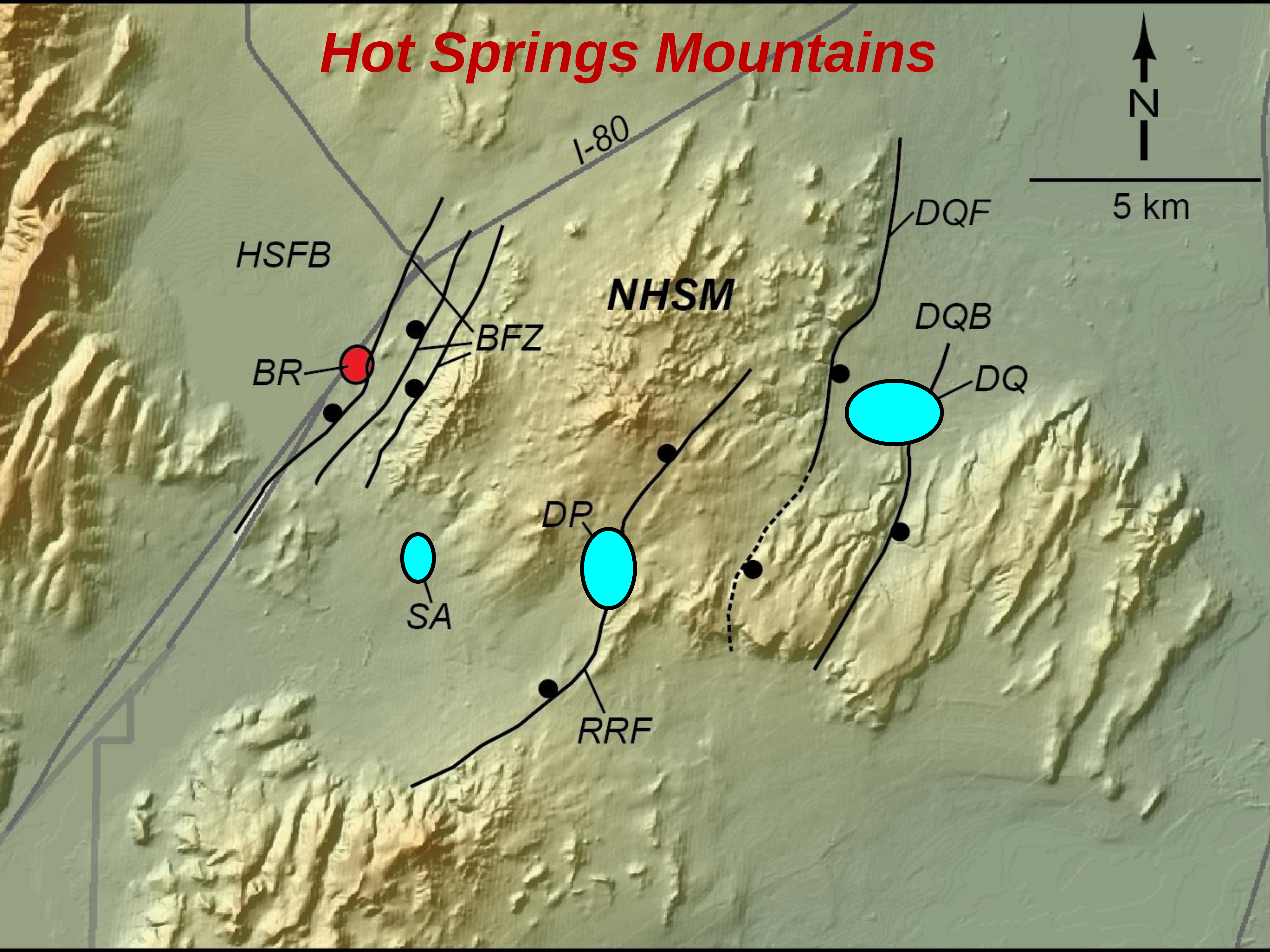
Structural Settings - ~400 Systems Analyzed

- **Structural settings for geothermal fields:**
  - **Major normal fault (<3%)**
  - **Normal fault tip or termination (~22%)**
  - **Step-over or relay ramp in normal fault (~33%)**
  - **Fault intersection-normal and strike-slip or oblique fault (~22%)**
  - **Accommodation zone (~9%)**
  - **Displacement transfer zone (~5%)**
  - **Pull-apart (~4%)**
- ***Quaternary faults in most systems***
- **Most common settings – critically stressed – fluid pathways more likely to remain open**
- **Many productive systems have >1 type of favorable setting at single locality**

