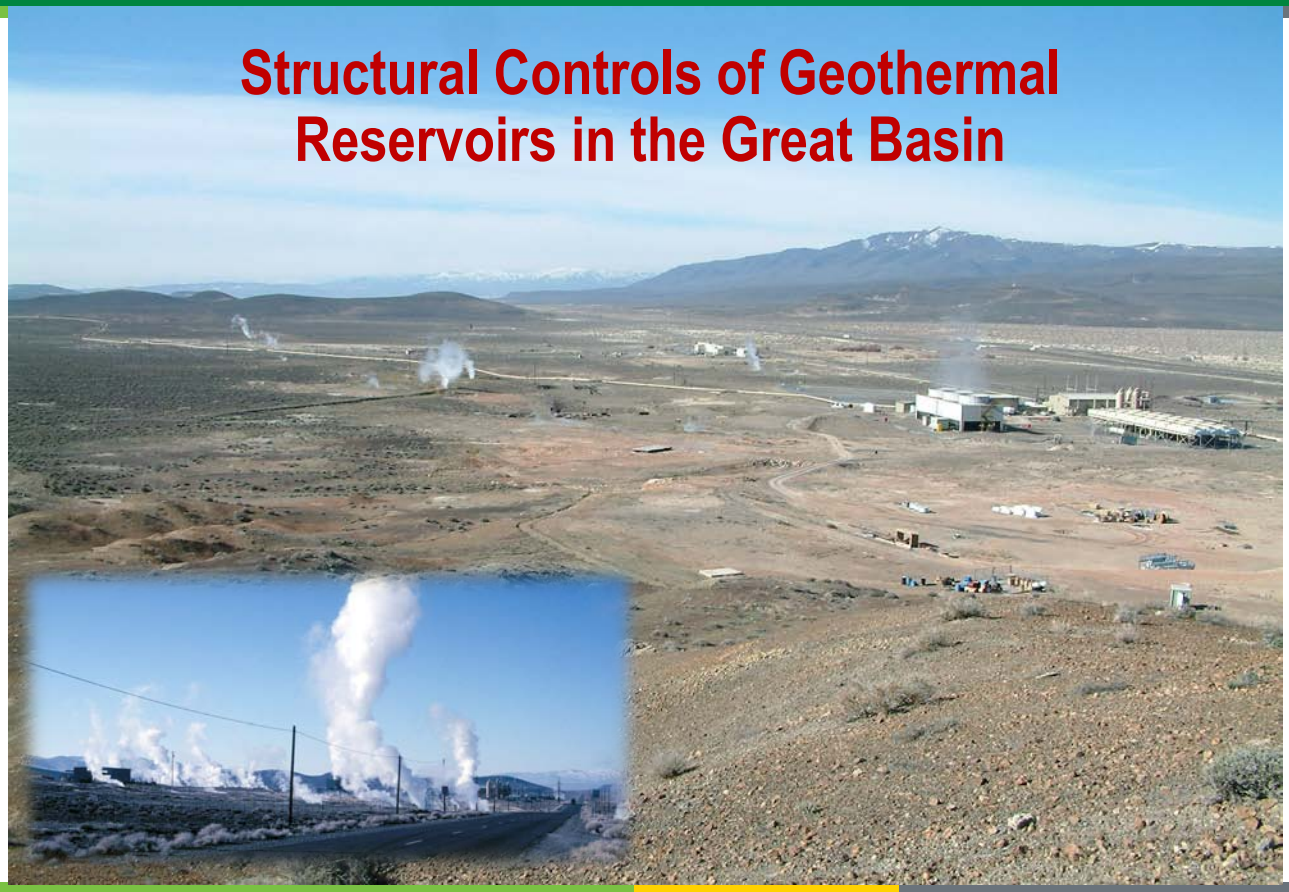
Structural Controls of Geothermal Reservoirs in the Great Basin



Characterizing Structural Controls of EGS Candidate and Conventional Geothermal Reservoirs in the Great Basin: Developing Successful Exploration Strategies in Extended Terranes

May 19, 2010

Principal Investigator:
James Faulds
University of Nevada, Reno

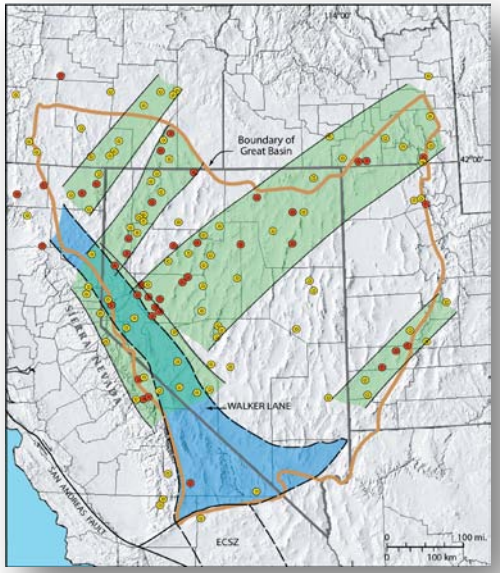
Track Name: Tracers and Exploration Technologies

