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John Shervais, **USU**: *Petrology, geochemistry, volcanology, geothermal exploration.*

James Evans, **USU**: *Structural geology, petroleum systems, fractures and seals.*

Dennis Newell, **USU**, *Light stable isotope studies of thermal fluids.*

Dennis Nielson, **DES**: *Geothermal exploration, conceptual models, drilling.*

Jonathan Glen, **USGS**: *Potential field geophysics, gravity, magnetics.*

Lee Liberty, **BSU**: *Geophysics, seismic reflection/refraction.*

Patrick Dobson, **LBNL**: *Geochemistry and isotopes of thermal fluids.*

Eric Sonnenthal, **LBNL**: *Thermal modeling of igneous and geothermal systems.*

Erika Gasperikova, **LBNL**: *Geophysics, electrical and magnetotelluric imaging.*

Drew Siler, **USGS**: *Structural geology, stress analysis*

Hari Neupane, **INL**: *Water chemistry of thermal fluids*

Neil Snyder, **NREL**: *Geothermal systems, NGDS, land use.*

Sabodh Garg, **Leidos, Inc**: *Geothermal reservoir modeling, engineering.*

Jacob DeAngelo, USGS: *Lead GIS Programmer*

Snake River Plain PFA

Project Officer: Holly Thomas

Total Project Funding: $1.8M

November 15, 2017

John W Shervais

Utah State University

PLAY FAIRWAY

Mandatory slide

Relevance to Industry Needs and GTO Objectives

Project Objectives – Snake River Plain PFA:

- Adapt methodology of *Play Fairway Analysis* and create a formal basis for its application to geothermal exploration.
- Build a geothermal play fairway model for the Snake River Plain that will allow us to identify the most promising plays, and identify prospects for further exploration.
- Phase 1: Collated existing data on the SRP and created a GIS-based approach to data integration and analysis;
- Phase 2: Filled select data gaps and integrated these results with data from Phase 1.
- Phase 3: Validate this approach through targeted drilling.
- *Ultimate Goals: Develop a PFA methodology to lower the risk and cost of geothermal exploration and development throughout geothermal industry, and stimulate development of new geothermal power in Idaho, especially blind geothermal systems.*

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Phase 1: Data compilation and Creation of GIS-based Data Integration Method

- Conceptual framework for geothermal PFA formalized and component data types identified.
- Existing data were compiled and integrated into a series of evidence layers evaluated using a GIS-based approach.
- New GIS-based method for Play Fairway Analysis was created that integrated favorability and risk into a series of comprehensive risk maps (CRS) and combined CRS maps (CCRS).
- Data processing was carried out using Python scripts that (nearly) automated processing, facilitating the evaluation of large data sets and regional geographic areas.
- Several prospective plays were identified regionally, and focus areas selected for possible Phase 2 work on data gaps.

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Phase 2: Fill Data Gaps, Refine Thermal Models, and Update GIS-based PFA Integration Method

- Collect new geologic, geochemical, and geophysical data to fill data gaps and update Risk Maps.
- Build new thermal and THC models to validate our conceptual model.
- Update and enhance our GIS-based PFA system to improve data handling and facilitate 'what if' analyses using different evidence layer or risk map weights.
  - New, more efficient Python scripting
  - Ability to more easily modify layer weights and risk map weights
  - Validate using data from other PFA projects
  - Better targeting for potential Phase 3 validation drilling.
- Integrate new and old data using improved GIS methods.
- Build new CRS and CCRS risk maps for each focus area.