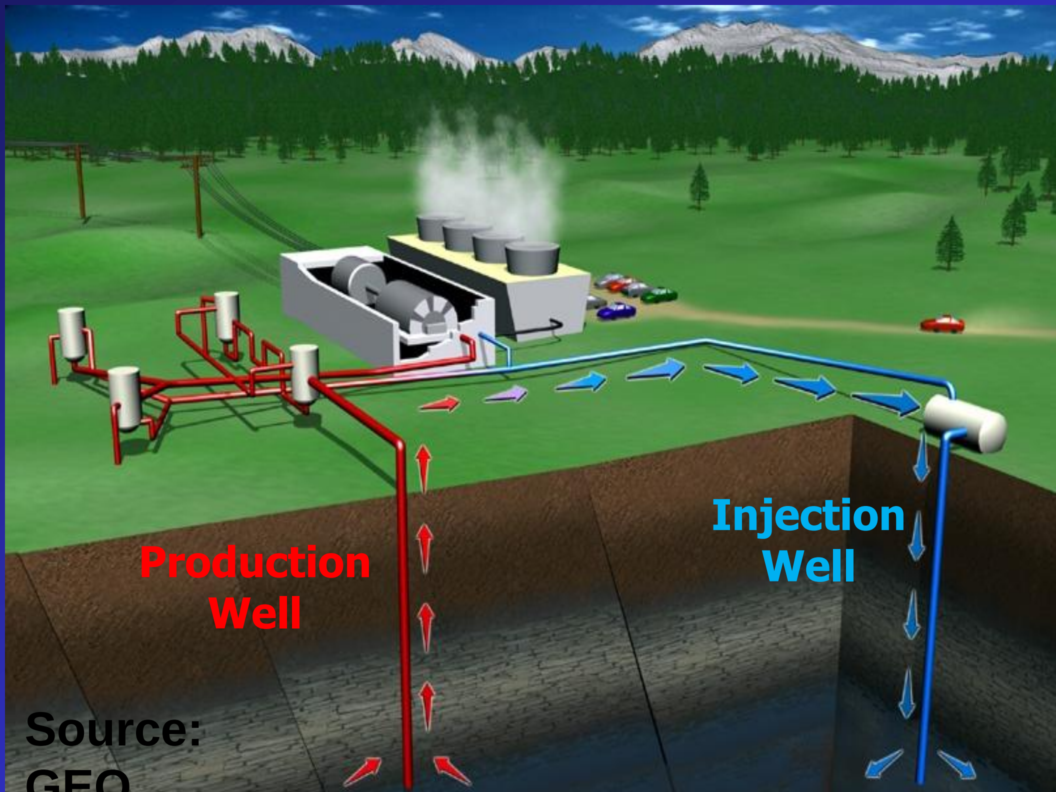


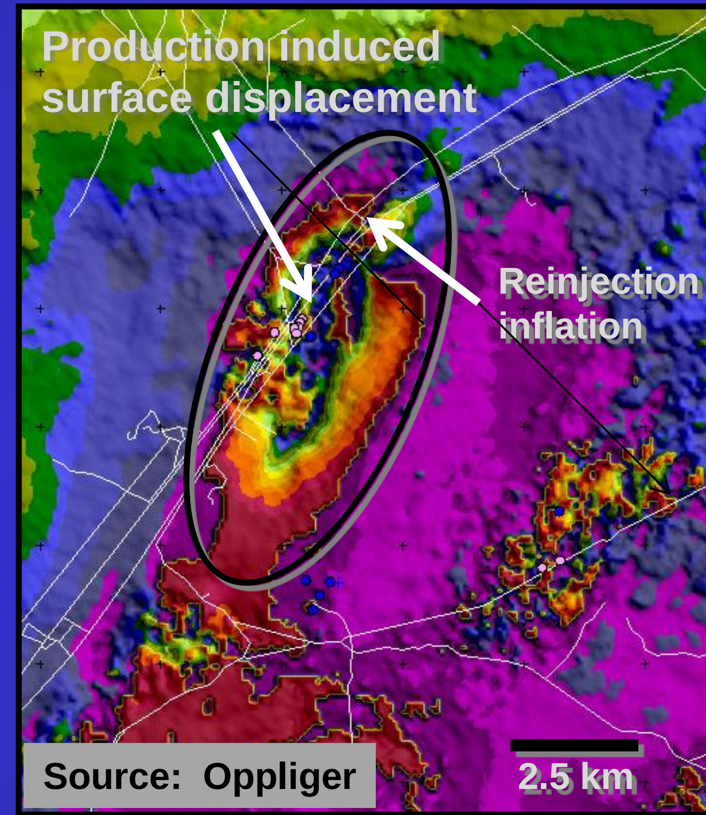

Blind Systems
N
Carson Sink, Nevada

Hot Springs Mountains



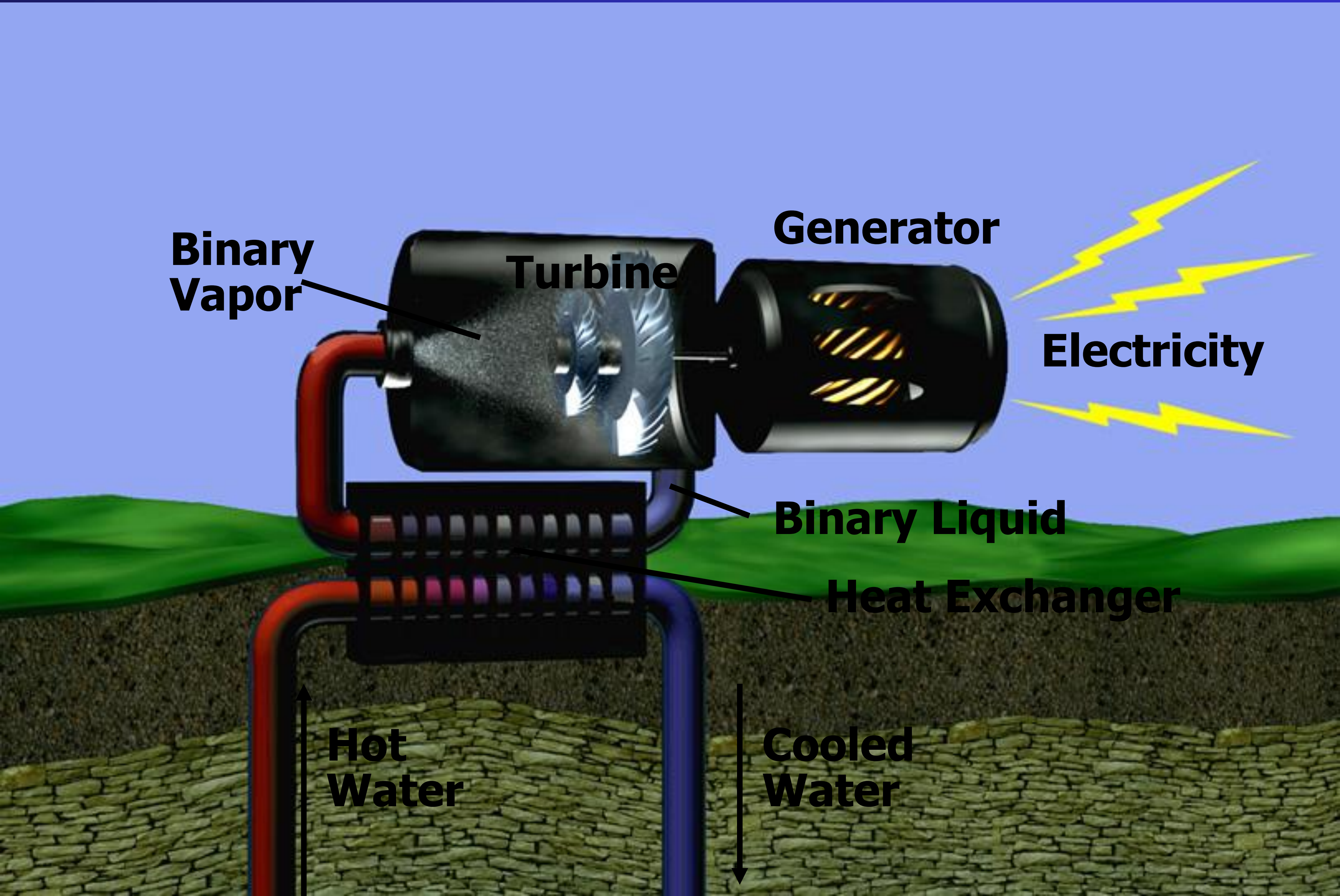
Water Consumption at Geothermal Plants



