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Farm

Geothermal Play Fairway Analysis, Snake River Plain, Idaho

Project Officer: Eric Hass

Total Project Funding: $565K

May 12, 2015

John W Shervais
Principal Investigator

Play Fairway Analysis

Project Objectives:

- Adapt methodology of *Play Fairway Analysis* and create a formal basis for its application to geothermal exploration.
- Assemble relevant data for the Snake River Plain (SRP) volcanic province from publicly available and private sources. The SRP is characterized by high heat flow, voluminous young volcanism, and a range of structural settings that may enhance permeability.
- Build a geothermal play fairway model for the Snake River Plain that will allow us to identify the most promising plays, and formulate a strategy for identifying prospects for further exploration.
- Ultimate Goals: Lower the risk and cost of geothermal exploration and development, not just in SRP but throughout geothermal industry, and to stimulate development of new geothermal power sources in Idaho.
- Innovative aspects of our project include the use of petroleum industry software tools, as well as a new conceptual model for basaltic plays, and GIS processing scripts developed by the USGS.

Scientific/Technical Approach

- Assemble a team of technical experts across a wide range of disciplines with extensive experience in geothermal systems:
  - John Shervais, USU: *Petrology, geochemistry, volcanology, geothermal exploration*.
  - James Evans, USU: *Structural geology, petroleum systems, fractures and seals*.
  - 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 magneto-telluric imaging*.
  - Drew Siler, LBNL: *Structural geology, stress analysis*
  - Charles Visser, NREL: *Geothermal systems, petroleum systems, land use*.
  - Sabodh Garg, Leidos: *Geothermal reservoir modeling, engineering*.
  - Jacob DeAngelo, Noah Athens, USGS; Jerome Verriale, USU: *GIS Specialists*
- Partnerships with other GTO-funded projects in same area:
  - Pat Dobson and Mack Kennedy, LBNL: *Use of He isotopes for Geothermal Resource Identification in the Cascades and Snake River Plain*.
  - Earl Mattson, Travis McLing, Hari Neupane (INL), Mark Conrad (LBNL), Tom Wood, Cody Cannon, Wade Worthing (U-Idaho): *Geothermometry Mapping of Deep Hydrothermal Reservoirs in Southeastern Idaho*.

Scientific/Technical Approach

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- Our primary technical approach includes:
  - Data search and compilation from existing databases (USGS, IGS, NGDS, NREL, SMU, Earthscope, Seismic Data Exchange), geologic maps, publications, and unpublished sources.
  - Definition of specific play types and their critical elements.
  - Construction of *Critical Element Charts* that assess probability of success vs. data confidence for each play type.
  - Use of *Arc GIS* to compile data for each evidence layer, *Google Earth* to review data sets, and shared cloud drive to assemble data and files.
  - *Python* scripts in Arc GIS to evaluate the evidence layers quantitatively and construct common risk segment maps.
- Other technical approaches include:
  - Calculating fault dilation tendency and slip tendency using 3DStress software for both surface faults and inferred subsurface faults.
  - Calculating equilibrium reservoir temperatures for springs and wells using solute and multicomponent geothermometry (RTEst).
  - Construction of 3D stratigraphic models using Petra®.
  - Correlation of high $^3He/^4He$ ratios with favorable plays related to magmatism.

Scientific/Technical Approach

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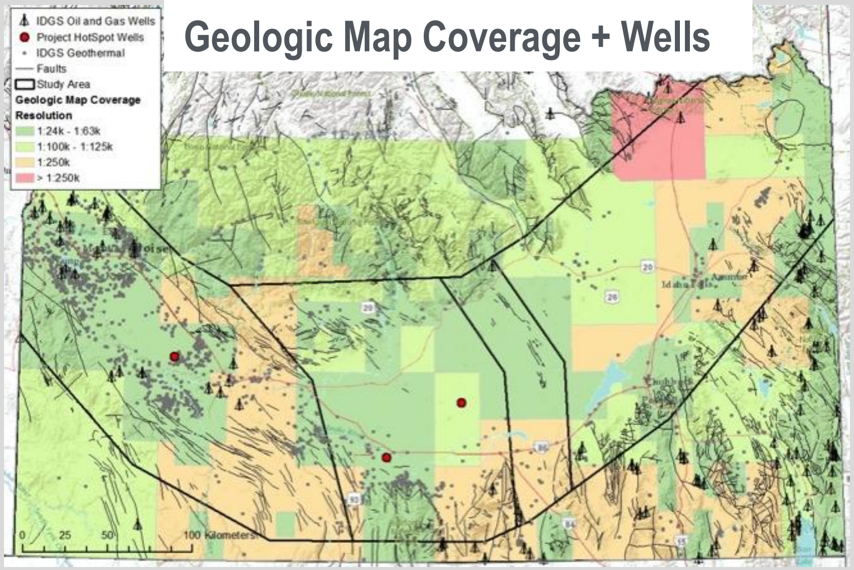

