- **Team Members**
  - NV Bureau Mines & Geology, Univ Nevada (Faulds, Hinz, Sadowski, McConville, Craig, others)
  - ATLAS Geoscience (Coolbaugh, Shevenell)
  - USGS (Siler, Glen)
  - Hi-Q Geophysical (Queen)
  - Utah Geol Survey (Hardwick)
  - Zonge International, Inc. (Lide)
  - LBNL (Spycher)

Discovering Blind Geothermal Systems in the Great Basin Region: An Integrated Geologic and Geophysical Approach for Establishing Geothermal Play Fairways

Project Officer: Michael Weathers

Total Project Funding: $2,824,992

November 15, 2017

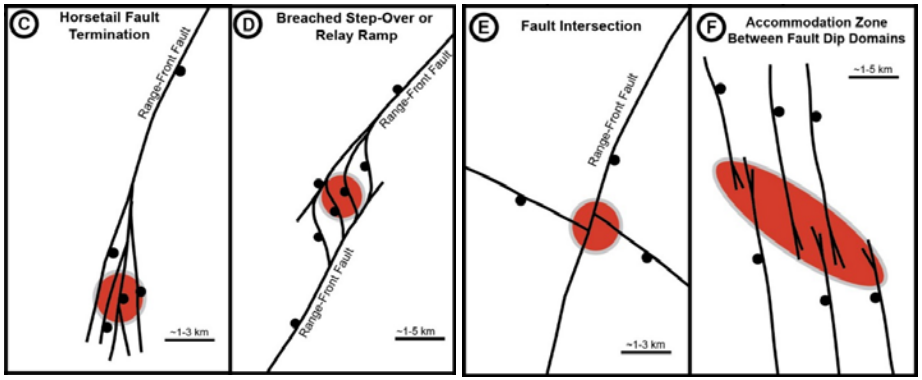
Principal Investigator: James Faulds

Board of Regents on behalf of University of Nevada, Nevada Bureau of Mines and Geology

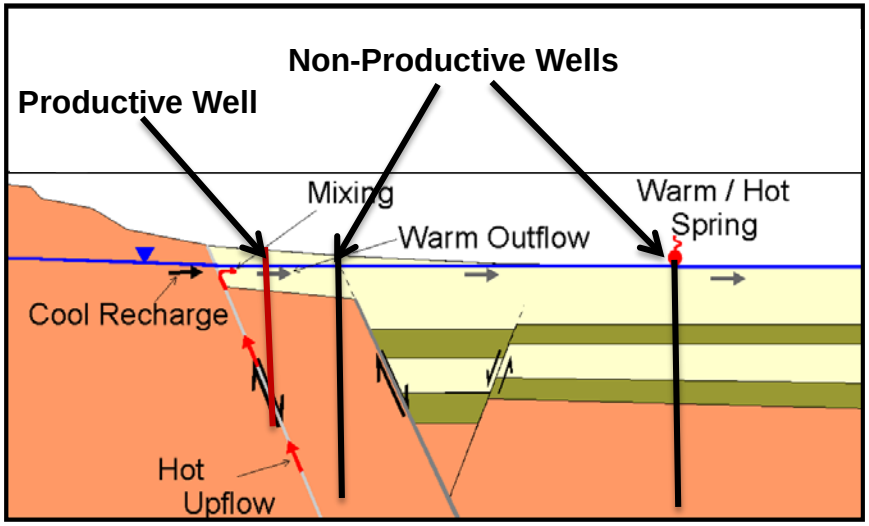
Track Name: Play Fairway Analysis

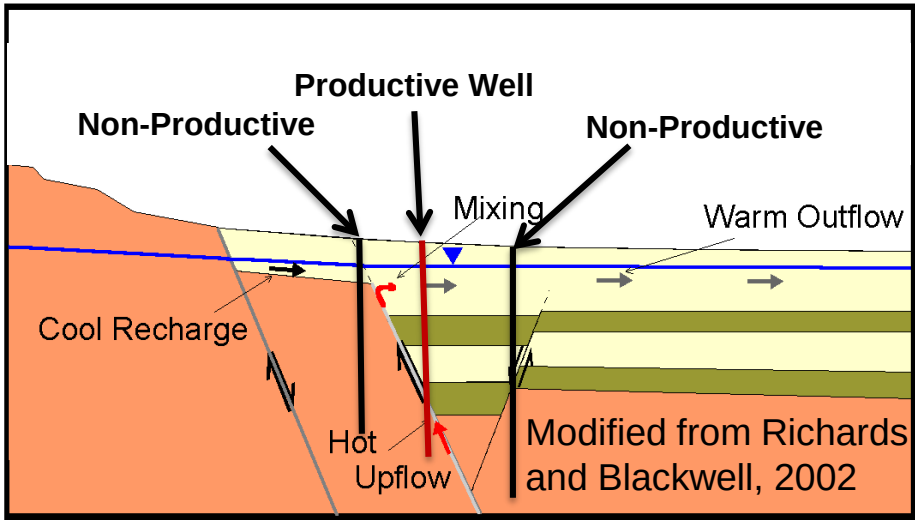
Relevance to Industry Needs and GTO Objectives: Challenges and Barriers

- **Exploration Challenges – Blind Systems**
  - Spring directly above upflow from deep source (uncommon)
  - Outflow from source common – drilling usually results in non-productive well
  - Hidden or blind systems most common
  - Difficult to find permeability sweet spot or play fairway
- **Barriers**
  - Assessing potential resources
  - Prioritizing sites for exploration and development
  - Minimizing risk of expensive drilling
- **Faulds et al. (2015) characterized structural settings of known systems in Great Basin**