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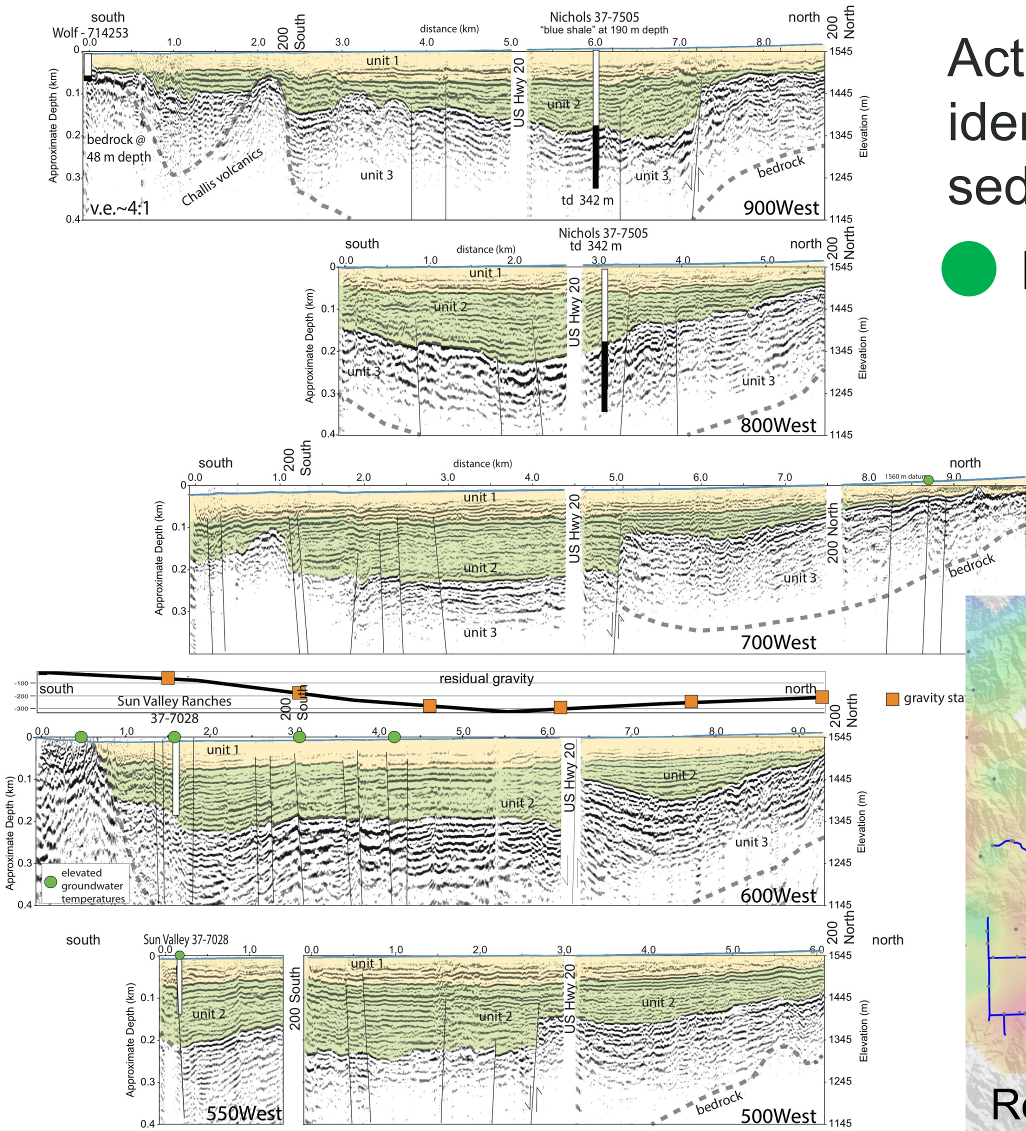
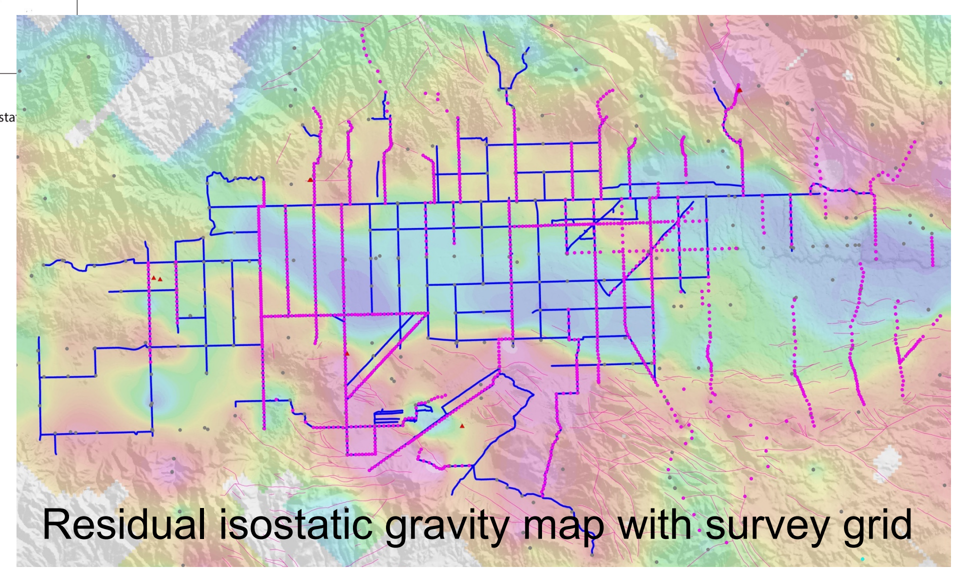
Methods/Approach: Seismic, Gravity, Magnetics



Active source seismic surveys that identify depth to basement, offset sediment reflectors, and fault locations.