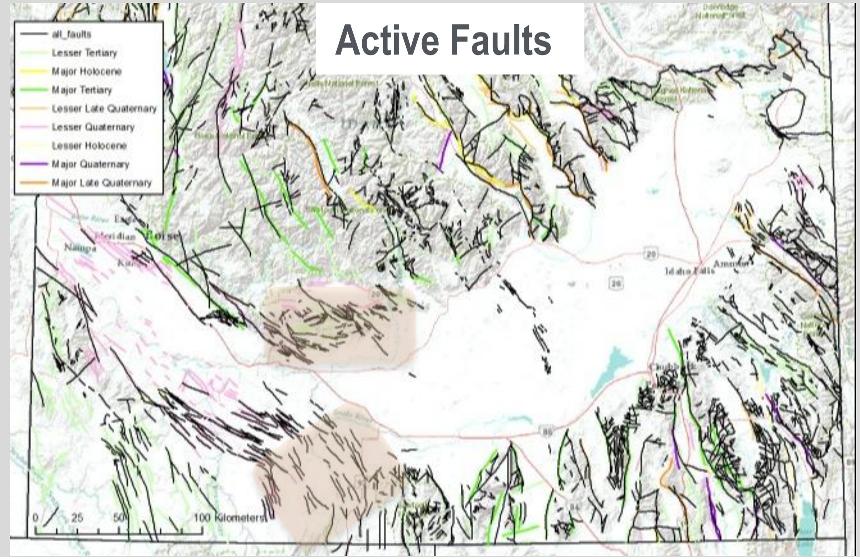

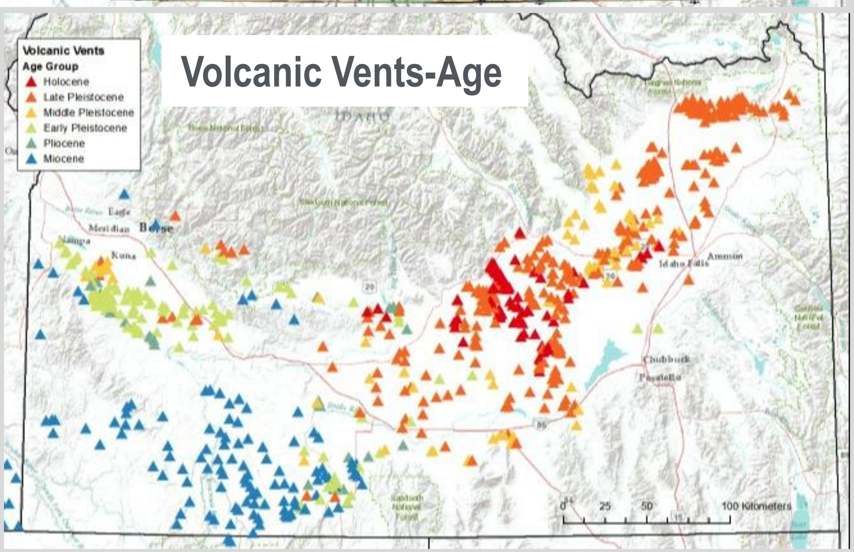

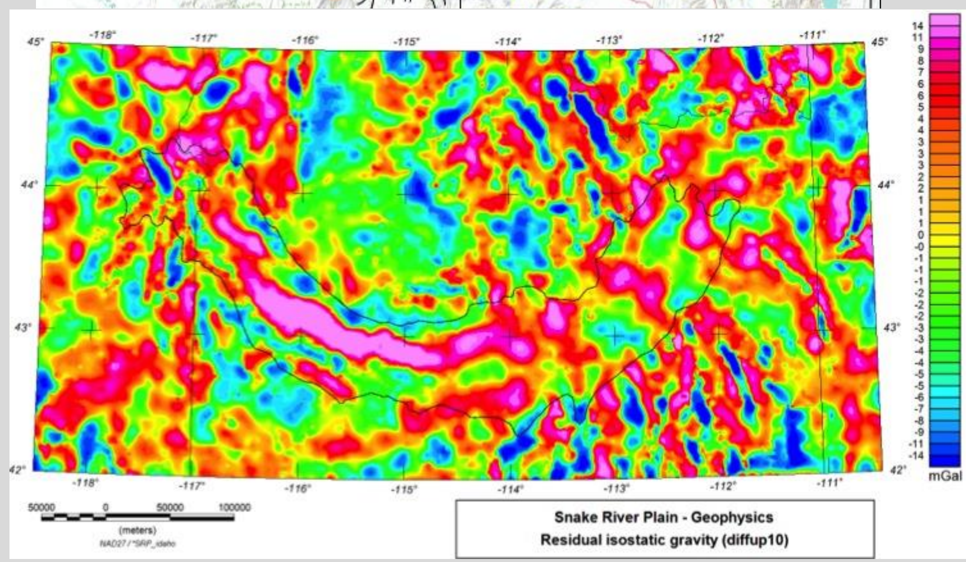