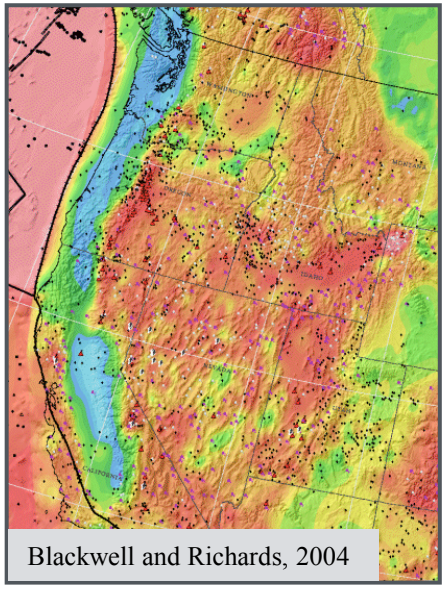
Overview

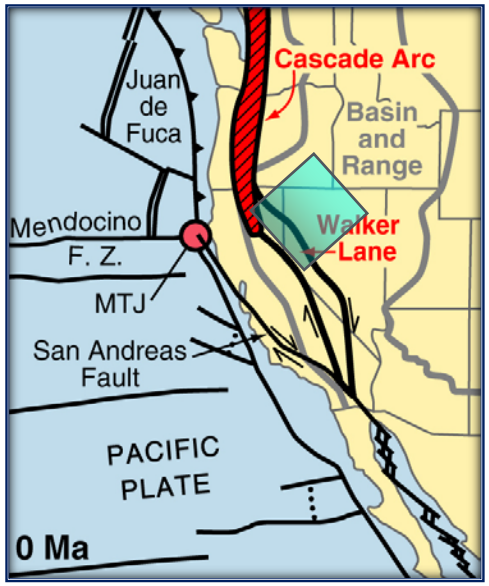
- Timeline
  - Initiation: 1/31/10 , Funds Arrived 3/16/10, end date: 1/31/2013
- Budget
  - Project funding: $1,170,505 total; $935,505 (DOE); $235,000 (awardee)
  - FY10: ~$390,000
  - Leveraging significant match from UNR (Faulds), USGS STATEMAP funds for geologic mapping, and collaboration with industry
- Barriers
  - Ability to assess potential EGS resources, prioritize potential EGS sites, and achieve acceptable levels of site selection risk ahead of expensive drilling
  - Inadequate measuring techniques and knowledge preclude low-risk options to effectively select sites and characterize their physical parameters as potential EGS reservoirs before stimulation
- Partners (>30 yrs collective experience in geothermal studies)
  - University of Nevada, Reno (PI-James Faulds; co-PI's-Mark Coolbaugh, Nick Hinz, John Bell) – all with substantial experience analyzing geothermal systems
  - Helmholtz Center, GFZ, Potsdam, Germany (Dr. Inga Moeck) - > 5 yrs experience in analyzing + modeling geothermal systems
  - Private consultant, gravity surveys – 25 yrs experience

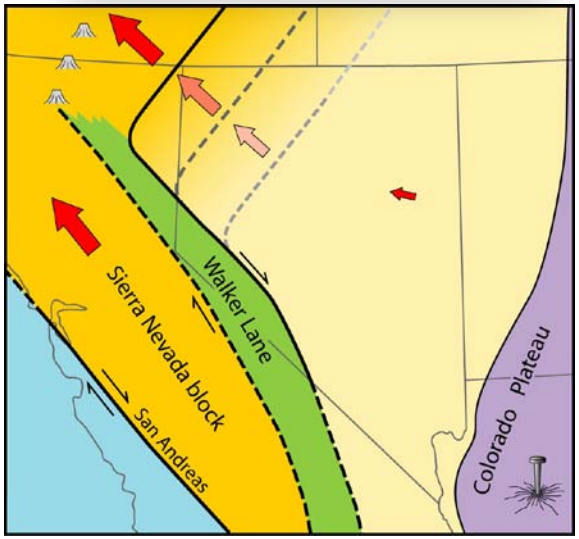
Relevance/Impact of Research: Background

- **Tectonic Setting**
  - Broad region of high heat flow, but geothermal activity focused in NW Great Basin
  - Walker Lane – ~20% of plate motion
  - Dextral shear at NW end transferred to NW-directed extension
  - Transtensional to extensional domain
  - Volcanism generally ceased in middle to late Miocene
- **Geothermal belts = Loci of extension**
  - But details of favorable structural settings not well defined
  - Limited guides for exploration and targeting well sites
  - Many undiscovered blind geothermal systems




Blackwell and Richards, 2004





Relevance/Impact of Research: Background

- **Exploration Challenges**
  - **Hot dry wells**
  - **Overturn in down-hole temperature gradients**
  - **Wet cool wells**
- **EGS one answer**
- **But also need better conceptual models to guide exploration**

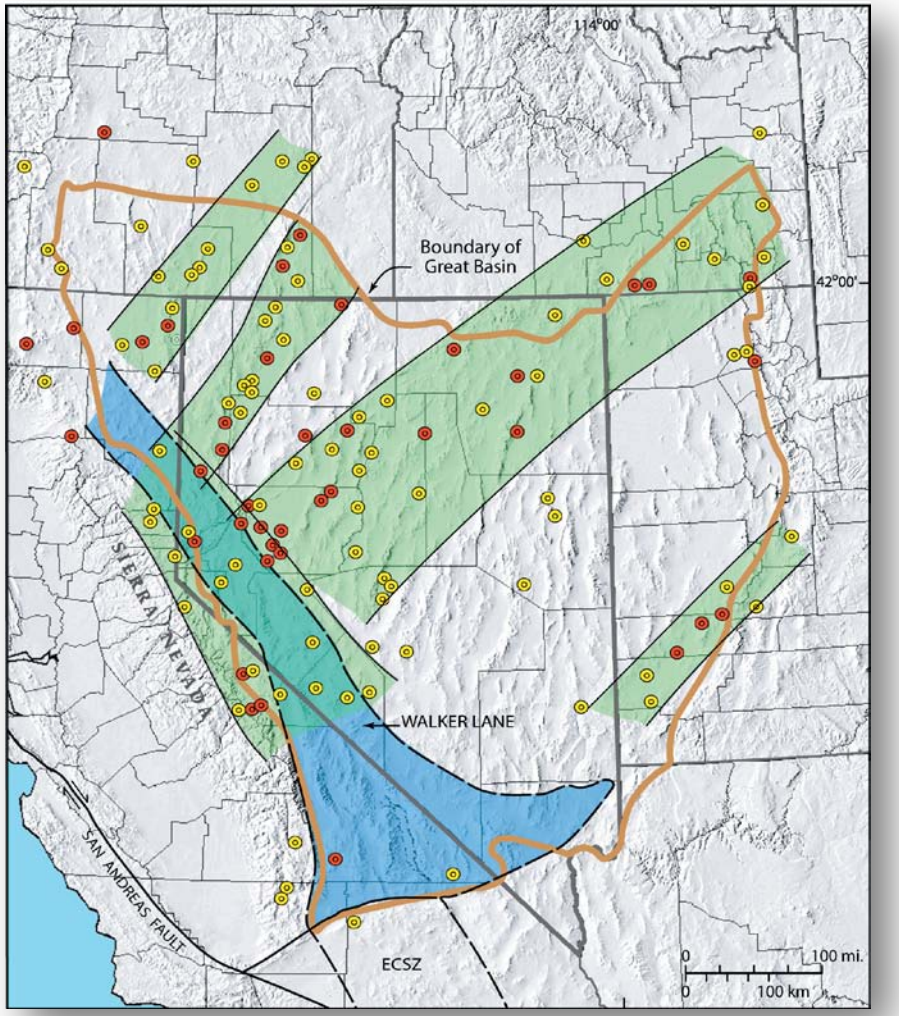

Blue Mt., Nevada


Desert Peak, Nevada


Brady's, Nevada

Relevance/Impact of Research: Project Objectives

- Develop catalogue of favorable structural environments and models
- Improve site-specific targeting of resources through detailed studies of representative sites
- Compare structural controls and models in different tectonic settings
  - Basin and Range
  - Cascades
  - Walker Lane
  - Magmatic vs. nonmagmatic
  - High vs. low temperature
- Synthesize data
- Develop methodologies for enhancement of exploration strategies
  - Reduce risk of drilling non-productive wells in conventional systems
  - Selecting best sites for stimulation in EGS systems