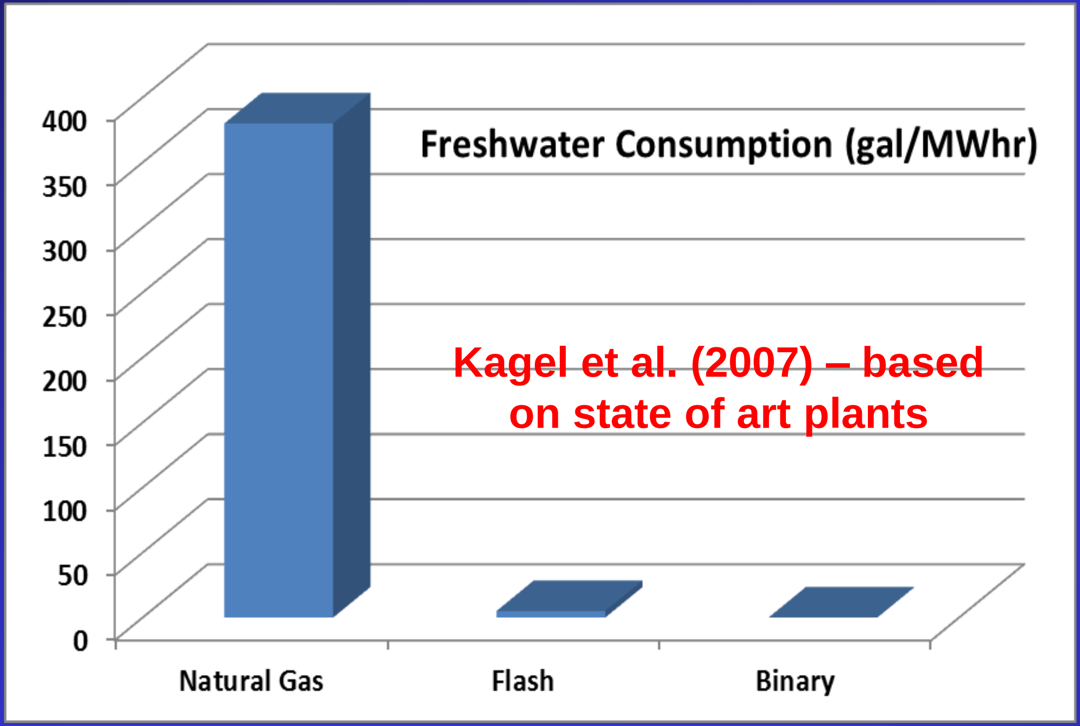


- Injection strategy critical
- Subsidence and draw-down if not balanced
- Sustainable if utilizing geologic and engineering innovations
- Geothermal reservoirs deep – 300 to 2,900 m