Geophysics: Gravity, Mag, Seismic, MT

Scientific/Technical Approach

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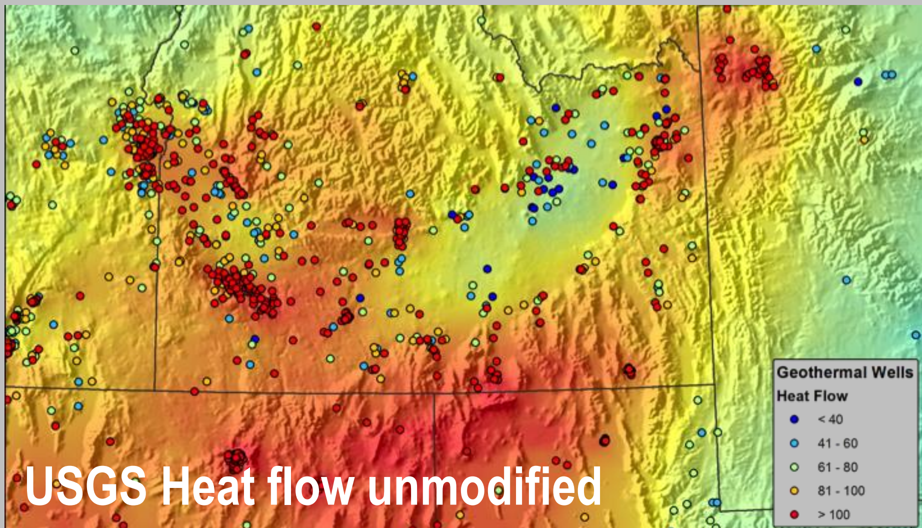