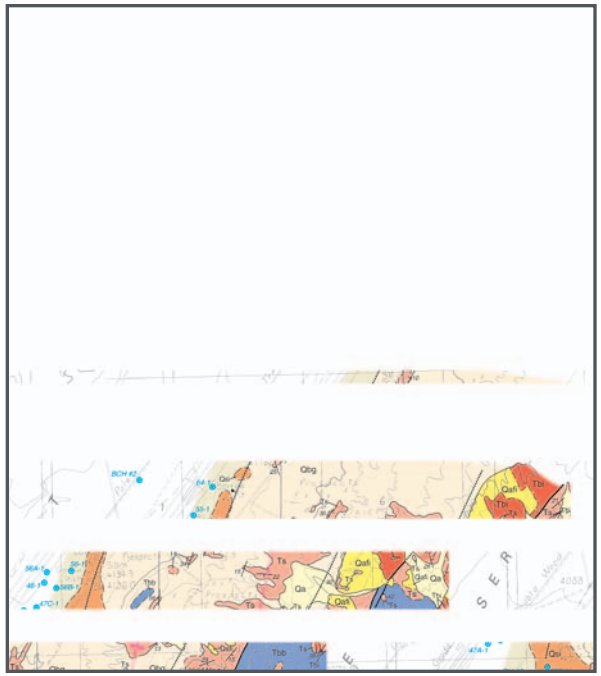


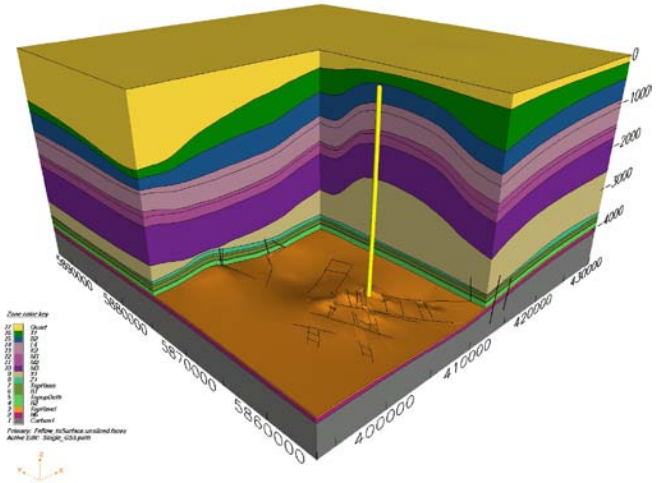
Previous Accomplishments/ Scientific Approach

- Previous research initiated characterization of favorable structural settings in western Great Basin (since 2002)
  - Detailed studies – 8 sites
  - Reconnaissance – 10+ sites
  - 23 papers, 4 geologic maps, 2 M.S. theses, 3 senior theses
  - Facilitated development at Salt Wells, Desert Peak, Blue Mt
  - Facilitating anticipated development at Pyramid Lake, Hawthorne, Desert Queen, and San Emidio
- Approach – More robust analyses needed
  - Comprehensive structural inventory
  - Comparative analysis of structural controls
  - Select representative sites for detailed analysis
  - Quantitative approach to elucidating fluid pathways, including slip tendency analysis and 3D modeling of systems
  - Enhance strategies
    - Exploration for undiscovered sites (blind)
    - Expansion of conventional systems
    - Best sites for EGS development

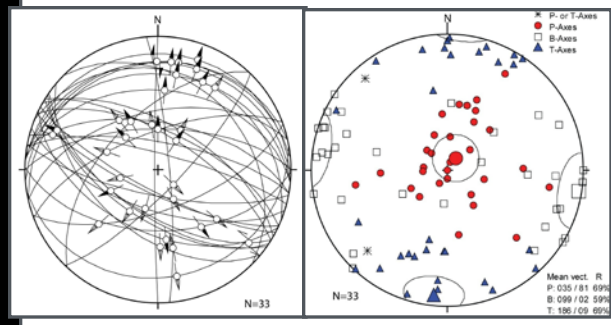
Review Criteria: Technical Merit and Innovation

- Combine conventional and modern techniques
  - Detailed geologic mapping
  - Structural analyses
  - Gravity studies
  - Integrating other geophysical data
- Innovative approaches
  - Slip tendency analysis of faults and fractures at both regional and local scales
  - 3D modeling of key systems
  - Generating 3D geologic maps
- Utilizing Great Basin as natural laboratory to elucidate 4D evolution of geothermal systems