- Hot Springs, Wells
- Gravity station
- High-resolution gravity
- Magnetic surveys



Residual isostatic gravity map with survey grid

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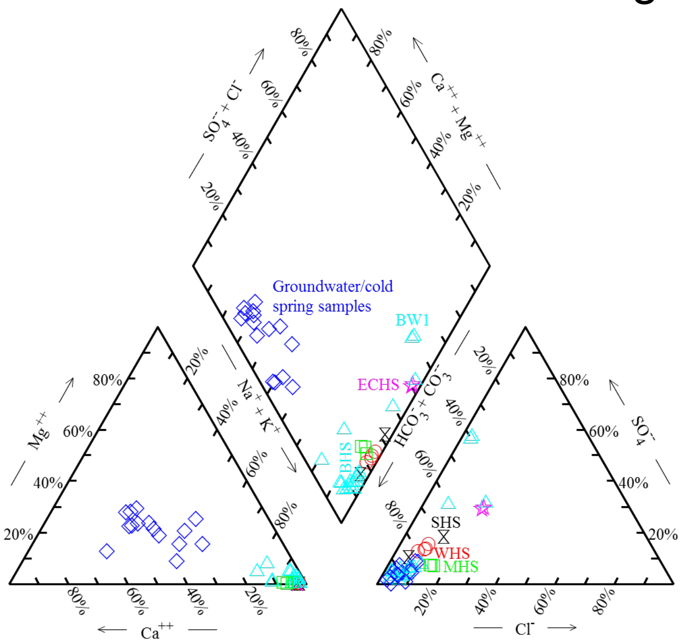
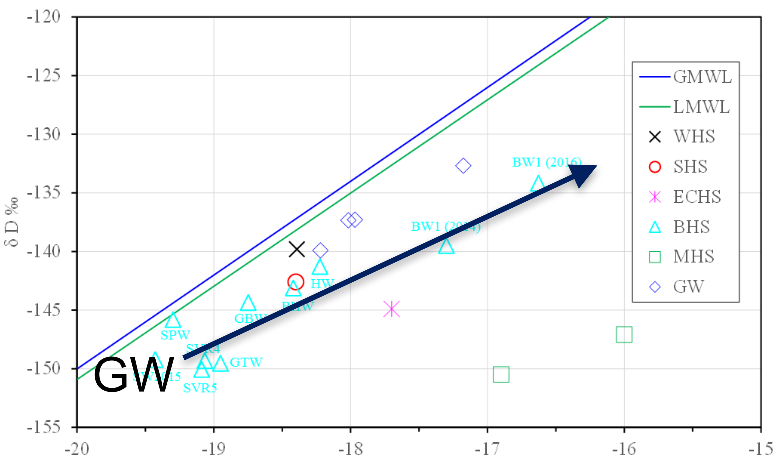
Methods/Approach: Water Chemistry and Isotopes

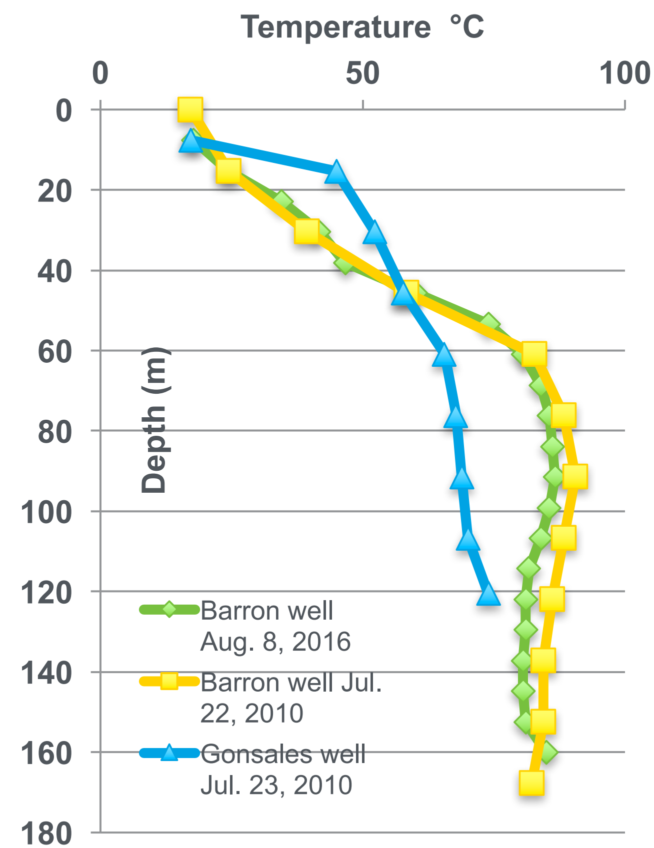
Groundwater in Camas is Ca-Mg HCO_3, thermal waters are Na-K SO_4-HCO_3.