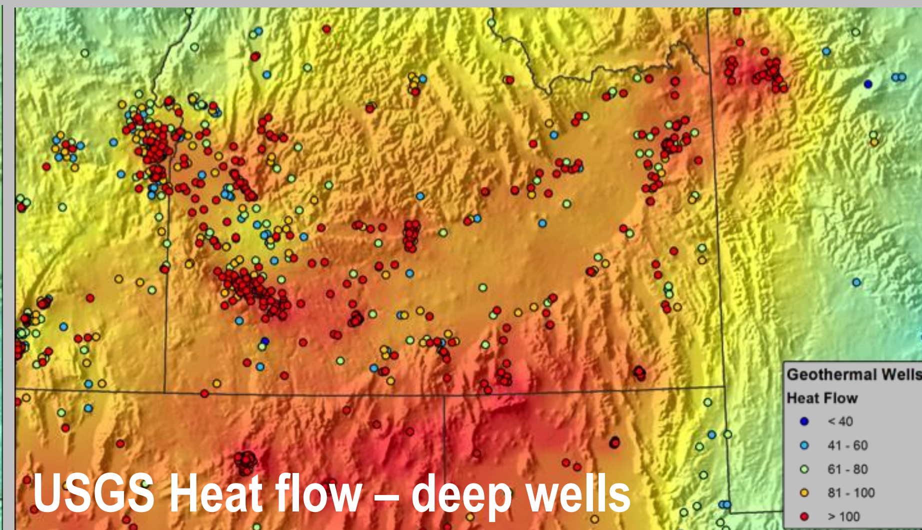
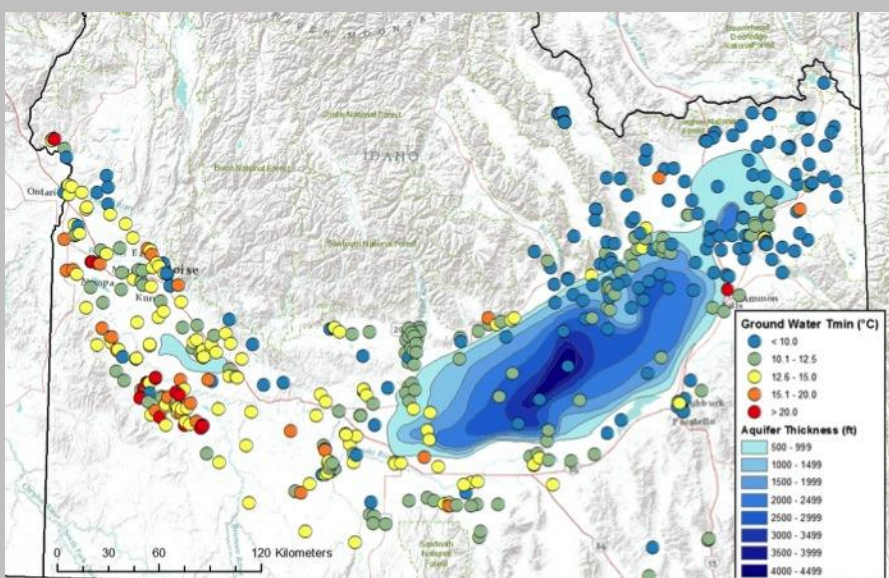
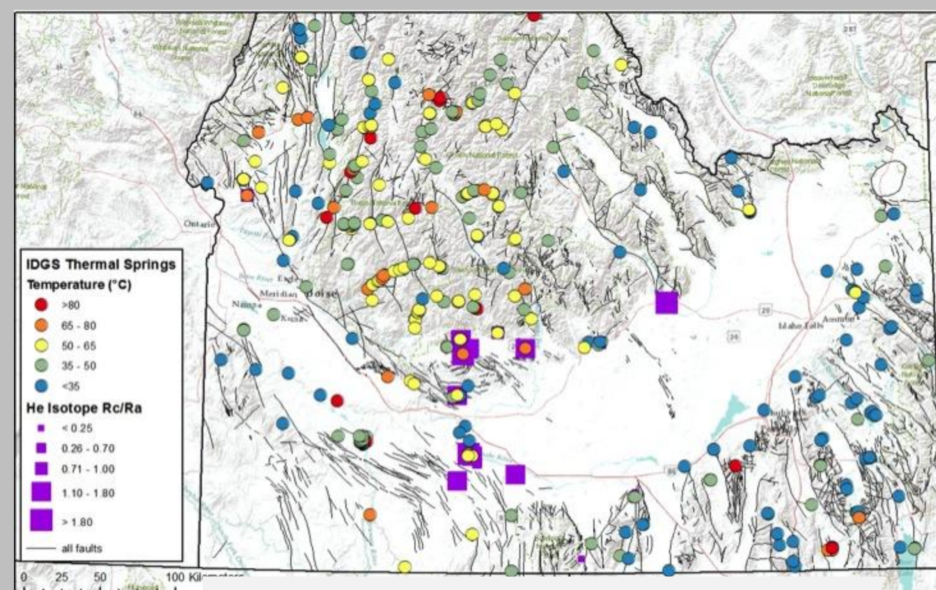