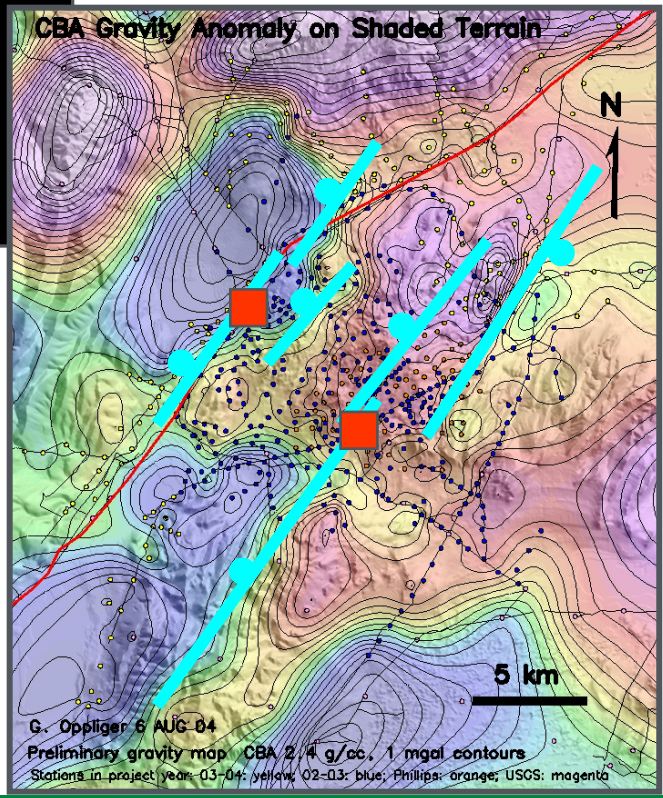




Scientific/Technical Approach: Methods

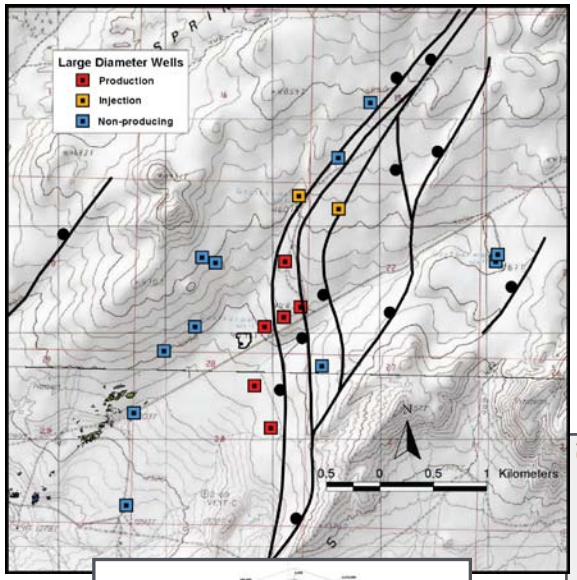


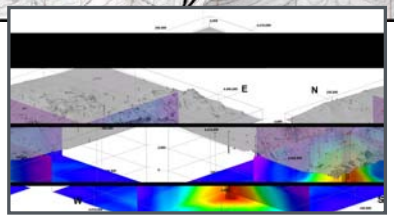
- Detailed mapping
- Structural analysis
  - Fault kinematics
  - Stress determinations
- Studies of surficial geothermal features
- Gravity surveys
- Integrate available geophysics
- 3D Modeling

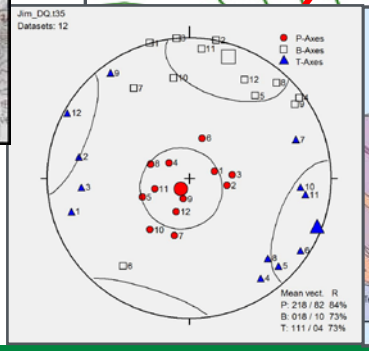


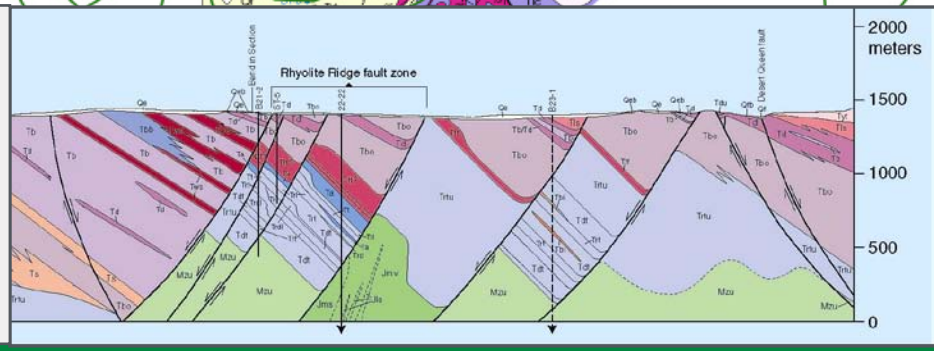
Scientific/Technical Approach: Case Study

- Desert Peak
  - Blind reservoir-218ºC
  - 12.5 MWe flash plant
  - Potential-further development
  - Stepover in normal fault zone
  - Multiple fault splays produce subvertical conduits of highly fractured rock
  - Provide avenue for fluids