Multicomponent geothermometers indicate reservoir temperatures of 103ºC (rTest) to 143ºC (GeoT) in Camas focus area.



Meteoric water mixes with thermal waters. $^3He/^4He$ 1.5-2.2x Ra



Camas Prairie Temperature Gradients

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Technical Accomplishments and Progress

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- Over 50 km of new active source seismic lines in Camas Prairie area document fault locations and orientations (Glen et al., SGW, 2017).
- 1659 new gravity stations and over 1725 line-km of magnetic survey data collected around focus areas Camas Prairie and Mountain Home, which document basement offsets and lineaments that reflect buried fault systems. Maximum gradients in gravity and magnetic anomalies are digitized for input into GIS-based data system (permeability) (Glen et al., SGW, 2017).
- Camas Prairie: 28 new water samples were collected for chemical and isotopic analysis. Most samples are mixtures of thermal and meteoric waters. $^{3}He/^{4}He$ ratios are up to 1.5-2.2 R/Ra (mixing with a mantle He). The highest He R/Ra are found along the Pothole fault system (Neupane et al., SGW, 2017).
- Fully coupled THC (thermal-hydrologic-chemical) models built in *ToughReact* show that our conceptual model is consistent with long-term thermal anomalies, high heat flow, and hydrothermal systems, and matches the observed mineralogy in deep core (Nielson et al, SGW, 2017).
- These conclusions are supported by a natural state thermal model of the Mountain Home area (Garg, Leidos report, May 2017).

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Technical Accomplishments and Progress

- Equilibrium water temperatures range from 103ºC to 203ºC, based on standard solute and multi-component thermometers, with temperatures of 110-130ºC for springs along The Pothole fault system (Neupane et al., SGW, 2017).
- Basalt vents range in age from 1.2 Ma to 2.1 ka, indicating long term input of heat that continued into the Holocene.
- Camas Prairie: Phase 2 results document a highly prospective zone along The Pothole fault system, characterized by high fault densities, dilatant releasing bends, high $^{3}He/^{4}He$, large basement offsets, and moderate inferred reservoir temperatures. MT data indicate a clay cap over the prospective target.
- Mountain Home: Phase 2 results document highly prospective zones on the corners of Mountain Home AFB. This system is entirely blind, inferred from gravity and magnetic lineaments, and high thermal gradients in pre-existing deep wells. MT data indicate an extensive clay cap that pinches out to the NE.
- NO significant variances in cost or timeline; GRC Best Presentation Award, 2015
- Technical Challenges: Coordinating permissions for geophysical surveys on public (USAF, BLM) and private land.

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Technical Accomplishments and Progress