Four Structural Settings Account for Nearly 90% of Systems in Great Basin Region

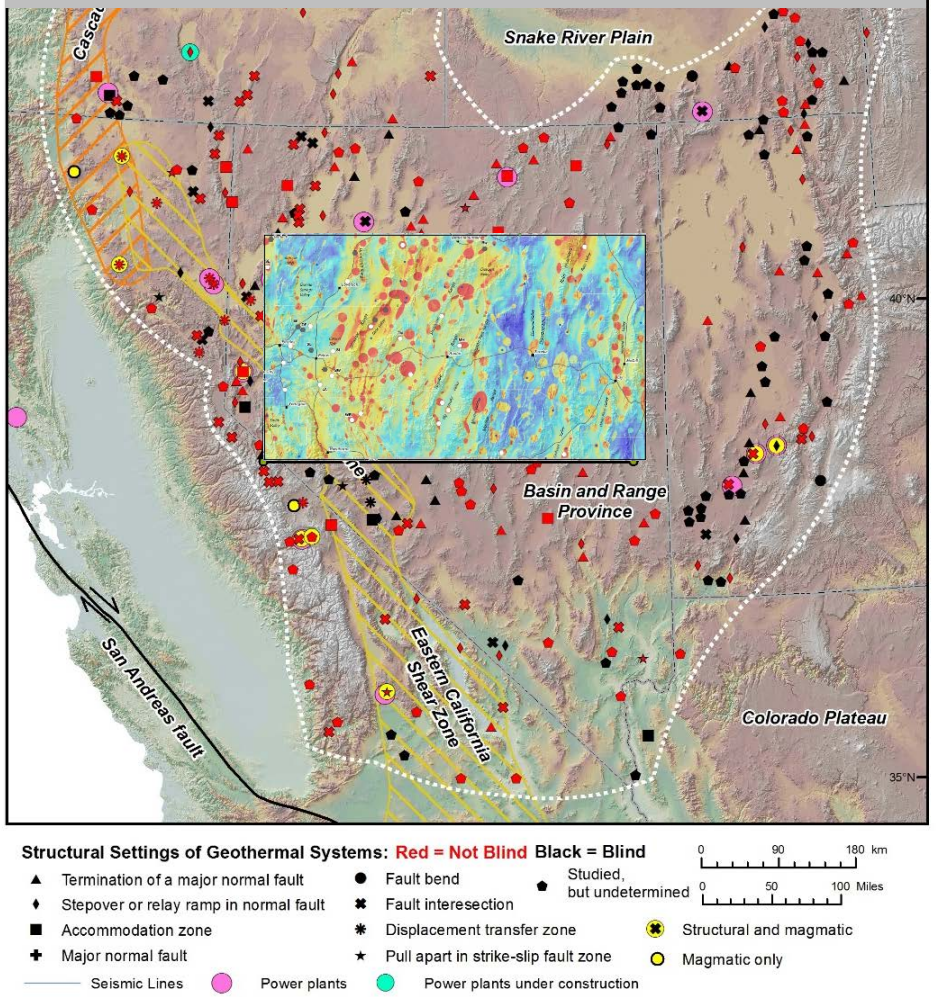




Methods and Phased Approach of Nevada Play Fairway Project

- **Phase I:**
  - Synthesize geologic, geophysical, and geochemical characteristics of geothermal fields
  - Prepare detailed geothermal potential maps
    - 240 km x 400 km transect in Great Basin
    - ~9 parameters incorporated
  - Identify areas with high potential for hosting blind systems
- **Phase 2:**
  - Select most promising sites for detailed studies
  - Conduct detailed studies
  - Refine play fairway methodology
  - Select drilling targets
- **Phase 3:**
  - Test methodology through drilling
  - Conduct additional analyses to determine:
    - Potential size
    - Commercial-grade viability of discovered systems
- **Currently starting Phase 3**

Map showing structural settings of Great Basin geothermal fields – box surrounds study area



Relevance to Industry Needs and GTO Objectives

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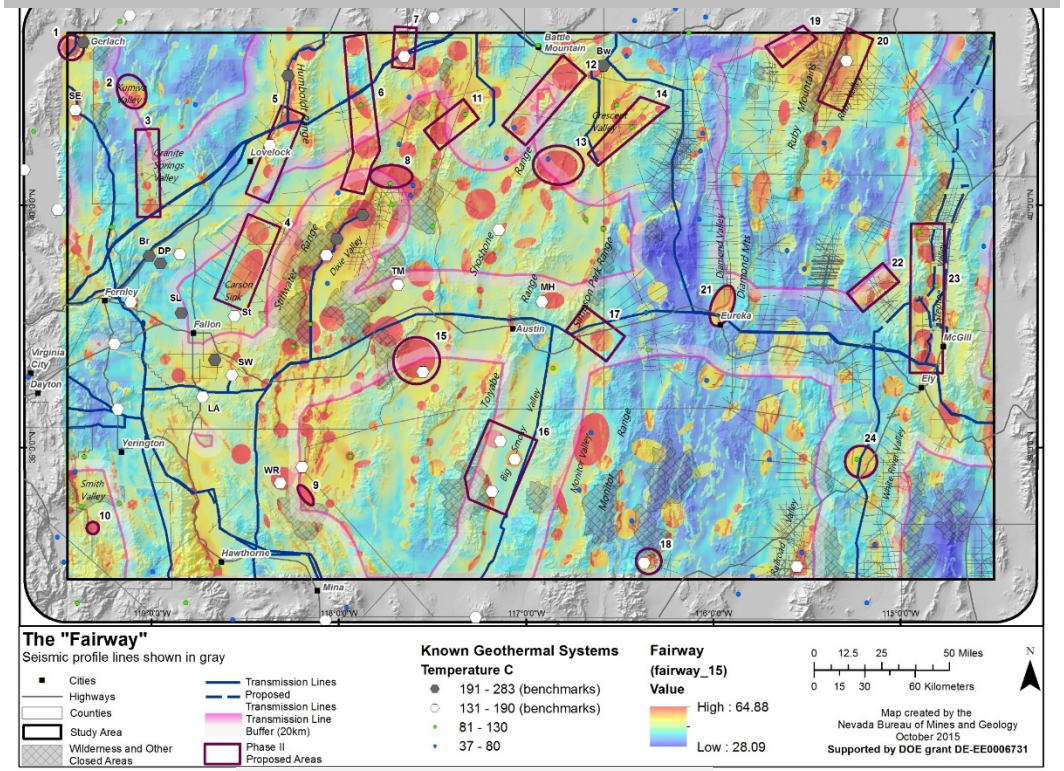
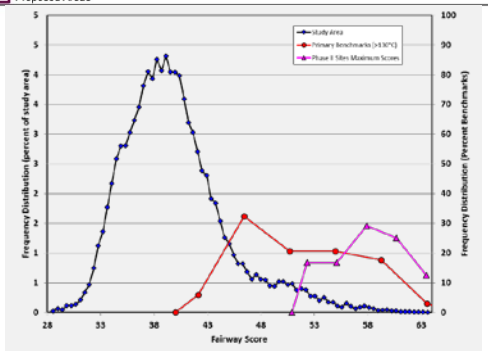
- Most detailed geothermal potential map to date
  - More input layers (9 vs 5) than any previous efforts
  - First comprehensive inclusion of structural data
  - Overlaid fairway map on land status
- Map may serve as prototype for similar efforts elsewhere
- Dynamic predictive model over multiple scales
  - Local
  - Intermediate
  - Regional
- Target-rich model
  - ~375 favorable structural settings
  - ~12% of study area, >11,000 km^2
- Fairway model predicts geothermal potential well
- Results
  - Will likely stimulate exploration
  - Reduce risks in drilling
  - Facilitate development of blind geothermal resources

Play Fairway Model with Power Grid and Land Status

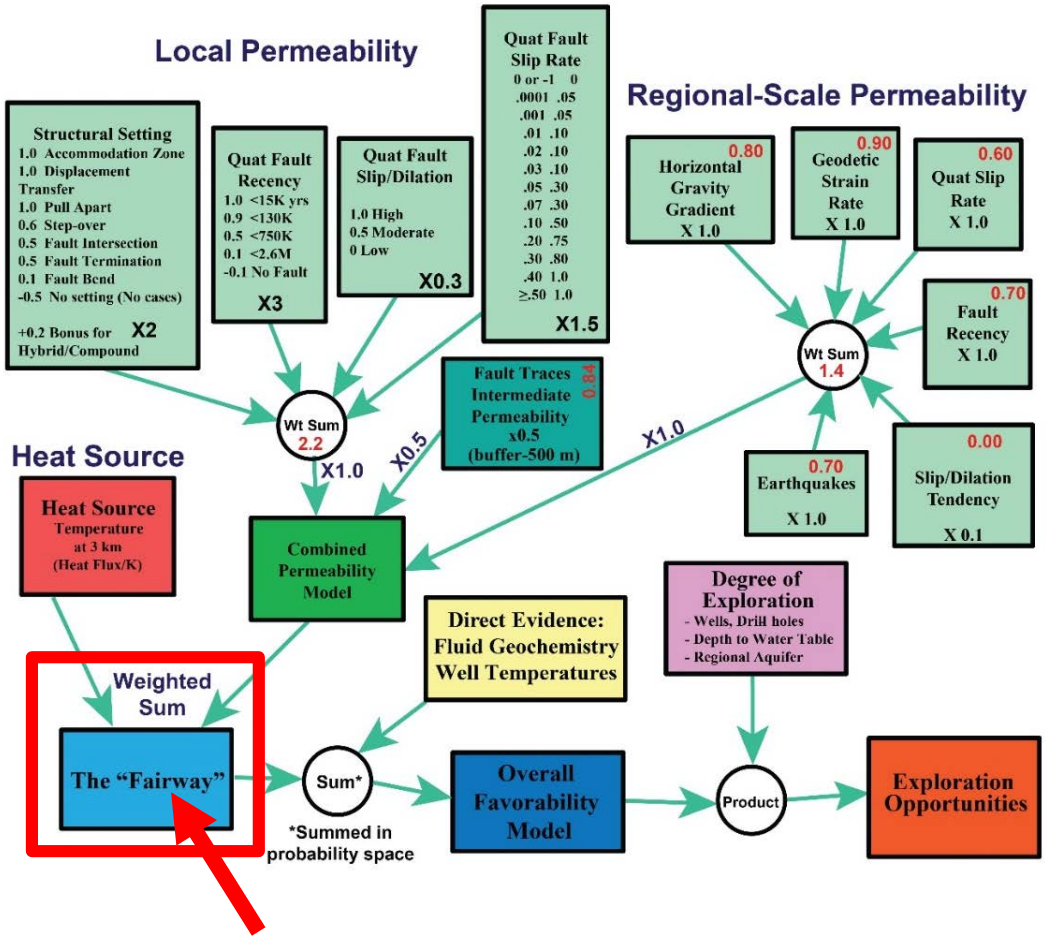




Fairway scores of 24 selected sites (purple) relative to benchmarks (red) and entire region (dark blue)