Binary Power Plants: Most Efficient for Water Use

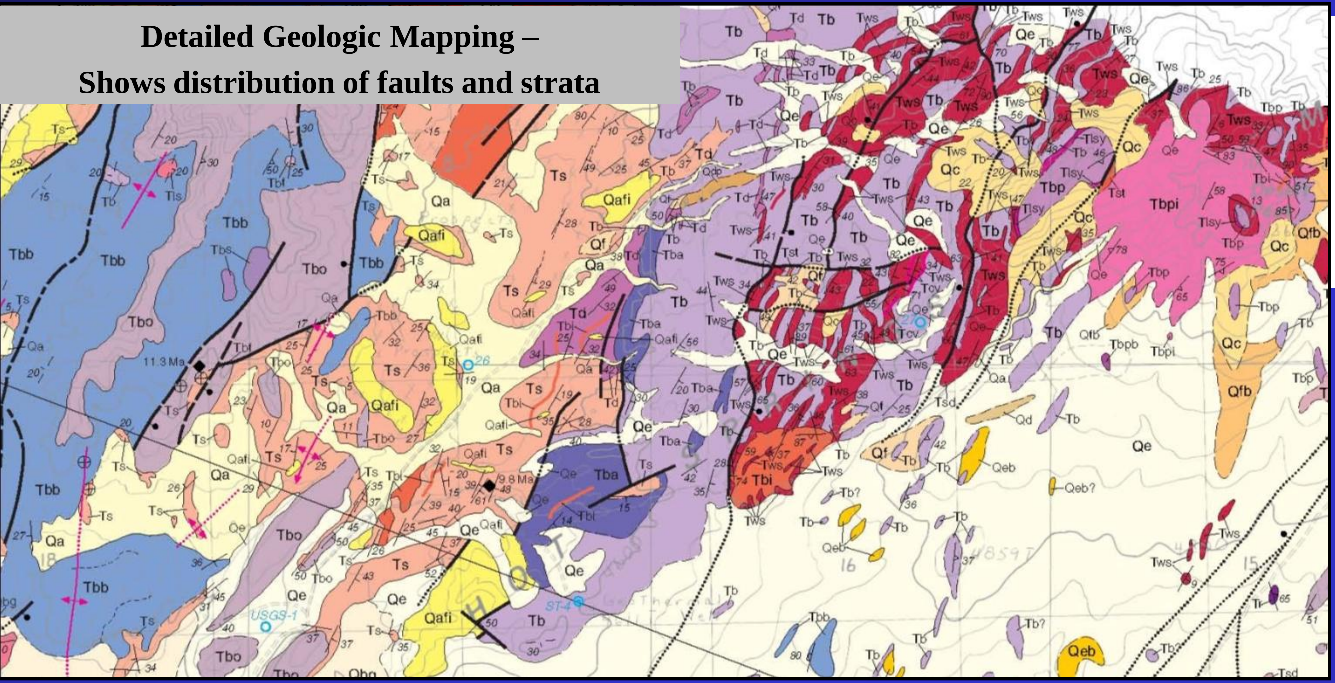


Water Loss – Binary Power Plants

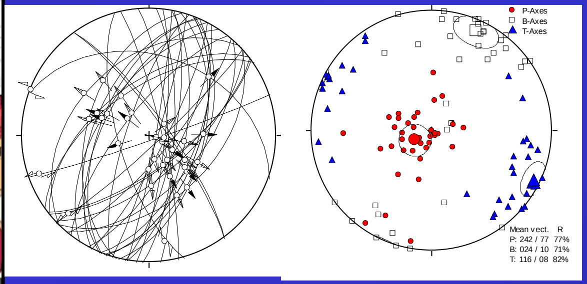


	Acre ft/yr
Empire	4-9%
Soda Lake	15-20%
Steamboat	3-7%
Stillwater	2%
Casa Diablo	4%
East Mesa	4%
Heber	6%