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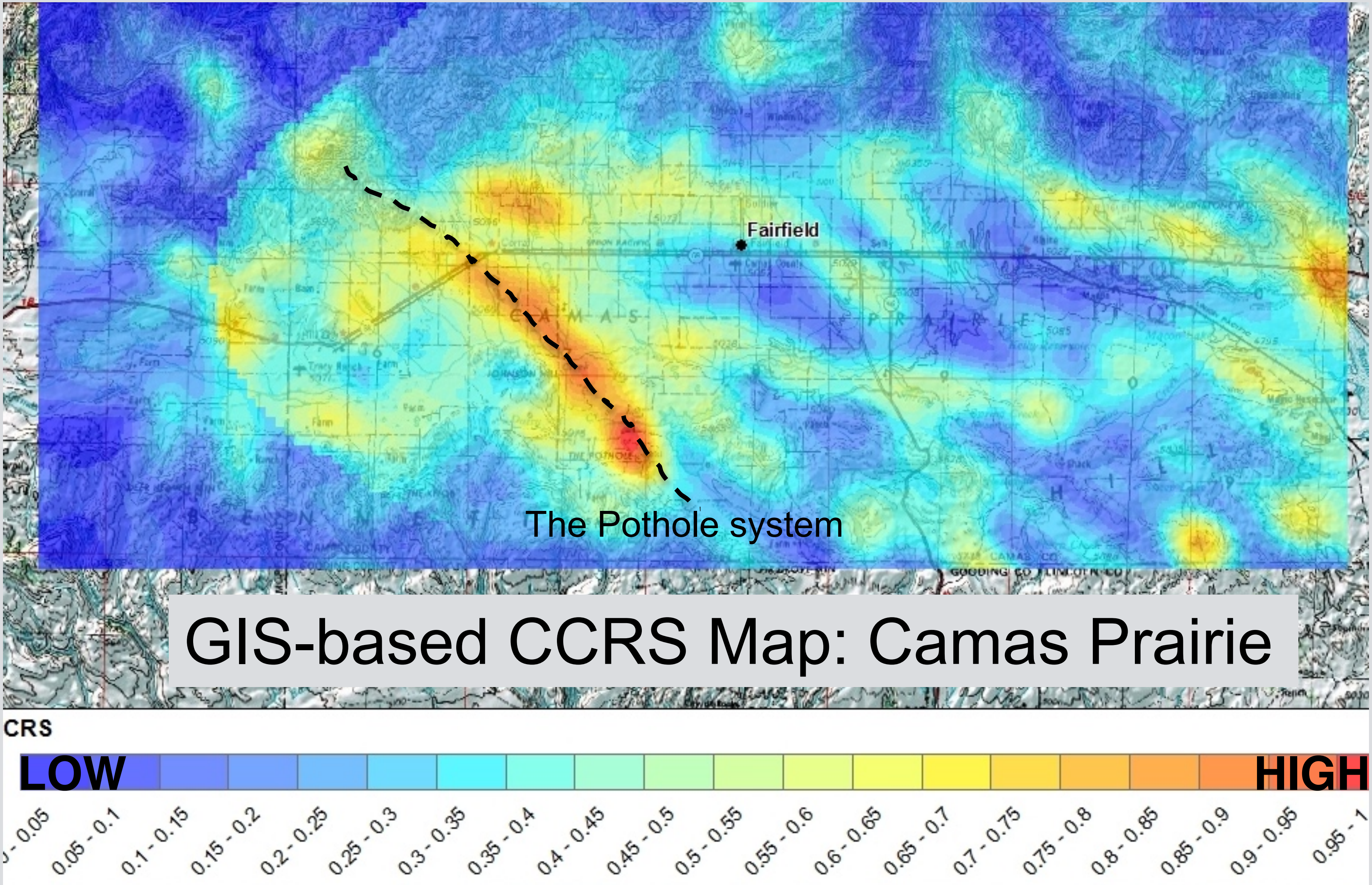

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Technical Accomplishments and Progress