Aquifer thickness from resistivity & groundwater T



Hot Springs with Equilibrium T & $^3He/^4He$

Accomplishments, Results and Progress

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Original Planned Milestone	Actual Milestone/ Accomplishment	Date Completed
M1: Will have defined data systems, data interchange protocols; assigned task responsibilities; and constructed critical element charts for heat source, reservoir, and seal.	Task 1 completed as planned.	30 November 2014
M2: 70% of critical data will be imported into our primary data management system; a Team Meeting will be held to evaluate status and re-level tasks and resources as needed.	Task 2 completed as planned. Over 90% of data assembled and is being synthetized. Task 3 in progress	31 March 2015

Progress to date:

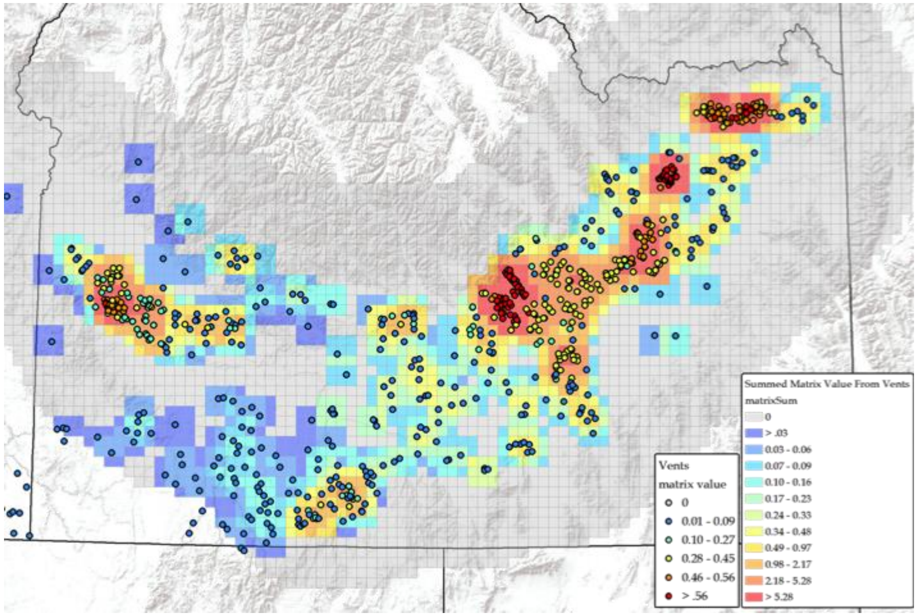
- Tasks 1 and 2 were both completed on time, on budget (*Milestones* above).
- There were *NO* performance and technical variances.
- The most important challenges encountered involve integrating diverse data products into single resource quality assessments, and integrating the significantly different risks attached to these diverse data into these assessments to produce common risk segment maps.
- These challenges were expected and have not had a negative impact on our technical accomplishments or progress.

Technical Accomplishments [1]:

- We have compiled an extensive database of regional geologic, geophysical, geochemical, geothermal, hydrologic, and cadastral data, and imported these data into a common GIS framework.
- Primary data processing was carried out in Oasis Montaj®, GeoMapApp, Google Earth Pro®, the RTEst multicomponent geothermometer, and Petrolog. Dilation and Slip tendency maps were created with 3DStress®.
- We defined 3 key elements of the Play Fairway concept for Geothermal Systems:
  (1) **Source**: *HEAT* is the critical component for geothermal plays,
  (2) **Reservoir**: Geothermal reservoirs require *PERMEABILITY*, which is commonly associated for complex fault interactions.
  (3) **Seal**: Geothermal systems may be self-sealed by alteration, or sealed by impermeable cap rocks (e.g., clay-rich sediments).
- Critical element matrices were developed for specific evidence layers (*e.g.*, heat source, permeable reservoir pathways, and seals). The critical element charts combine probability of success with data quality to produce a risk assessment that will be used to construct the common risk segment maps.
- We identified 3 main play types: (1) basaltic sill plays, with fault-controlled reservoir system, either self-sealed by alteration or sealed by lacustrine sediments, (2) rhyolite domes/cryptodomes, with intrusion-related breccia reservoir, (3) *Basin-and-Range* style systems on the SRP margins, (4) granitic basement plays in Idaho batholith.

Technical Accomplishments [2]:

- Primary *evidence layers* were constructed in Arc GIS for all major data sets, *e.g.*, geologic maps, structural maps, vent distributions and ages, seismic line locations, gravity and magnetic data, magneto-telluric data, heat flow data, thermal features and their temperatures, and cadastral data.
- Additional layers were constructed for synthetic data, *e.g.*, fault dilation tendencies, fault density maps, vent density maps weighted by age, buried faults derived from maximum horizontal gradients in gravity and magnetic data, and equilibrium reservoir temperatures.
- Workflow has been created for integrating data into risk maps, using Python® scripts in Arc GIS, as well as Google Earth Pro®, and Exprodat®, an industry extension to ArcGIS for PFA. Python scripts developed at USGS automate the processing of GIS evidence layers to identify regions with favorable play characteristics, and are essential in our development of Common Risk Segment Maps.
- Scripts are being developed to quantify risk in spatially distributed data (e.g., wells used for heat flow gradients, geophysical survey lines) using fuzzy logic approach, based on distances to the nearest neighbor and next-nearest neighbor data points.
- Geologic map coverage is near universal, so data derived from these maps (e.g., fault and vent locations) is risked based on scale of mapping. >80% of area is mapped at 1/125,000 or better (compiled from 1/24k and 1/63k quads).