Technical Accomplishments: Play Fairway Components

- **Parameters synthesized:**
  - Structural setting
  - Age of Quaternary faulting
  - Quaternary fault slip rate
  - Regional strain rate
  - Slip and dilation tendency on Quaternary faults
  - Earthquake frequency
  - Gravity data
  - Temperature at 3 km depth
  - Temperatures of springs and wells
- **Permeability assessed at multiple scales:**
  - Regional
  - Intermediate
  - Local
- **Combined permeability + Heat The "Fairway"**
- **34 benchmarks >130°C in area**
- **14 geothermal power plants**
- **5 of most promising areas selected for detailed analyses in Phase 2**



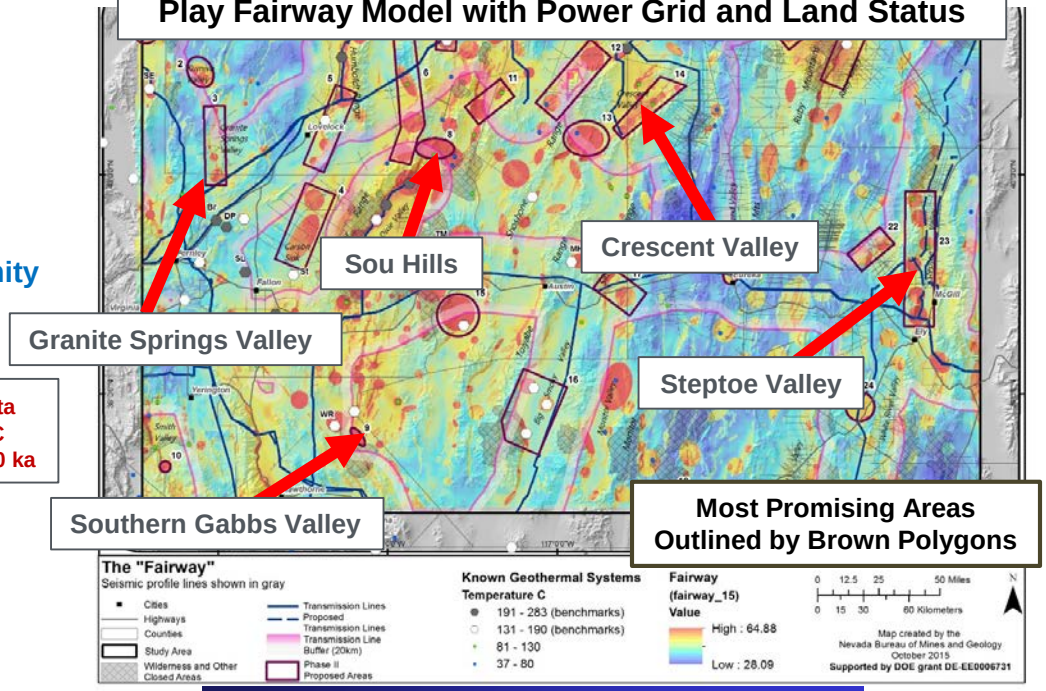
Combined Permeability + Heat = "The Fairway"

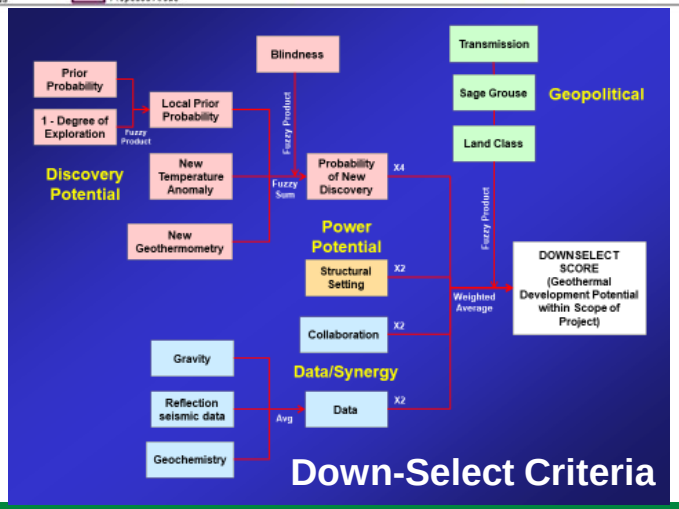
Technical Accomplishments and Progress: Phase 2 Tasks

- **Task 13: Recon of 24 promising areas to down-select most promising – Criteria:**
  - Type of structural setting
  - Proximal Quaternary faults <750 ka*
  - Quality of exposure/existing data
  - High potential for development based on geothermal potential, land status, and proximity to transmission corridors
- **Finalists:**
  - Southern Gabbs Valley
  - Granite Springs Valley
  - Sou Hills
  - Crescent Valley
  - Steptoe Valley
- **Target-rich region afforded broad distribution of detailed study areas**
- **Major tasks for 5 detailed study areas:**
  - Geologic studies
  - Geochemical investigations
  - Shallow temperature surveys
  - LiDAR surveys
  - Gravity surveys
  - Seismic reflection analysis
  - Slip and dilation tendency analysis
  - 3D modeling of 2-3 areas
  - Thermal modeling – 1 area
  - Select temperature-gradient drilling sites

*Based on Phase 1 data showing most >130°C systems near faults <750 ka

Play Fairway Model with Power Grid and Land Status





Technical Accomplishments and Progress: Phase 2 Tasks

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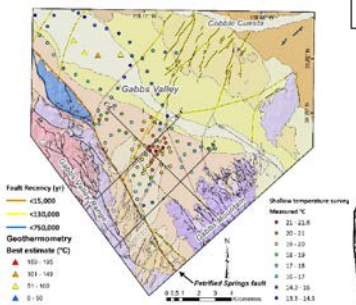
- **Geologic studies – Task/Milestone 14**
  - Reconnaissance and detailed mapping
  - Quaternary fault analysis
  - Analysis of any geothermal features
  - Logging of available cuttings and core
  - Delineation of stratigraphic and structural framework
  - Define potential reservoirs
  - Assess regional stress field
- **LiDAR surveys – Task/Milestone 17 (DOE and UNR funds)**
  - Original plan for 80-100 km^2
  - Sou Hills – 290km^2 acquired
  - Granite Springs – 215 km^2 acquired
  - Existing data used for Gabbs Valley
- **Geochemical investigations – Task/Milestone 15**
  - Water chemistry, measured temps, and geothermometry evaluated
  - Helped to located 2 blind systems
  - Geothermometry >130°C for all 5 areas

Note: Some tasks addressed out of order for more logical data groupings

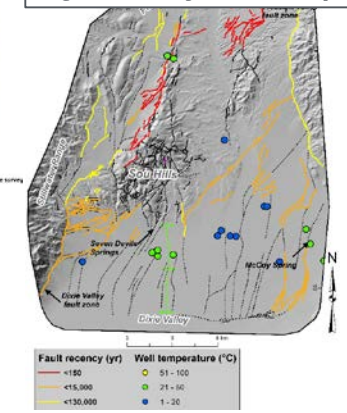
Geologic and Lidar Studies

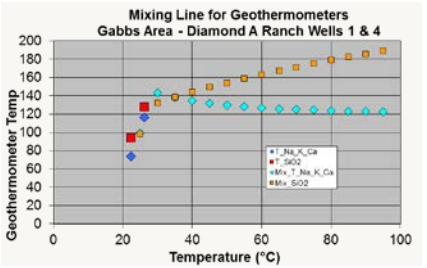
Location	Detailed Mapping (km^2)	Reconnaissance Mapping (km^2)	Geothermal Features	Quaternary Fault Analysis	New Well Logging (m)	LiDAR (km^2)
Crescent Valley	0	~500	✓	✓	2,638	0
Gabbs Valley	179	~120	N/A	✓	N/A	160
Granite Springs Valley	50	~1,000	✓	✓	N/A	215
Sou Hills	62	~250	✓	✓	2,000	290
Steptoe Valley	0	~1,220	✓	✓	7,925	0