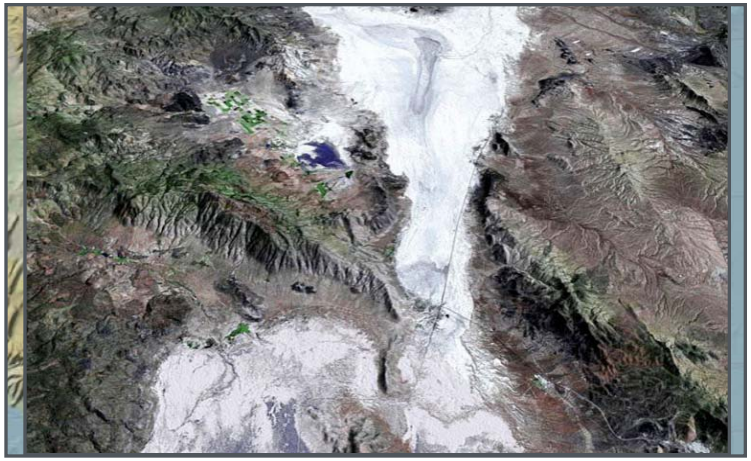


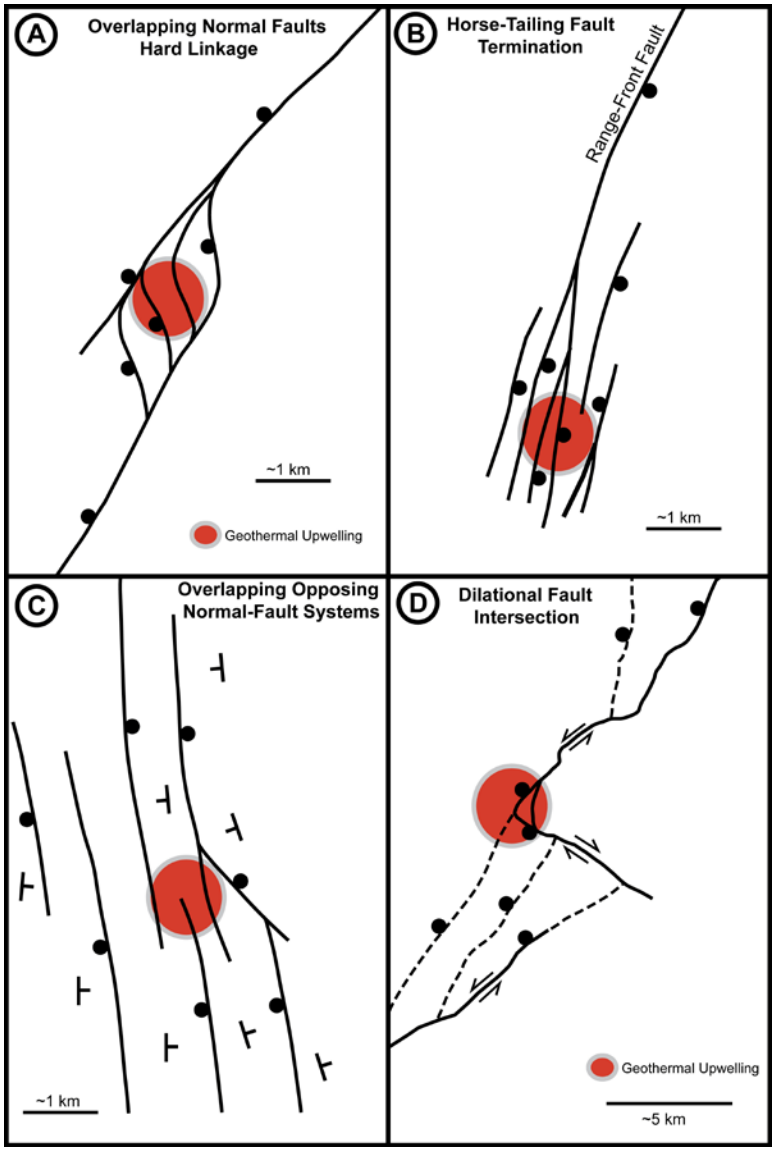




Scientific/Technical Approach: Summary – Structural Controls

- **Most fields not on major faults**
- **Most on less conspicuous normal faults**
- **Most common occurrences**
  - **Discrete steps in normal fault zones**
  - **Terminating, horse-tailing faults**
  - **Overlapping opposing fault zones**
  - **Intersecting faults – dilational**
  - **Small pull aparts in strike-slip faults**
- **Indicative features**
  - **Steps in range fronts**
  - **Interbasinal highs**
  - **Ranges of low discontinuous ridges**
  - **Lateral terminations of mountain ranges**





Scientific/Technical Approach: Slip Tendency Analysis

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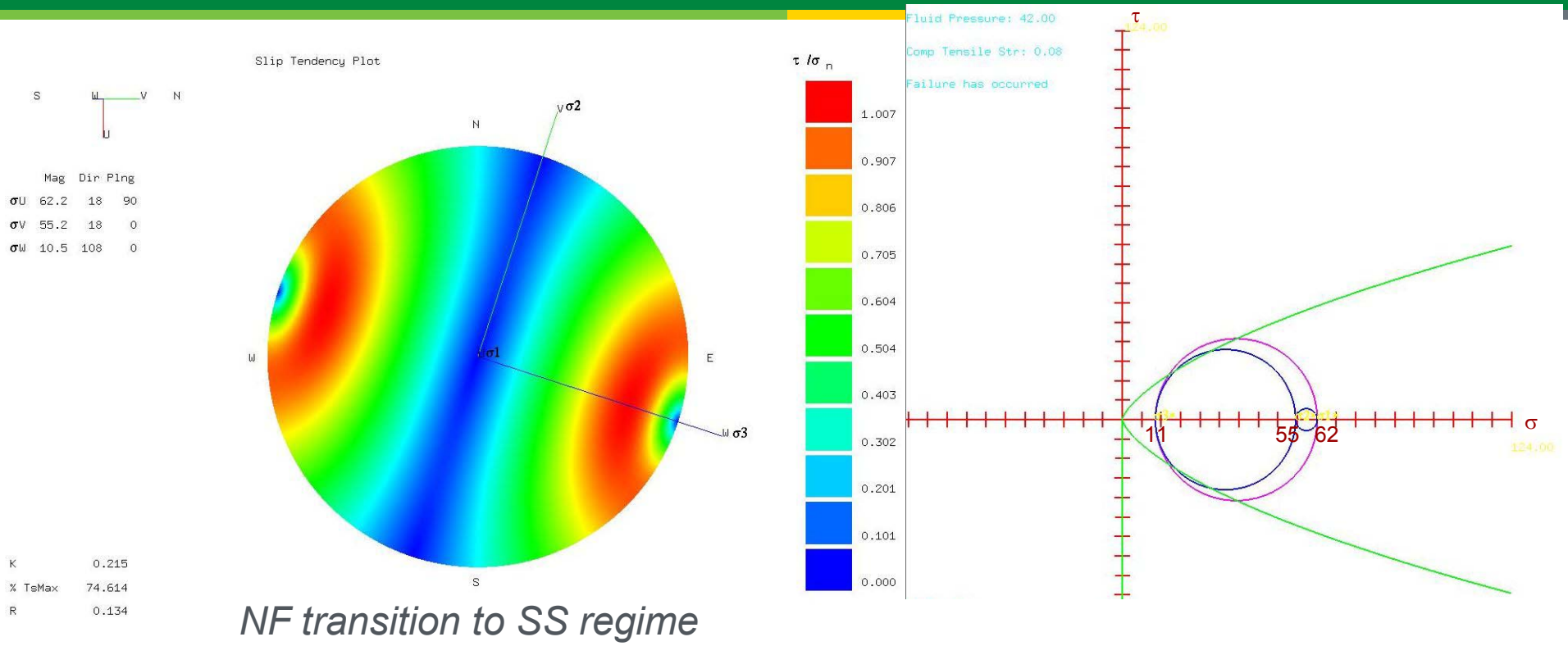