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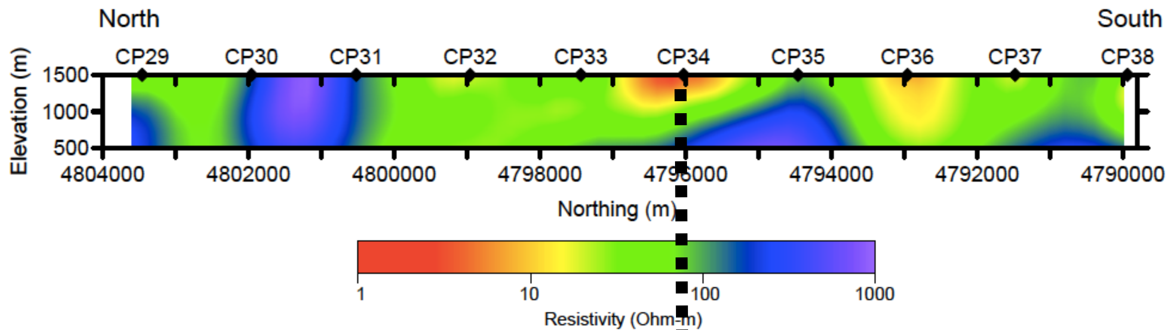
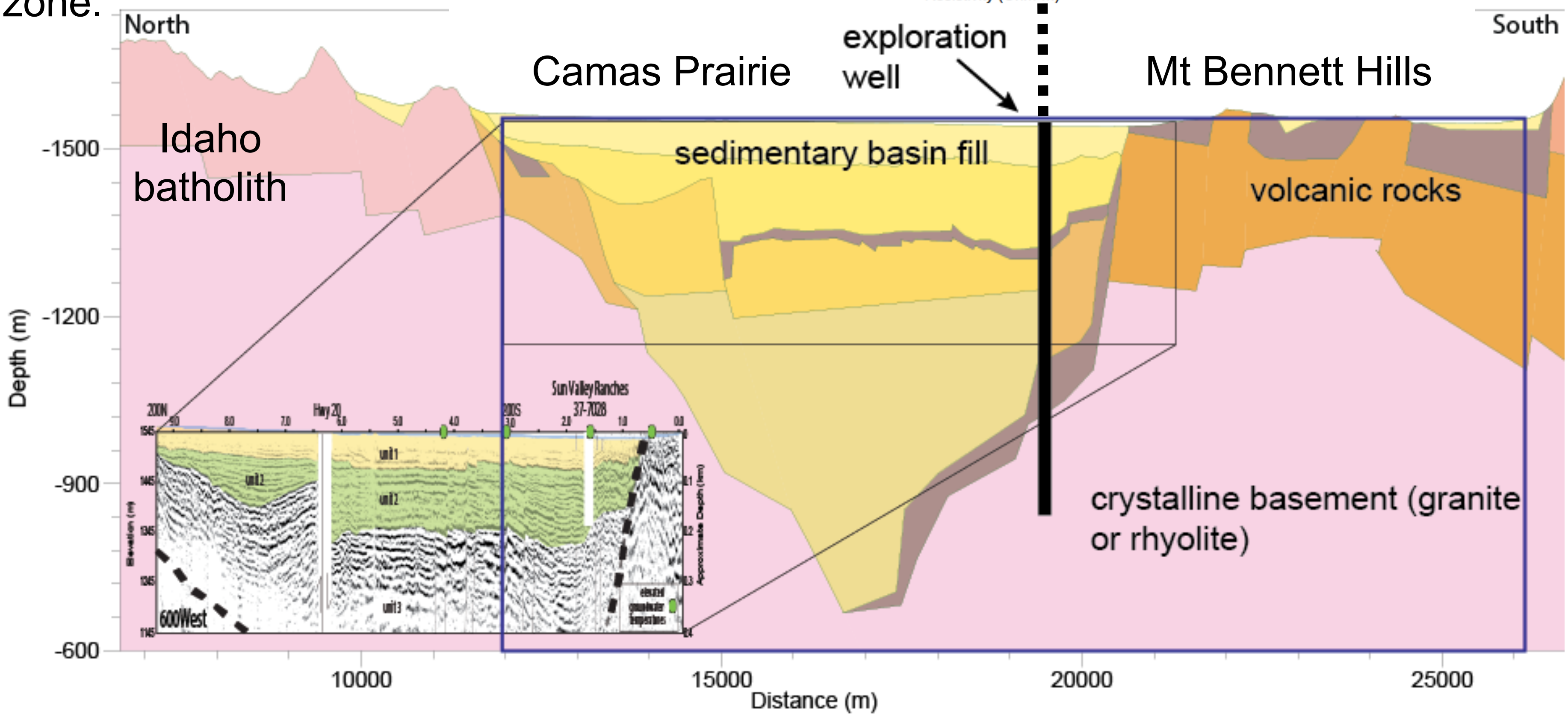
Joint gravity and magnetic model with seismic constraints and MT constraints showing clay cap over target zone.





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Technical Accomplishments and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Task 5.1: Recruit industry advisory board	Industry Advisory Board recruited with four representatives.	3/31/16
Task 5.2: Kickoff meeting, focus site selection, field campaign plans.	Team meeting in Boise to review sites and carry out field visits; final focus sites chosen.	6/30/16
Task 6: Collection of new field data (geology, geophysics, geochemistry).	Collection of magnetotelluric, seismic, gravity-mag surveys, and geochemical samples complete. Detailed mapping complete.	9/30/16
Task 7: Complete thermal, conceptual and THC models.	Thermal, conceptual and THC models completed and presented at Stanford Geothermal Workshop and GRC, 2017.	3/30/17
Task 8: Integration of geologic and geophysical data with thermal & conceptual models	All geophysical, geochemical, and geologic data integrated into our GIS-based analysis model, and new CCRS maps produced.	4/30/17

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Research Collaboration and Technology Transfer

- *Industry engagement*: We have an Industry Advisory Board comprising Andy Sabin (USN), Patrick Walsh (Ormat), Ian Warren (U.S. Geothermal), and Roy Mink (Mink Geohydro Inc.).
- *Industry engagement*: Two of our team members are geothermal industry related (DES Inc., Leidos Inc.).