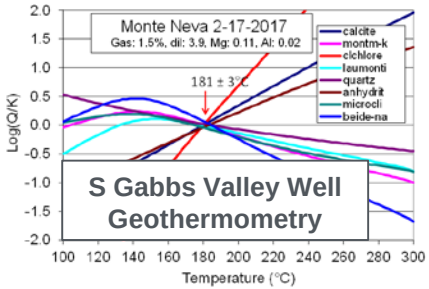


S Gabbs Valley Geologic Map

Sou Hills LiDAR and Quaternary Fault Map







S Gabbs Valley Well Geothermometry

Geochemical Investigations

Location	Total Water Analyses Available	Historical Water Samples	New Analyses	Samples Collected - PFA project	Minimum Temp (°C)	Maximum Temp (°C)	Source of New Analyses
Crescent Valley	31	8	15	8	8.3	125.5	US Geothermal
Gabbs Valley	20	11	5[a]	4	8	130	Ormat Technologies; Payne, 2013
Granite Springs Valley	34	11	15	8	7.8	41.7	AquaTrac Water Importation Project
Sou Hills	23	20	0	3	13.8	76.7	NA
Steptoe Valley	19	17	1	1	14.5	79	Chovanec, 2003

Technical Accomplishments and Progress: Phase 2 Tasks

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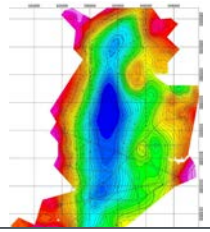
- **Shallow temperature surveys – Task/Milestone 16**
  - Initial reconnaissance surveys for many of the 24 sites - > 200 stations, with anomalous temps found at 5 sites
  - 292 stations in detailed study areas
  - Extremely wet winter probably suppressed some thermal anomalies
- **Gravity surveys – Task/Milestone 18**
  - Critical for constraining subsurface geometry of faults
  - New gravity surveys in all 5 study areas
  - 237-415 new stations acquired in each area
  - Merged with legacy data (as many as 3,000 stations)
  - Products:
    - Complete Bouguer
    - Horizontal gradient
    - First vertical derivative
    - Depth to basement profiles

Shallow Temperature Surveys

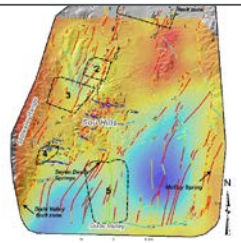
NV PFA	Location	Number Stations	Acquisition Date	Max Temp (°C)	New Thermal Anomaly	Notes
DETAILED STUDY AREAS	**Crescent Valley**	31	5/17	11.1	No	Probably affected by very wet winte
	Gabbs Valley	124	8/16, 12/16	25.7	Yes	Discrete thermal anomaly
	Granite Springs Valley	55	3-4/17	13.3	Yes	Possible very weak anomaly in nort area (Adobe Flat area)
	Sou Hills	82	9/16, 3-4/17	26.3	Yes	Weak unconfirmed anomaly in west graben area
	Steptoe Valley	0	N/A	N/A	N/A	Not acquired due to wet conditions
Runners Up and Reconnaissance Areas	**Dun Glen Area**	30	7/16, 9/16	27.4	Yes	Thermal anomaly near step-over
	North Fox Range	35	7/16	20.4	No	
	McLeod Area	19	9/16	24.7	No	
	Mt. Tobin area, Pleasant Valley	21	8/16	22.6	No	
	Peterson Area (Smith Creek Valley)	19	9/16	69	No	Hot near hot springs, 14-20°C elsewhere
	Humboldt Range (south range front)	36	9/16	26.6	Yes	East of Lovelock, NV (informally referred to as "Lovelock Meadows")
	Humboldt Range (northern step-over)	22	8-9/16	25.9	Yes	Thermal anomaly within a step-over and fault intersection

2 m Temp Survey



Granite Spgs Valley Gravity Map

Sou Hills Gravity Map



Gravity Surveys

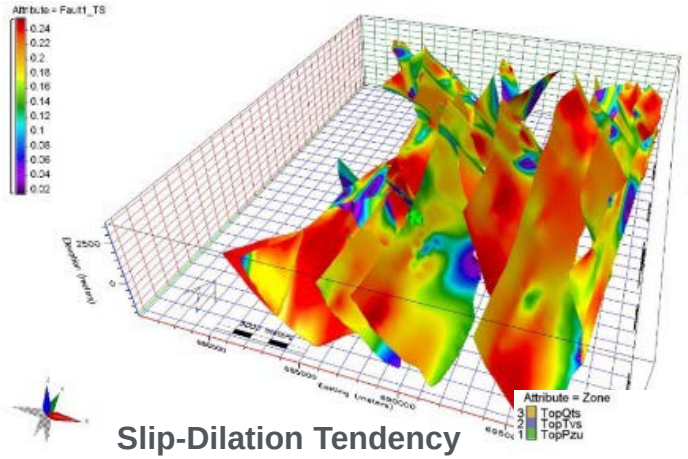
Location	Total New Stations	Contractor	Merged Legacy Stations	Complete Bouguer Anomaly	Horizontal Gradient Magnitude	First Vertical Derivative	Depth to Basement Profiles
Crescent Valley	237	Zonge	3,000*	✓	✓	✓	4
Gabbs Valley	274	Zonge	0	✓	✓	✓	2
Granite Springs Valley	415	Tom Carpenter	673	✓	✓	✓	9
Sou Hills	355	Zonge	0	✓	✓	✓	8
Steptoe Valley	278	Utah Survey	1,764	✓	✓		7

Technical Accomplishments and Progress: Phase 2 Tasks

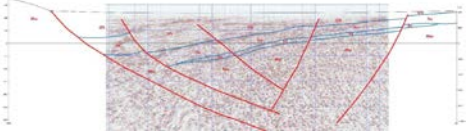
- **Seismic reflection analysis – Task/Milestone 19**
  - 540 km of legacy reflection profiles purchased and interpreted
  - 35 profiles analyzed
  - Goals:
    - Constrain fault geometries
    - Identify favorable structural settings in basins
    - Basis for 3D models
- **Slip and dilation tendency analysis – Task/Milestone 20**
  - Quaternary faults in all areas
  - 3D in two areas
  - Based on acquired slip data and regional data
- **3D modeling – Task/Milestone 21**
  - Models completed for Steptoe and Granite Springs Valley
  - Sou Hills – preliminary model
  - Define favorable settings in basin, potential reservoirs, and fault segments conducive for fluid flow

Seismic Reflection Analysis

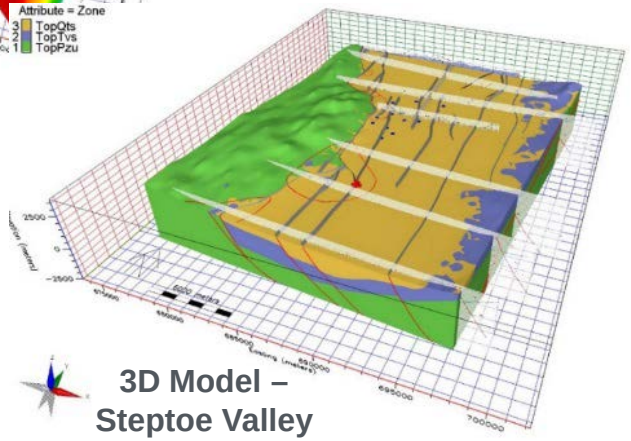
Location	Purchased Profiles*	Length of Profiles (km)	Available SGY files	Available velocity models
Crescent Valley	4	92	3	4
Gabbs Valley	0	0	0	0
Granite Springs Valley	9	144	6	9
Sou Hills	7	105	0	4
Steptoe Valley	15	199	13	15