NF transition to SS regime

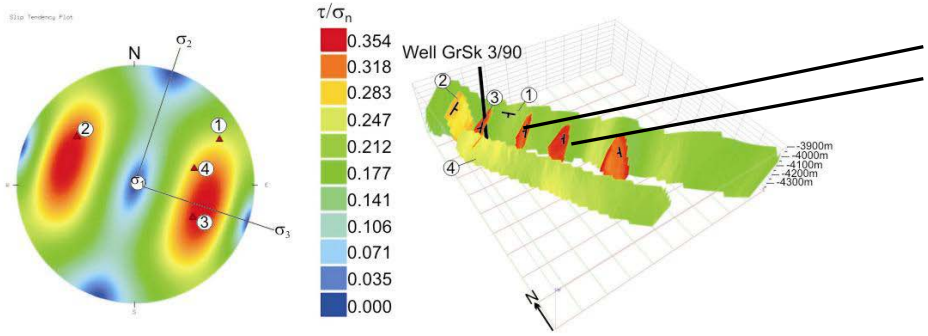
In situ stresses: σ_V=104 MPa, σ_{Hmax}=97 MPa, σ_{hmin}=53 MPa; P_p=42 MPa
Effective stresses: σ_{Veff}=62 MPa, $\sigma_{Hmaxeff}$=55 MPa, $\sigma_{hmineff}$=11 MPa;

Hoek-Brown strength parameters for a moderately fractured rock: m=2.301 and s=0.00198; UCS=80

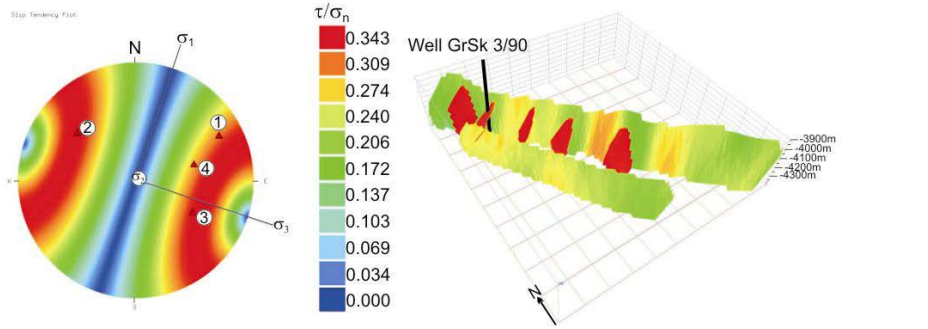
All Figures from Moeck et al. 2008

Scientific/Technical Approach: Slip Tendency Analysis

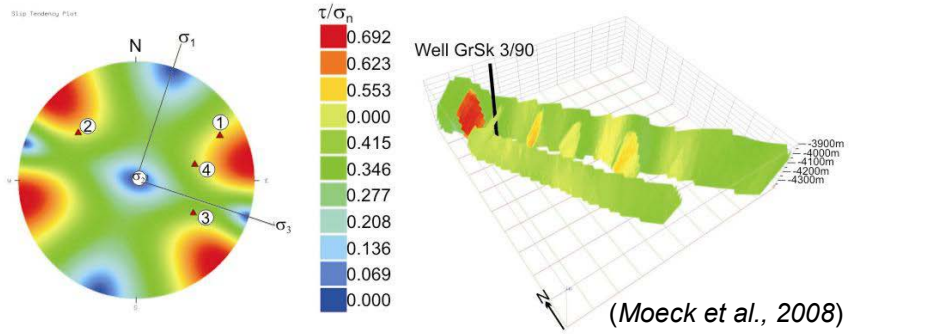
Normal faulting stress regime: SH*max*/SV=0.78, Sh*min*/SV=0.55



Transition normal-strike slip faulting: SH*max*/SV=1.0, Sh*min*/SV=0.55



Strike slip faulting: SH*max*/SV=2.1, Sh*min*/SV=0.79



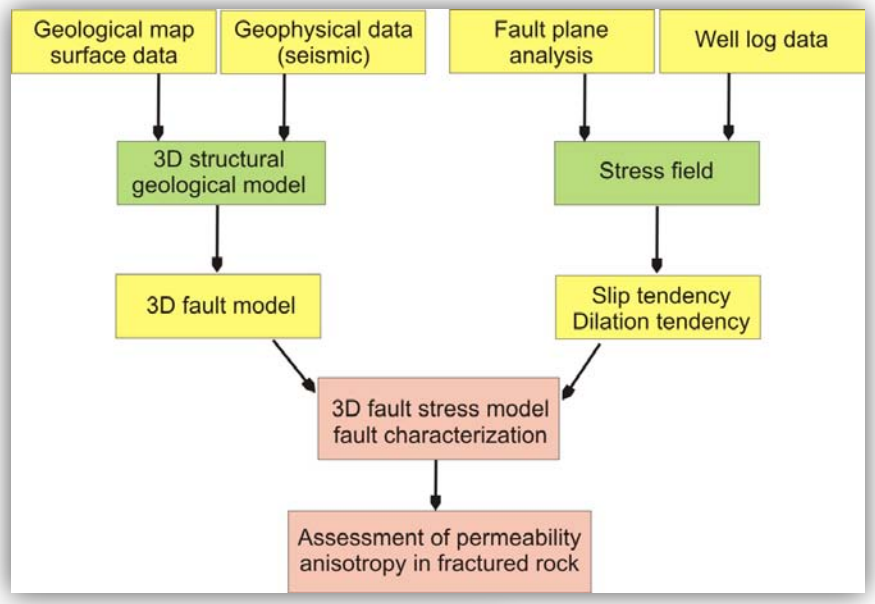
(*Moeck et al., 2008*)

Faults with high shear stress and high slip tendency

Potential fluid flow along critically stressed faults

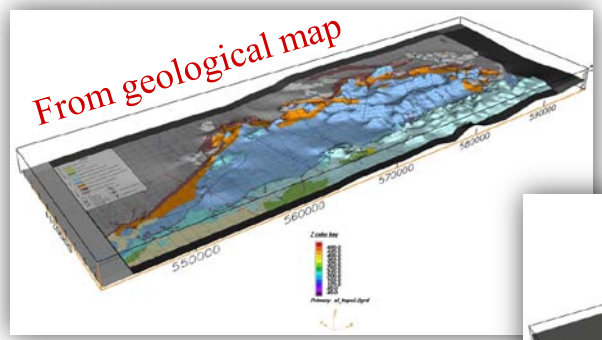
Assessment of reactivation potential of faults with high slip tendency