- Matrix is created providing weight for every age class, density class combination
- Vents are assigned an age class
- Density surface created from vent locations in order to show clustering
- Density value sampled to vents
- Density values normalized to density classes from matrix
- Vents are assigned weights from matrix table using their age class and density class
- For every grid cell, weight values for vents in all surrounding cells are summed and appended to the cell

Vents	Vent Age	Oldest Vents V6 >5.23 Ma	Old Vents V5 2.58-5.23 Ma	Old Vents V4 0.8-2.58 Ma	Older Vents V3 400-780 ka	Young Vents V2 400-75 ka	Young Vents V1 <75 ka
	Vent Density	0.2	0.4	0.6	0.8	0.9	1
Extensive Vent Clusters	1	0.20	0.40	0.60	0.80	0.90	1.00
Small Vent Clusters	0.8	0.16	0.32	0.48	0.64	0.72	0.80
Few Isolated Vents or Inferred from PMag	0.6	0.12	0.24	0.36	0.48	0.54	0.60
No vents in grid cell but vents in adjacent cells	0.4	0.08	0.16	0.24	0.32	0.36	0.40
No Vents in grid or adjacent grid cells	0.1	0.02	0.04	0.06	0.08	0.09	0.10

Accomplishments, Results and Progress

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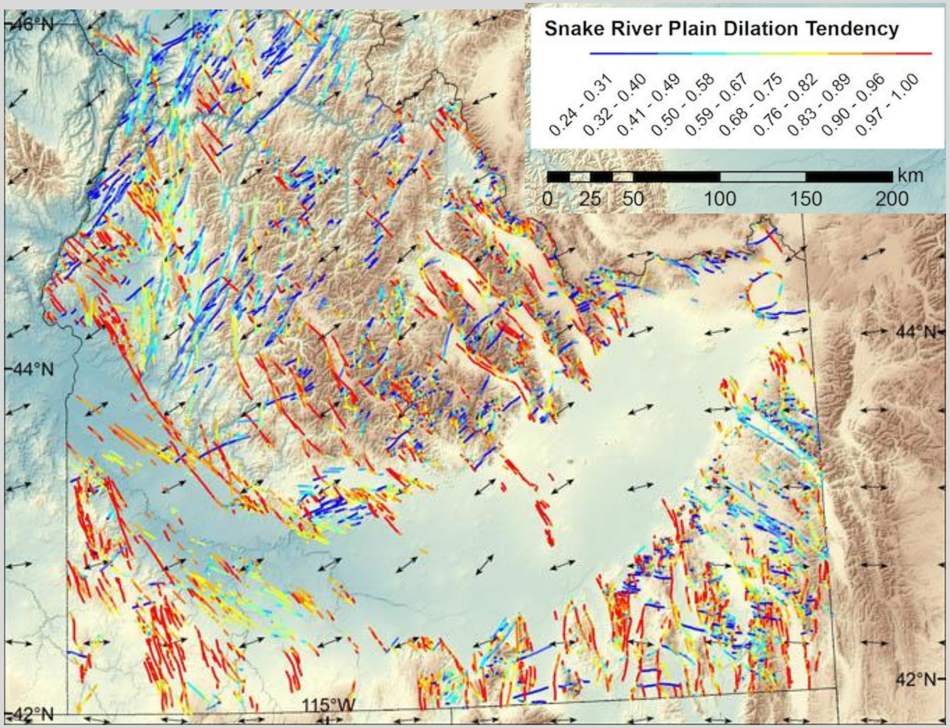
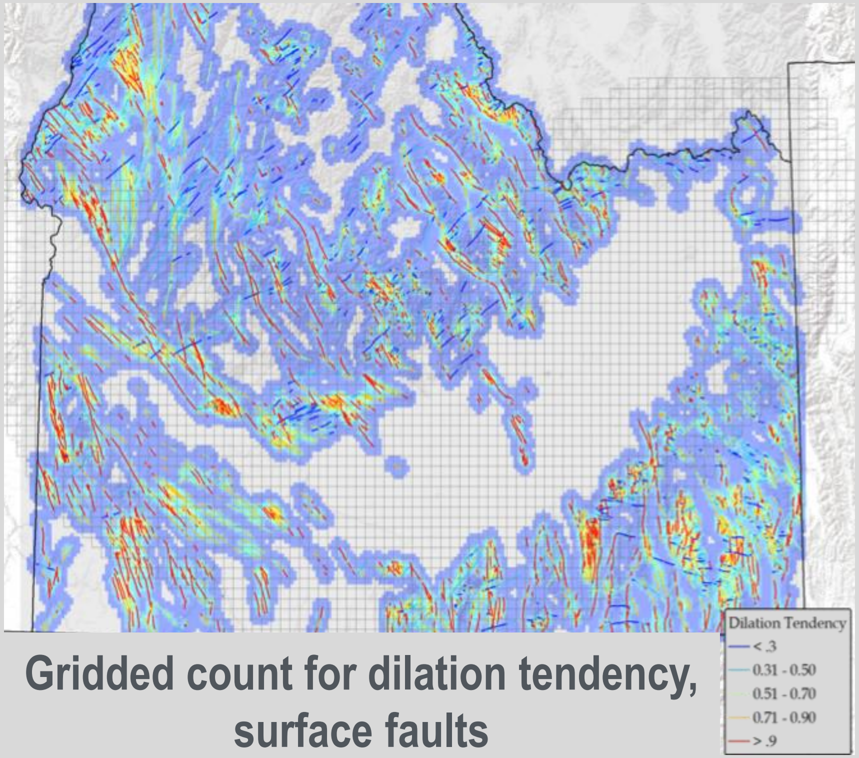
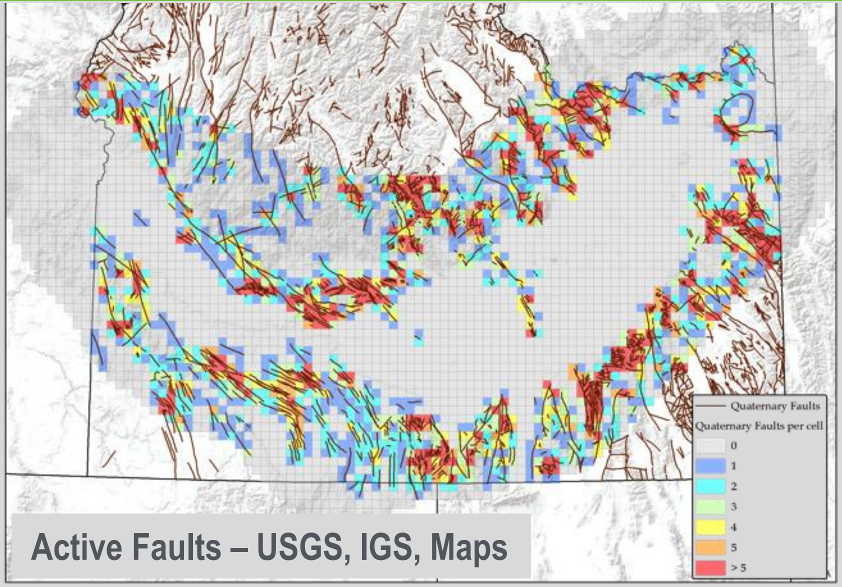