Slip-Dilation Tendency Analysis – Steptoe Valley



Example of Interpreted Reflection Profile, Granite Sprgs Valley

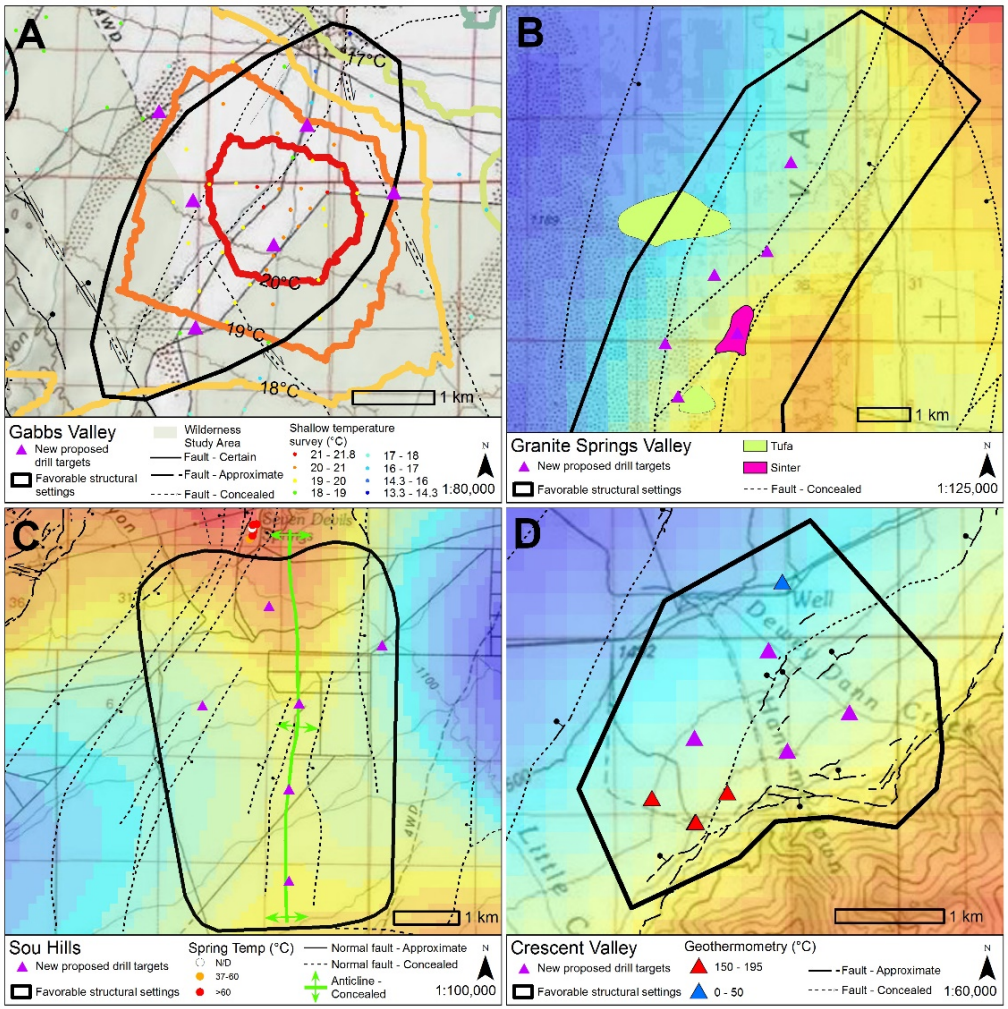


3D Model – Steptoe Valley

Technical Accomplishments and Progress: Select Drilling Targets

- **Select drilling targets – Task/Milestone 23**
  - **Southern Gabbs Valley (A)**
  - **Northern Granite Springs Valley – Adobe Flat (B)**
  - **Sou Hills (C)**
  - **Crescent Valley (D)**
  - **Gabbs and Granite Springs are priority sites**
- **Geologic, geochemical, and geophysical data from Phase 2 detailed studies synthesized to select drilling sites for TG holes in Phase 3**
- **All areas warrant further exploration**
- **Budget allows drilling of TG holes at two sites in Phase 3**
  - **Southern Gabbs Valley**
  - **Granite Springs Valley**

Proposed TG Drilling Targets



Technical Accomplishments and Progress: Completed Milestones in Phase 2

- ✓ Down-select to final sites for detailed study
- ✓ Geologic studies
- ✓ Geochemical studies
- ✓ Shallow temp surveys
- ✓ LiDAR surveys
- ✓ Gravity surveys
- ✓ Seismic reflection analysis
- ✓ Slip and dilation tendency analysis
- ✓ 3D modeling
- ✓ Thermal modeling
- ✓ Selection of drilling targets
- ✓ Final reporting and project review
- ✓ **All accomplished with no variances although completion of some tasks delayed slightly by very wet winter**

Table 2. Milestone Summary for Budget Period 2

Recipient Name: Nevada Bureau of Mines and Geology, University of Nevada, Reno

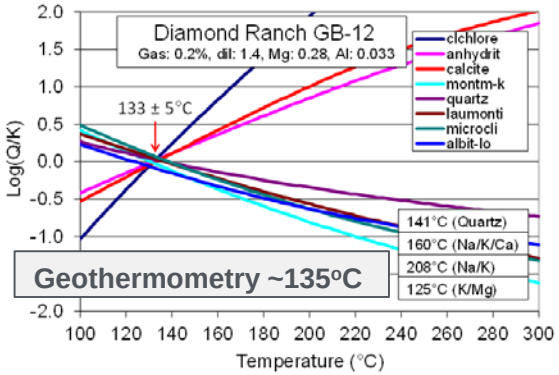
Project Title: Discovering Blind Geothermal Systems in the Great Basin Region: An Integrated Geologic and Geophysical Approach for Establishing Geothermal Play Fairways

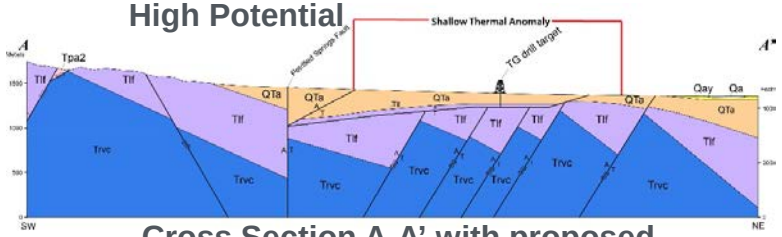
Task #	Task Title or Subtask Title	Milestone or Go/No Go Pt	Milestone # or Go/No-Go Pt #	Milestone Description and Decision Criteria	Milestone Verification Process	Ant. Mo.	Ant. Qtr	Comp. Qtr
13	Down Select to Final Sites for Detailed Study	Milestone	M13.1	Compilation of geological and geophysical data	GIS databases of available geologic maps and geophysical data sets	5	Q2	Q3
13	"	Milestone	M13.2	Select 3-5 sites for detailed studies	List of 3-5 most promising sites	5	Q2	Q3
14	Geologic Studies	Milestone	M14.1	Compilation of all available and new data	GIS databases of 3-5 sites including preexisting and new data	12	Q4	Q6
14	"	Milestone	M14.2	Detailed geologic maps	Detailed digital geologic maps showing bedrock and Quaternary units, as well as faults	15	Q5	Q6
15	Geochemical Investigations	Milestone	M15.1	Compilation of available and new geochemical data for most promising areas	GIS database of geochemical data for most promising sites	5	Q2	Q3
15	"	Milestone	M15.2	Geochemical characterization of 3-5 detaield study sites	GIS database/geochemical assessment of 3-5 detailed study areas	12	Q4	Q6
16	Shallow Temperature Surveys	Milestone	M16.1	Reconnaissance shallow-temp surveys for most promising areas	GIS database of reconnaissance shallow temperature surveys	5	Q2	Q3
16	"	Milestone	M16.2	Detailed shallow-temp surveys for 3-5 detailed study areas	GIS database of detailed shallow temperature surveys of 3-5 detailed study areas	12	Q4	Q6
17	LiDAR Surveys	Milestone	M17.1	New LiDAR acquired for some of the 3-5 detailed study sites	GIS databse of new LiDAR data for some of the 3-5 detailed study areas	9	Q3	Q6
17	"	Milestone	M17.2	Interpretations of new LiDAR data	GIS database of interpreted LiDAR and incorporation into geologic maps	13	Q5	Q6
18	Gravity Surveys	Milestone	M18.1	Compilation and analysis of available gravity data in some of the most promising areas	Maps showing gravity data for some of the most promising sites	5	Q2	Q3
18	"	Milestone	M18.2	Acquisition and processing of new gravity data in 3-5 detailed study areas	GIS database and maps showing interpreted gravity data with inferred faults	12	Q4	Q6
19	Seismic Reflection Analysis	Milestone	M19.1	Obtain reflection profiles from Seismic Exchange, Inc. for some of the detailed study areas	Amended license with Seismic Exchange, Inc., permitting interpretation of newly purchased profiles	6	Q2	Q3
19	"	Milestone	M19.2	Interpretation of seismic reflection profiles	GIS database of interpreted profiles and time to depth conversions	12	Q4	Q6
20	Slip and Dilation Tendency Analysis	Milestone	M20.1	Complete slip and dilation tendency analyses of 3-5 detailed study areas	Digital map showing slip-dilation tendency of faults for detailed study areas	13	Q5	Q6
20	"	Milestone	M20.2	Conduct 3D slip and dilation tendency analysis for those detailed study areas modeled in 3D	Model showing slip and dilation tendency in 3D for some of the detailed study areas	15	Q5	Q6
21	3D Modeling	Milestone	M21.1	Construct 3D models for some of the 3-5 detailed study sites	3D models constructed from geologic map data, seismic reflection profiles, and gravity data for some of the sites studied in detail (~3 sites)	15	Q5	Q6
22	Thermal Modeling	Milestone	M22.1	Complete thermal modeling of some of the detailed study sites in eastern Nevada	Digital thermal models of some of the detailed study sites	11	Q4	Q6
23	Selection of Drilling Targets for BP3	Milestone	M23.1	Selection of promising drilling targets for geothermal reservoirs at the 3-5 detailed study areas	Digital maps showing locations of promising drilling targets for 3-5 detailed study areas	16	Q6	Q6
24	Final Reporting and Project Review	Milestone	M24.1	Synthesis of project	Submittal of report and databases	17	Q6	Q6