- *Technology transfer to the private sector*: Our GIS-based approach uses industry standard Arc GIS with Python scripts to automate data processing and integration, facilitating interpretation and risk analysis.
- *Technology transfer:* Much of our project data has already been uploaded to the NGDS.

Mandatory- may utilize multiple slides

Research Collaboration and Technology Transfer

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Shervais et al, 2015, Snake River Plain Play Fairway Analysis - Phase 1 Report. *GRC Transactions, v39*.

Shervais et al., 2016, Play Fairway Analysis of the Snake River Plain Volcanic Province: Phase 1. *Proceedings 41st Workshop on Geothermal Reservoir Engineering, Stanford University, SGP-TR-209*.

DeAngelo et al, 2016, GIS Methodology for Play Fairway Analysis: Example from the Snake River Plain Volcanic Province. *Proceedings 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, SGP-TR-209*.

Garg et al., 2016, Thermal modeling of the Mountain Home Geothermal Area. *Proceedings 41st Workshop on Geothermal Reservoir Engineering, Stanford University, SGP-TR-209.*

Garg and Nielson, 2016, Slim Hole Reservoir Characterization for Risk Reduction. *Proceedings 41st Workshop on Geothermal Reservoir Engineering, Stanford University, SGP-TR-209.*

Kessler et al, 2017, Geology and In Situ Stress of the MH-2 Borehole, Idaho, U.S.A.: Insights into Western Snake River Plain Structure from Geothermal Exploration Drilling, *Lithosphere*, doi:10.1130/L609.1.

Glen et al, 2017, Geophysical investigations and structural framework of the Camas Prairie geothermal system southcentral Idaho. *Proceedings 42nd Workshop on Geothermal Reservoir Engineering, Stanford* SGP-TR-212

Nielson et al, 2017, Mafic Heat Sources for Snake River Plain Geothermal Systems. *Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford Univeristy,* SGP-TR-212.

Neupane et al, 2017, Geochemical evaluation of the geothermal resources of Camas Prairie, Idaho. *Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University,,* SGP-TR-212.

Atkinson et al, 2017, Petrographic and thermal evidence of high-temperature geothermal activity from the MH-2B slimhole, western Snake River Plain, Idaho. *Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University* SGP-TR-212.

Shervais et al., 2017, Geothermal Play Fairway Analysis of the Snake River Plain: Phase 2. *GRC Transactions, v41.*

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Future Directions

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- We plan to collect key data to finalize site selection for Phase 3 drilling in Camas Prairie prior to Summer 2018. These include additional seismic lines, gravity, mag, and MT data, as well as field observations and structural modeling.
- In Spring 2018, we will collect additional key data around Mountain Home AFB to aid the USAF in site selection for their planned drilling activities. These include additional gravity, mag, and MT data, as well as structural modeling.
- Permitting will be finalized after final site selections. Go/NoGo decision.
- Drilling to verify our PFA methodology will be carried out by the USGS in Summer or early Autumn 2018 along The Pothole fault system. Logging and reservoir testing will be carried out prior to P&A. We have already met with landowners and obtained permission to drill with some site restrictions.
- Integration of site selection data with drilling results to assess success.

Milestone or Go/No-Go	Status & Expected Completion Date
Site Selection & Permitting	Go/NoGo Decision: June 2018
Complete Drilling and Logging	Milestone: October 2018
Post-drilling analysis and Final Report	Milestone: April 2019

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Mandatory Summary Slide

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- Phase 1: formalized a conceptual framework for geothermal PFA, collated relevant data, created a series of risk maps at regional scale in Arc GIS for southern Idaho, and identified prospects.
- Phase 2: collected new data in our focus areas, which we integrated with existing data to create new risk maps at the local play scale, using updated GIS tools.
- The Camas Prairie site was chosen for validation by drilling based on its structural favorability (documented by field mapping, gravity, magnetics and seismic surveys), high $^3He/^4He$ ratios, thermal gradients, water chemistry, and inferred reservoir temperatures.
- Thermal modeling and the occurrence of young volcanic rocks support our conceptual model of a magmatically heated system.
- Our work has identified additional targets in the western SRP that may be developed independently (e.g., Mountain Home AFB, near town of Mountain Home).