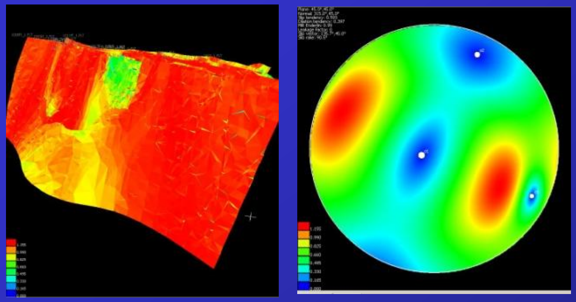
Geologic Methods



Detailed Geologic Mapping –
Shows distribution of faults and strata



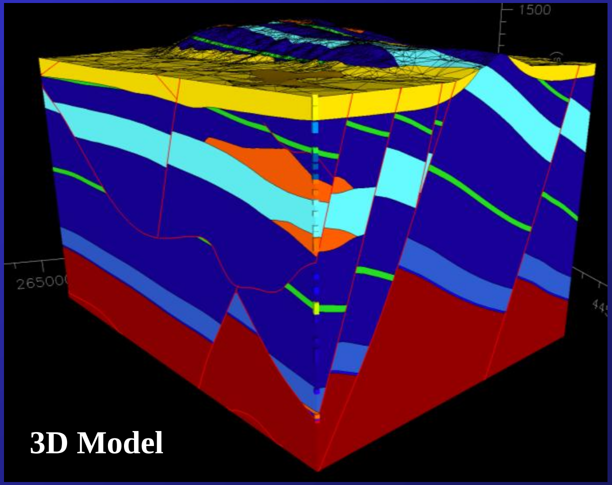
Stress inversion from fault-slip data



Slip-Dilation tendency analysis

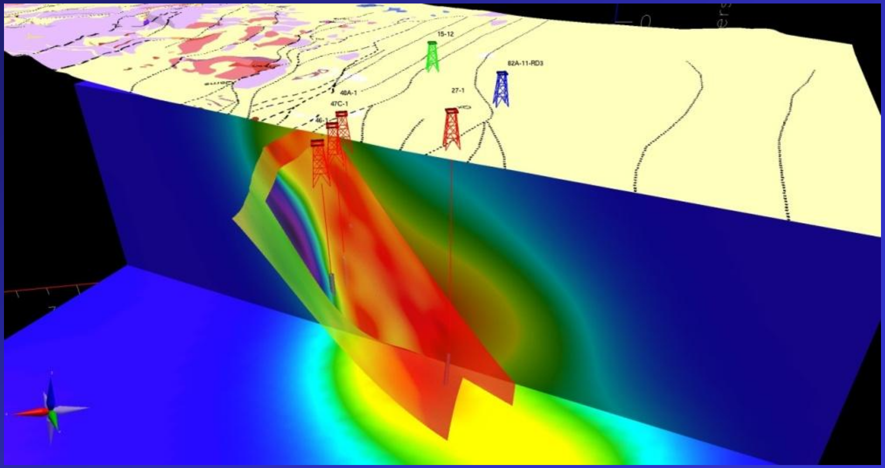
Fault Slip Data

- **Detailed mapping**
- **Structural analysis**
  - **Fault kinematics**
  - **Stress determinations**
  - **Slip-Dilation tendency analyses**
- **Gravity surveys**
- **Integrate available geophysics**
- **3D Modeling**

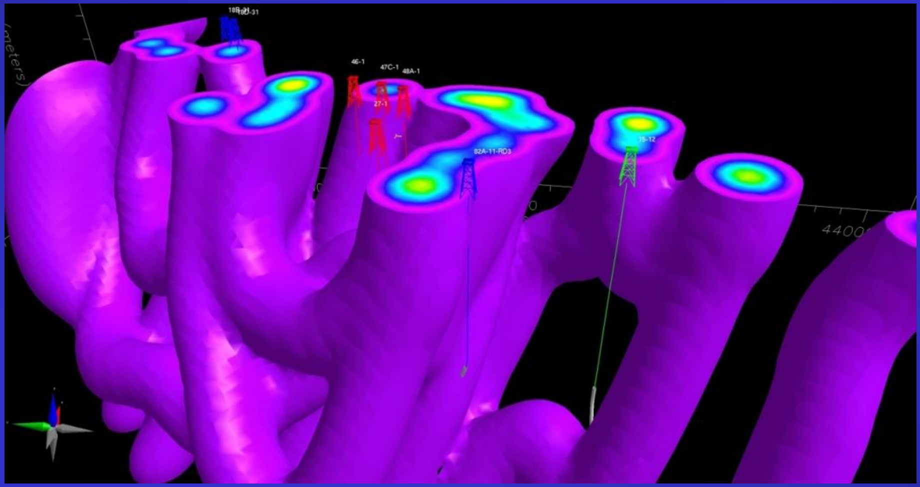


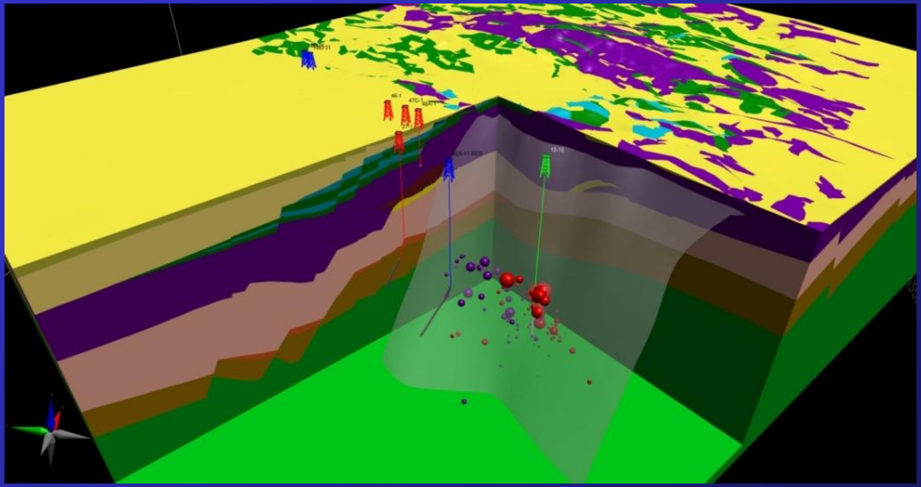
3D Model

3D Modeling: Quantifying and Visualizing Fluid-Flow Fairways



- Combine with slip and dilation tendency analysis
- 3D visualization of density of fault intersections
- Hitting the target – fluid-flow fairways?





Conclusions

- **Characterization of geothermal systems crucial for exploration & development**
  - **Better conceptual models**
  - **Catalogues of key settings and indicators of such settings**
  - **Involves integrated geologic-geophysical work**
- **3D models critical for future development & reducing risks in drilling**
- **Many undiscovered blind geothermal systems**
- **Innovative geologic and engineering technologies can facilitate development and sustainability with minimal impact on water resources**