Scientific/Technical Approach: 3D Modeling Results

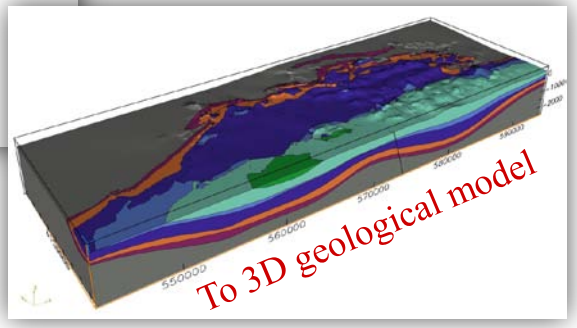


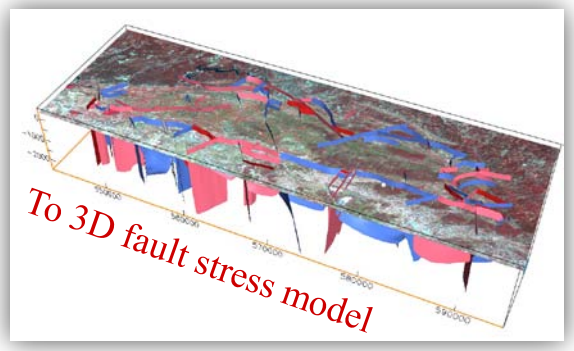
3D Model Permits

- Subsurface fault geometries
- Cross sections – any orientation, multiple slices
- Stress modeling – favorable fluid pathways
  - Near surface
  - At depth
- Determine slip and dilation tendency – faults and fractures of various orientations
  - Fluid flow paths
  - Induced seismicity
- Field optimization by understanding fluid flow
- Basis for selecting future well sites and paths



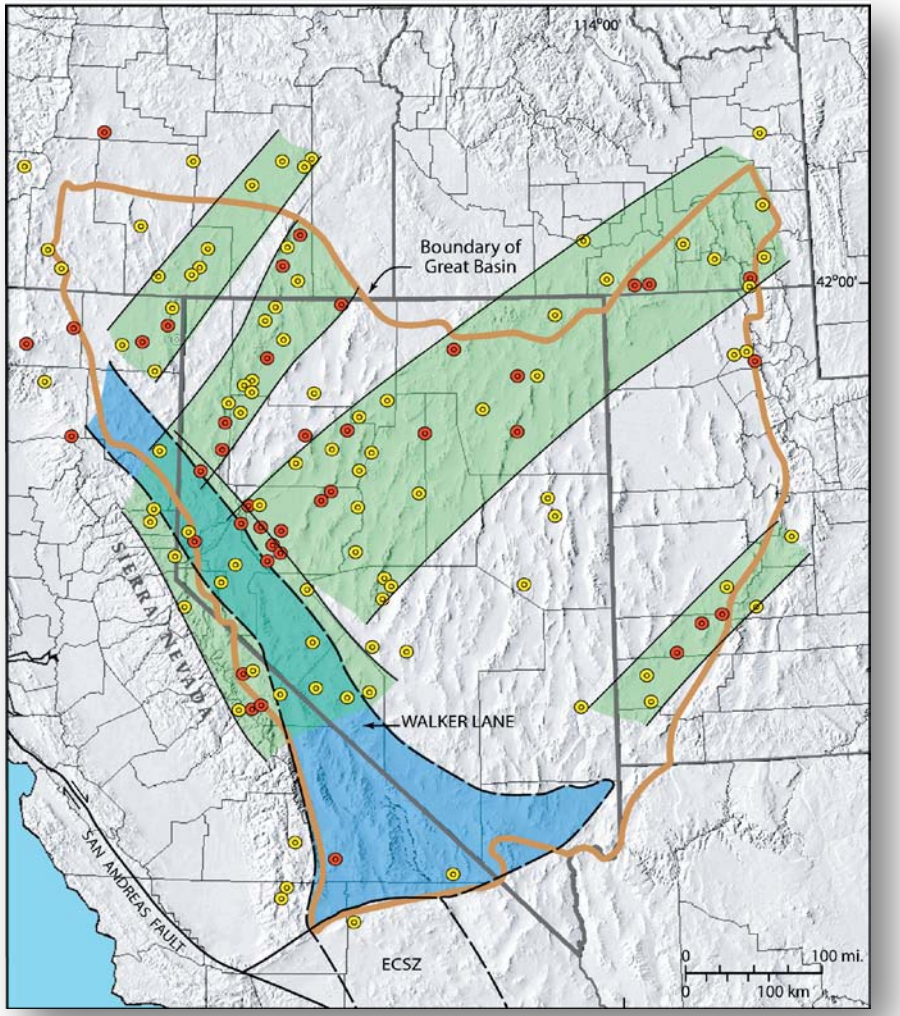
From Moeck et al. (2005)





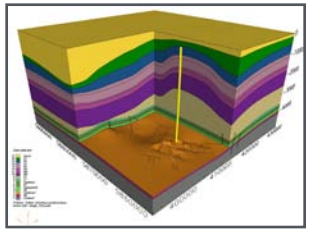
Project Management/Coordination

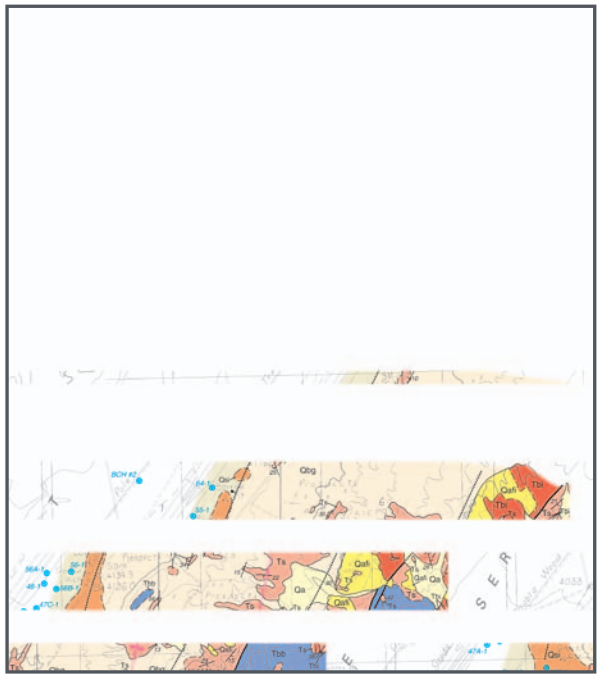
- Year 1 (Regional Assessment)
  - Recruit-add students to research team
  - Structural inventory
  - Compile different settings
  - Regional slip tendency analysis
  - Initiate detailed studies
- Milestones (Year 1)
  - Preliminary structural catalogue (3/2011)
  - Favorable settings defined (1/2011)
  - Regional slip tendency map (1/2011)
  - Students initiate thesis research (8/10)
- Project Reporting (all 3 years)
  - Faulds coordinates all quarterly and annual reports
  - Subcontractors provide quarterly reports
  - Several meetings of research team/year
- Leveraged UNR match, industry support, USGS STATEMAP funding (all years)
- GBCGE staff ensures data from project incorporated in National Geothermal Data System (all years)