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Additional Information

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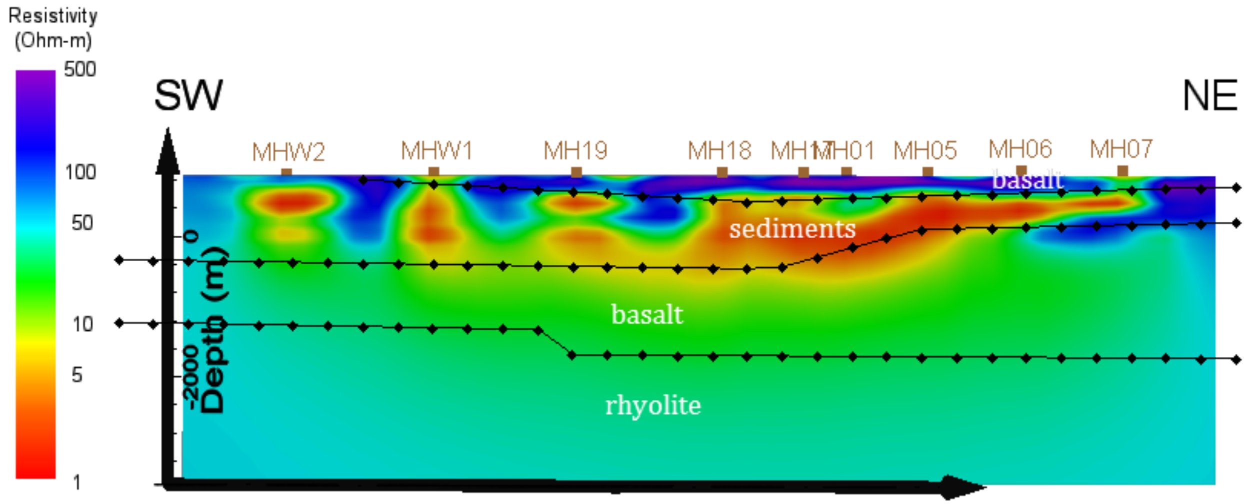
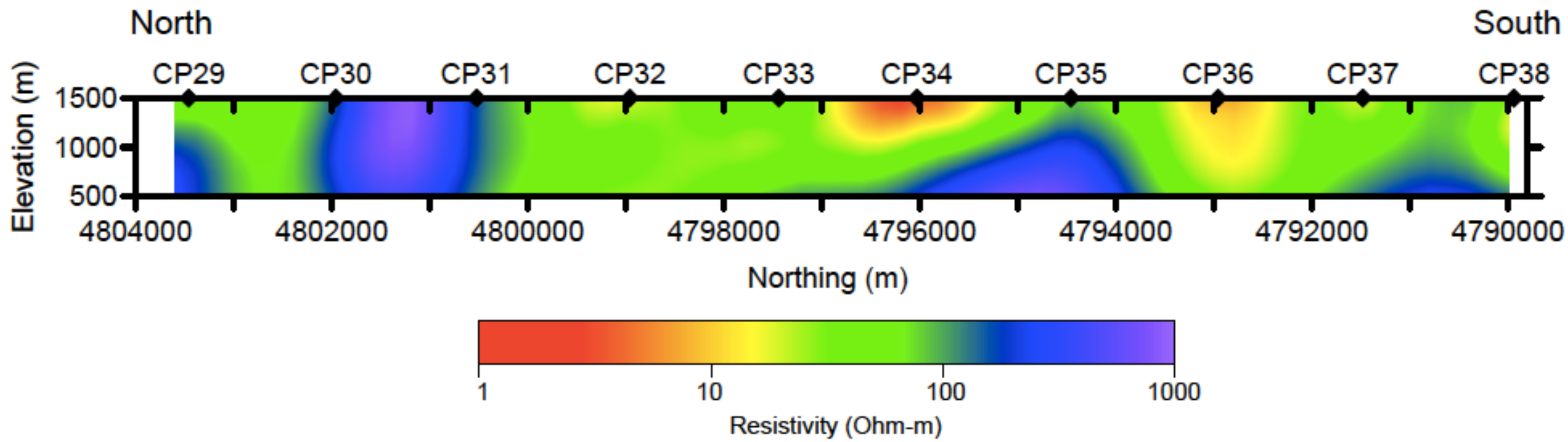


Mountain Home: SW-NE resistivity cross-section extracted from 3D resistivity model. Black lines with diamonds indicate unit interfaces from gravity inversion along a profile 3 km SE of this profile.



Final resistivity structure deduced by MT inversion at **Camas Prairie**.

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