Technical Accomplishments: Example of Detailed Study, Southern Gabbs Valley

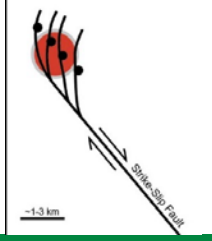
- **Only Gabbs Valley described in this presentation due to time-length constraints, but similar data acquired for all 5 detailed study areas.**
- **New discovery-blind system, no previous exploration**
- **Masters thesis project for Jason Craig**
- **Wells 32°C and geothermometry – 135°C**
- **Shallow (2 m) temperature anomaly (124 stations)**
- **Geologic map (179 km^2) + cross sections**
- **Gravity survey (274 stations) – depth to basement**
- **LiDAR analysis**
- **Quaternary fault analysis – age and slip rates**
- **Slip and dilation tendency analysis**
- **Thermal anomaly at fault intersection in displacement transfer zone**

Play Fairway Analysis Shows High Potential

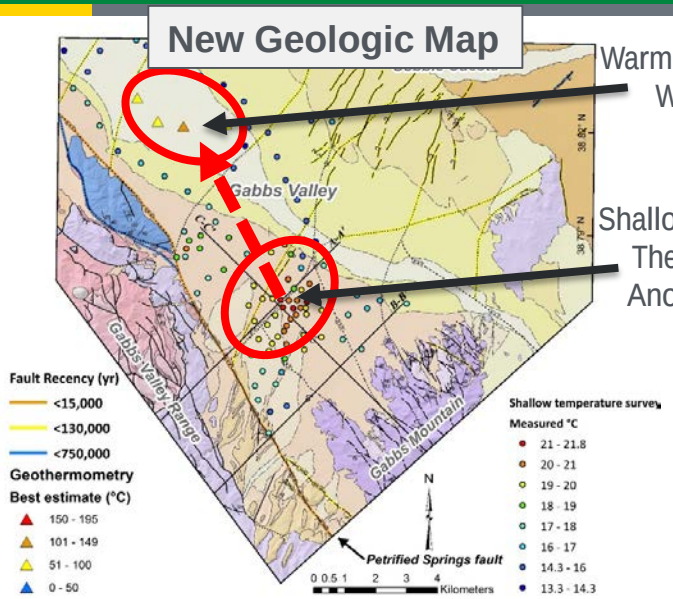




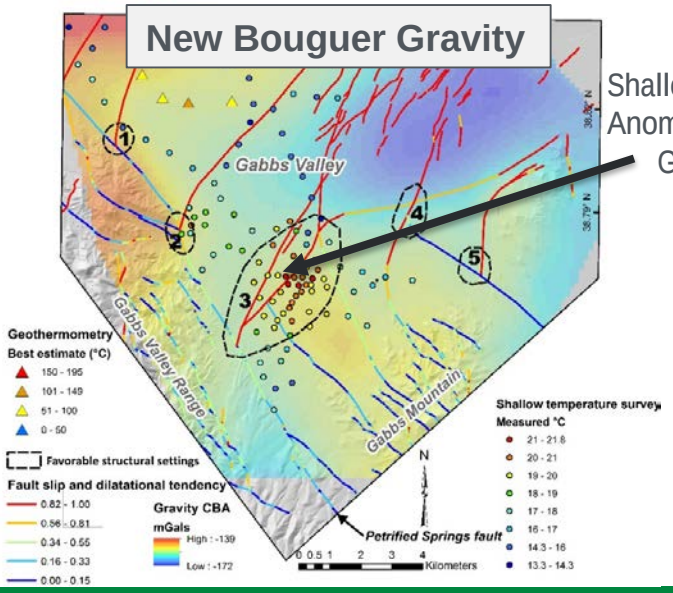
Cross Section A-A' with proposed drill site