Project Management/Coordination

- Year 2 (Detailed Investigations)
  - Selection of 5-6 sites for detailed studies using following criteria:
    - Quality of exposure
    - Geothermal surface manifestations
    - Potential for development
    - Available data
    - Type of system
  - Detailed Studies
    - Geologic mapping
    - Delineate reservoir hosts
    - Structural analysis-fault kinematics + stress determinations
    - Geochronology
    - Gravity Surveys
    - 3D modeling
    - Slip tendency analysis
    - GIS Database compilations
  - Develop geothermal exploration course

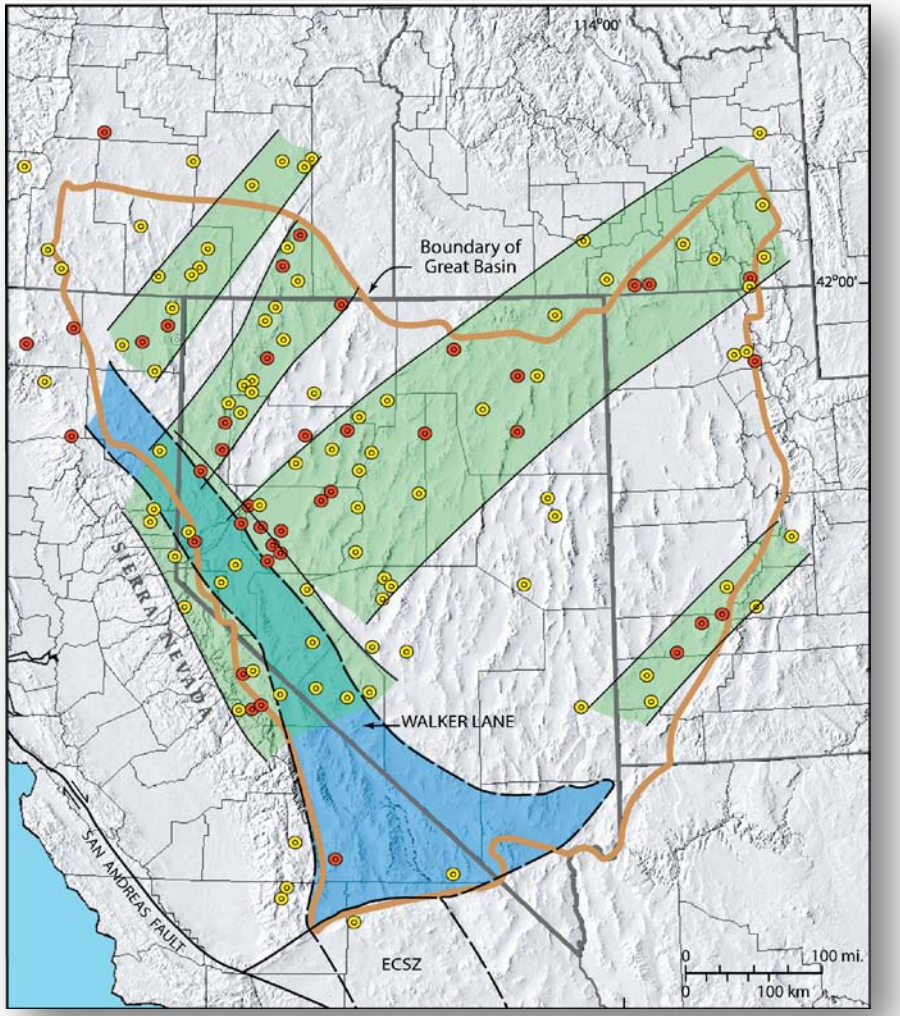




- Milestones
  - Complete detailed analyses of 3 representative sites (3/2012)
  - Embellish catalogue (1/2012)
  - Several additional papers (3/2012)
  - Teach geothermal exploration course (Spring 2012)

Project Management/Coordination

- Year 3 (Detailed Investigations & Synthesis)
  - Detailed analyses continue
  - Comparative analysis of different systems in different settings
  - Completion of structural catalogue
  - Development of exploration strategies
- Milestones
  - Complete detailed analyses of 2-3 additional representative sites (1/2013)
  - Publish catalogue of favorable structural settings (3/2013)
  - Revise geothermal potential maps based on findings (1/2013)
  - Prepare papers (3/2013)
    - Systems studied in detail
    - Comparative analysis
    - Exploration strategies



Expected Outcomes/Future Directions

- Expected Outcomes – Deliverables
  - Catalogue (NBMG report) and accompanying peer-reviewed paper describing favorable settings
  - Several papers – structural controls of representative systems studied in detail
  - Published geologic maps of systems studied in detail
  - Comparative analysis paper
  - Geothermal exploration course
  - Infusion of techniques (structural analysis, 3D modeling, etc.) into industry with training of next generation (grad students)
  - Validation of innovative exploration techniques
  - Enhance exploration strategies in extended terranes (conventional + EGS)
- Future Research
  - Expand detailed studies to better define various structural controls
  - Incorporate cost-effective 3D modeling and slip tendency analysis as standard techniques in geothermal exploration
  - Investigate other tectonic settings – e.g., magmatic arcs
  - Applications to understanding induced seismicity in EGS systems
  - Linking processes of active geothermal systems with those in epithermal mineral deposits

Summary Slide

- Main objectives
  - Develop catalogue of favorable structural settings
  - Improve site-specific targeting of resources through detailed studies of representative sites
  - Compare structural controls and models in different tectonic settings
  - Synthesize data
  - Develop methodologies for enhancing exploration strategies
- Experienced PI's
- Methods
  - Detailed geologic mapping
  - Structural analysis
  - Gravity surveys
  - Integrate other geophysical data
  - Slip tendency analysis
  - 3D modeling
- Systematic work plan
  - Year 1 – Regional assessment
  - Year 2 – Detailed investigations
  - Year 3 – Detailed studies + synthesis
- Significant potential impacts
  - Training next generation in modern-innovative techniques
  - Refinement of exploration strategies
  - Enhancing understanding of hydrothermal processes