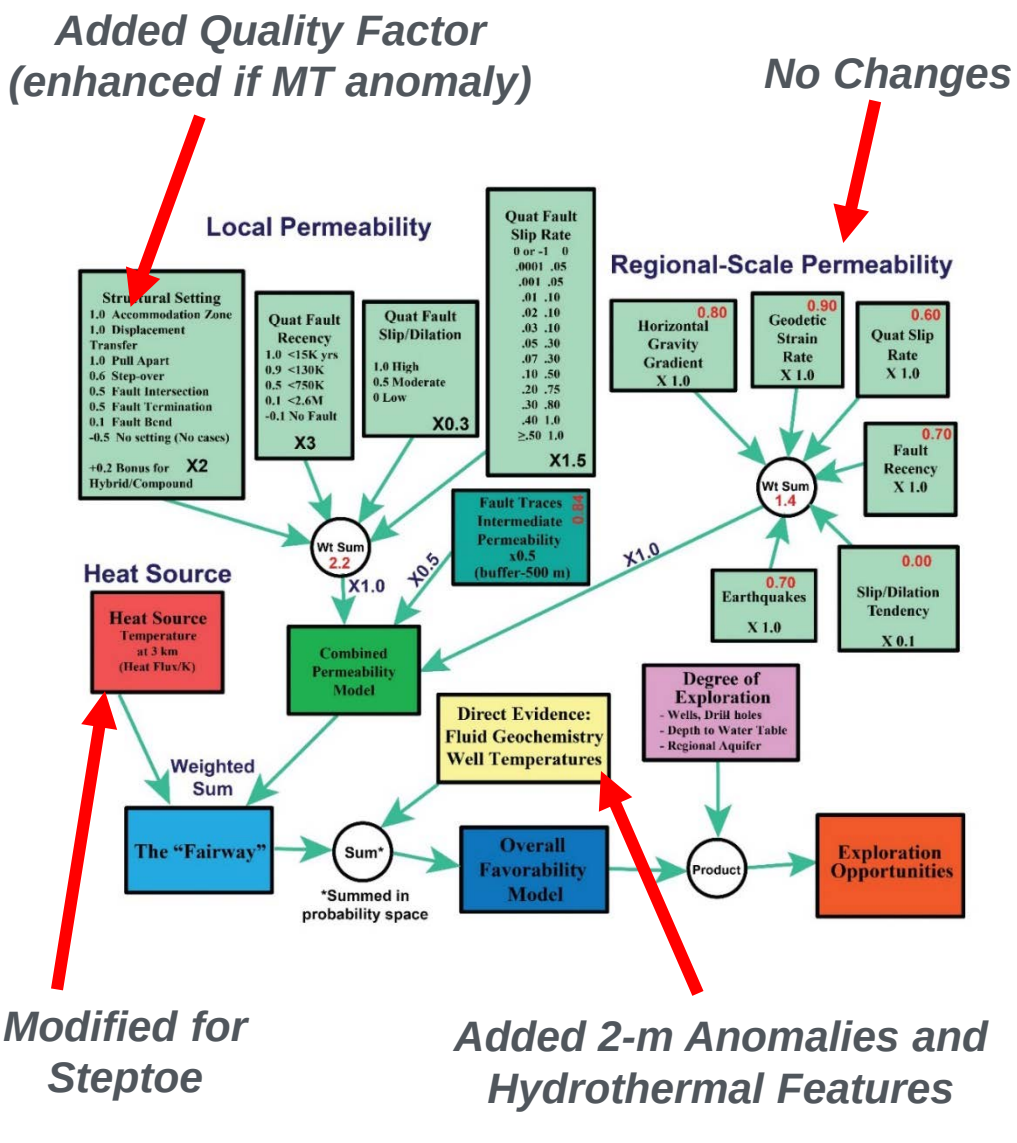
New Geologic Map



New Bouguer Gravity



Technical Accomplishments: Phase 1 vs. Phase 2 Play Fairway Analysis



- Predictive play fairway maps generated for each study area
- 3 types of maps generated:
  - Play fairway maps
  - Play fairway error maps
  - Direct evidence maps
- Regional permeability followed same procedure as Phase 1
- Changes made to methodology for local permeability
  - Structural setting quality factor (scale of 0 to 1)
  - MT data – only available for northern Granite Spgs Valley, so low resistivity enhanced structural quality by 0.1
- Detailed temp model replaced regional heat model for Steptoe Valley only (slice at 1,250 m bsl) Changes in direct evidence
  - 2 m temp anomalies added taking into account sources of error and probability of indicating system >130°C
  - Presence of silica sands, sinter, or explosion craters added

Technical Accomplishments: Phase 1 vs. Phase 2 Results

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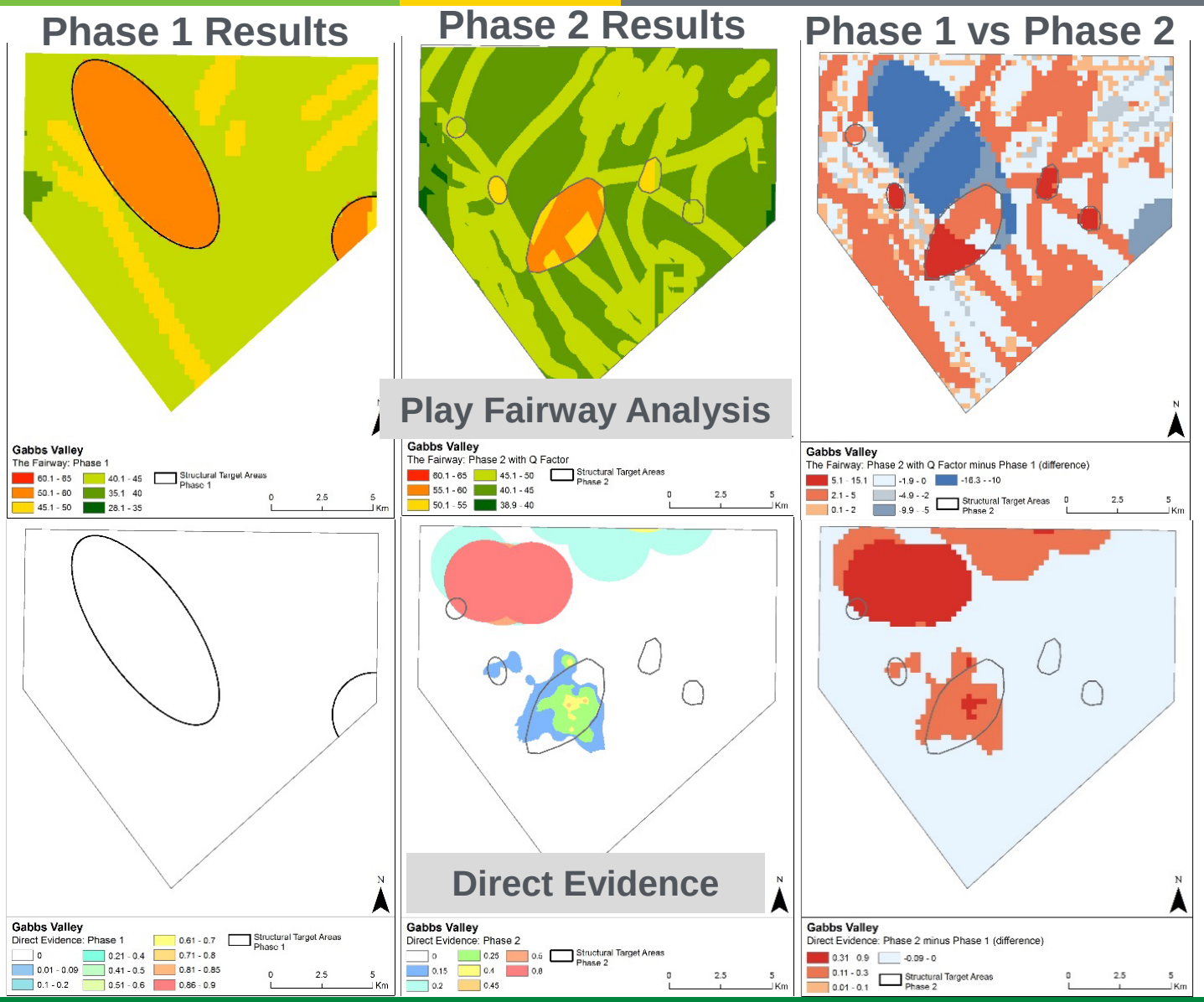
- Phases 1&2 – Similar fairway scores
- Phase 2:
  - Locations of higher favorability more accurately known
  - Each area has several favorable settings
  - Locations of favorable structural settings elucidated by data with some new and some shifted
  - Potential of late Cenozoic basins better understood – Critical since half of region covered by basins and basins have large untapped potential
  - Direct evidence shown in much greater detail
- Error analysis shows targets statistically significant (not included in this presentation)



Future Directions: Phase 3 of Nevada Play Fairway Project

- **Critical to test methodology to validate systems with sufficient temps and volume for commercial development**
- **Phase 3 will complete this testing with following tasks in FY18:**
  - **Task 25 – Permitting**
  - **Task 26 – Geoprobe drilling to obtain H_2O samples and measure temp at up to 3 sites and up to 18 holes**
  - **Task 27 – Temperature-gradient (TG) drilling to constrain size, depth, and commercial viability of system; up to 10 holes at 2 sites**
  - **Task 28 – Geochemical analyses for geothermometry**
  - **Task 29 – Potential field geophysics to refine structural model and select drill sites**
  - **Task 30 – MT surveys to refine fluid flow model and constrain drilling sites**
  - **Task 31 – Refined 3D modeling incorporating new data and to constrain conceptual models**
  - **Task 32 – Resource capacity estimates to evaluate commercial viability of systems**
  - **Task 33 – Final reporting**

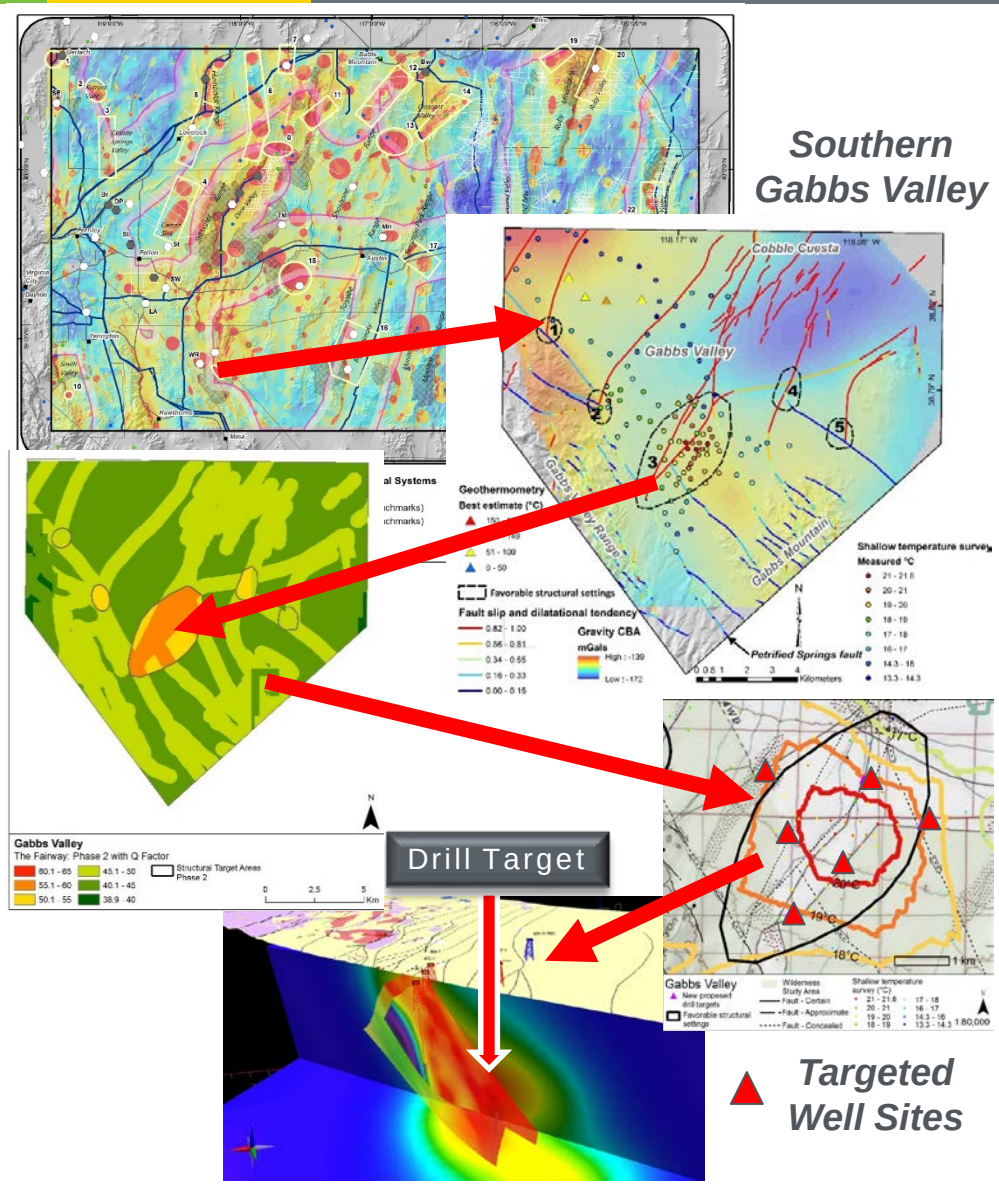
Timeline and Milestone Table

Task & Milestones	Q1	Q2	Q3	Q4	Q5	Q6
25. Permitting						
26. Geoprobe drilling						
27. TG Drilling						
28. Fluid Sampling and Analysis						
29. Potential Fields Geophysics						
30. MT Surveys						
Go-No-Go based on drilling results						
31. 3D Modeling						
32. Resource Capacity Estimates						
33. Final Report						

- **Timeline of tasks and milestones (see chart above)**
- **Drilling planned for Gabbs and Granite Springs Valleys. If initial results poor, will remobilize to Sou Hills and/or Crescent Valley.**
- **Research team for Phase 3**
  - **UNR-NBMG – Responsible for managing project, permitting, geochem, overall synthesis, reports (Faulds, Hinz, Ayling)**
  - **USGS – Responsible for potential fields, MT, 3D models (Glen, Siler), as well as drilling (Crawford)**
  - **Innovate Geothermal – Responsible for 3D gravity models (Witter)**

Future Directions: Phase 3 Outcomes and Implications

- **Phase 3 is third step in systematic multi-disciplinary effort to discover new commercial-grade geothermal resources in Great Basin region**
- **Rigorous play fairway analysis permits assessment of geothermal potential in target-rich region**
- **Dynamic predictive model at multiple scales**
- **Potential outcomes:**
  - **Validation of play fairway methodology**
  - **Constrain geologic-geochem-geophysical signature of geothermal system**
  - **Provide means to evaluate and reduce risks in geothermal exploration and drilling**
  - **Refine methodology for selection of deep drill targets**
  - **Facilitate development of blind systems**
  - **Help geothermal industry achieve higher productivity levels**
  - **Unleash potential of a world-class geothermal province**
- **Methodology applicable to other regions**



Research Collaboration and Technology Transfer

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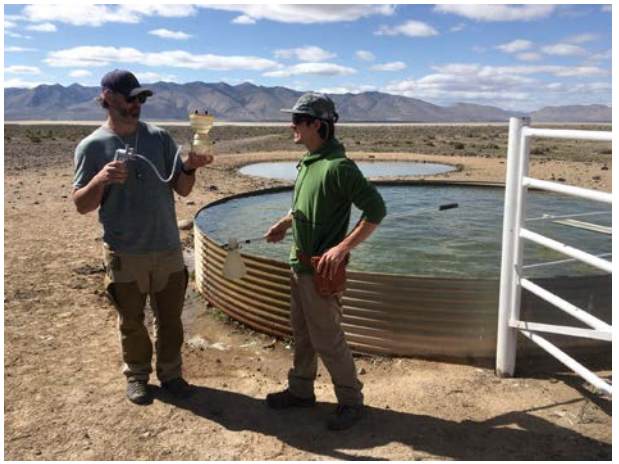
- **Academic engagement:**
  - Two UNR Masters students supported by Phases 2 and 3; Emma McConville on Crescent Valley and Jason Craig on Gabbs Valley.
  - One UNR undergraduate student supported by project.
  - Play fairway analysis and detailed studies incorporated into Faulds' geothermal exploration class, Spring 2017.
- **Industry engagement:**
  - Collaborating with U.S. Geothermal on Crescent Valley project with full exchange of data and interpretations.
  - U.S. Geothermal agreed to cost-share any Phase 3 drilling in Crescent Valley.
  - Several meetings with Ormat to discuss Gabbs and Granite Springs Valley prospects; Ormat provided data for parts of Granite Springs Valley.
  - Full cost-sharing on drilling difficult for industry to justify without secure leases.
- **Technology transfer/public outreach:**
  - Upload of all data from Phase 2 to GDR in progress.
  - Presented to public at annual NBMG open house.
  - Article on project released in *Nevada Today* (UNR weekly online publication-August 2017); https://nbmg.wordpress.com/2017/08/28/drilling-to-begin-in-universitys-great-basin-geothermal-exploration-project/
  - 7 papers and 5 abstracts published.
  - 15 presentations—GRC, GSA, IMAGE (Iceland), AAPG, Nevada Petroleum and Geothermal Society, and others.



Grad Students Sample Warm Well, Granite Springs Valley

Field Work by Grad and Undergrad Students, Crescent Valley

Summary: Nevada Play Fairway Project

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- Vast geothermal resources in region with abundant favorable structural settings
- Main challenges are finding sufficient permeability and selecting best well sites
- Play fairway methodology has produced new generation of geothermal potential maps defining high potential areas
- High-temperature systems probable at each selected detailed study area
  - Illustrates effectiveness of our play fairway methodology.
- Methodology adaptable at multiple scales
  - Facilitates exploration of best areas (known and unknown systems), and
  - Facilitates selection of specific drilling targets
- On threshold of major advances and more McGinness Hills discoveries
- Methodology has potential to unleash vast potential of region
- Favorable land status assures that methodology can be put to good use