Dilation tendency for surface faults: Red is High

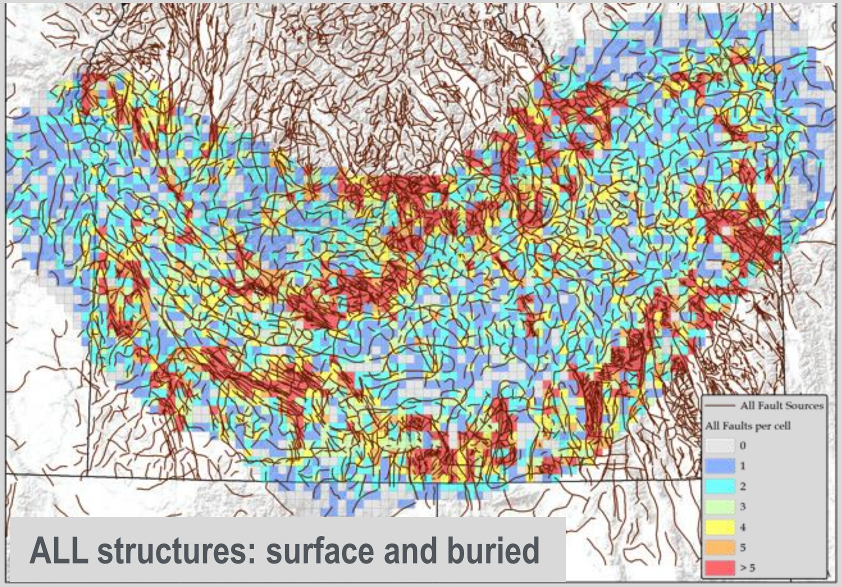


Gridded count for dilation tendency, surface faults

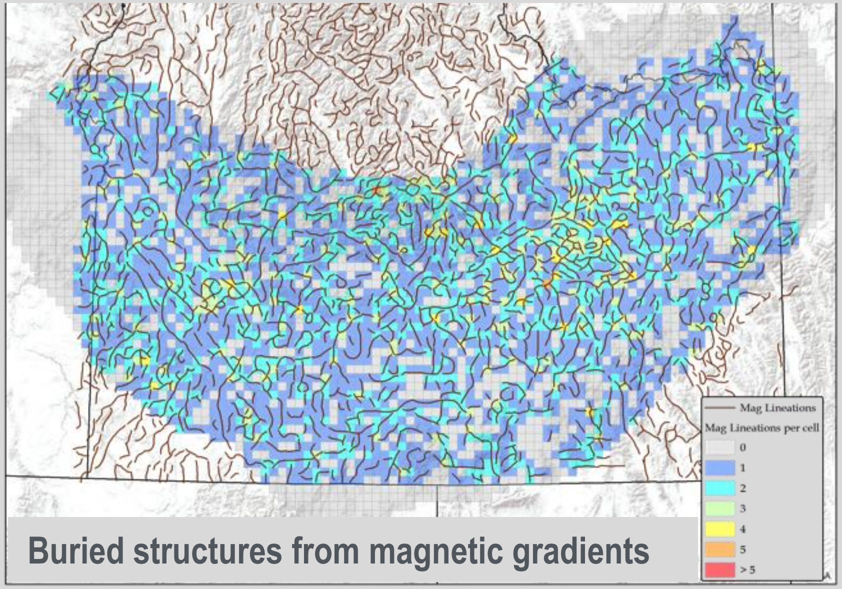
These figures illustrate the use of Python scripts developed at the USGS to automate definition of high probability regions for critical elements of the play types, such as reservoir permeability or vent density. These maps will be combined with data quality maps to produce our Common Risk Segment Maps. For basin-scale analysis, we use 6x6 km grid size; once specific plays have been identified, we will use tighter grid scale (2x2 km) to refine the localized models. Grid size can be modified on the fly. Future scripts will account for nearest-neighbor features, or distance to nearest and next-nearest neighbors.



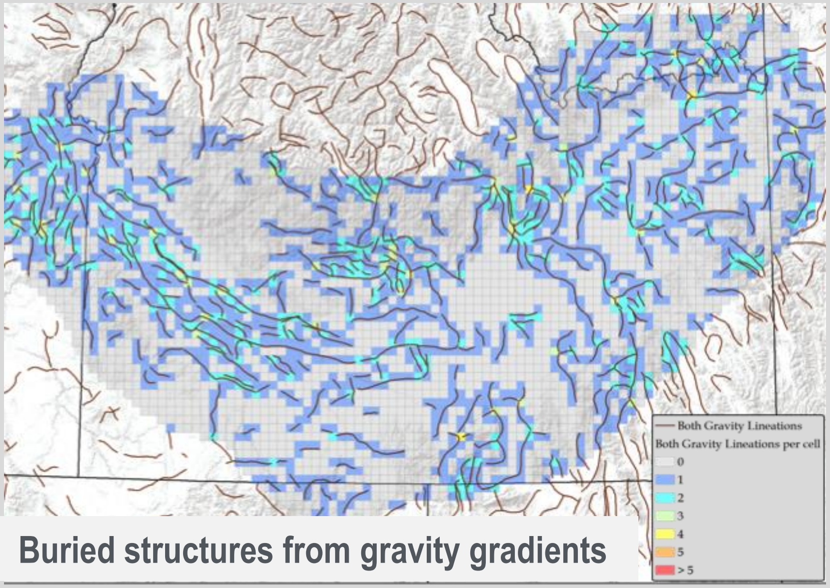
Active Faults – USGS, IGS, Maps



ALL structures: surface and buried



Buried structures from magnetic gradients



Buried structures from gravity gradients

Future Directions

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- Refine Python scripts for creating risk maps of data confidence and resource quality. We will test a range of approaches to find the most robust approach for each evidence layer and data category.
- Develop final CRS and CCRS maps in Arc GIS, using Python scripts to process the data layers, and Exprodat to create the common risk segment (CRS) maps and composite risk segment (CCRS) maps.
- Evaluate the results to identify favorable plays and prospects. We plan to meet in June 2015 to assess these results. Will then rebuild CRS and CCRS maps for focus areas (favorable plays and prospects).
- Build 1D theoretical model of magmatic heat flux from sill complex comprising 100m-200m thick sills, up to 10 km thick, intruded over 1-2 Ma time frame.
- Integrate heat flow, stratigraphic, down hole well logs, and DEM data for the high temperature-gradient area centered on WSRP and formulate a conceptual model. The latter model will be used in Phase 2 to construct a 3-D numerical model.
- Coordinate our work with the *Northwest Volcanic Aquifer Study* (Erick Burns, USGS).
- We will also search for potential industrial partners for Phase 2 activities. This will be aided by the Industry information session scheduled for the May 2015 Peer Review.

Future Directions

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Milestone or Go/No-Go	Status & Expected Completion
M3: Will have completed data integration and construction of the Play Fairway model; construction of common risk segment maps and composite common risk segment (CCRS) maps, initial development of conceptual reservoir model. Interim report.	In progress; expected completion 30 June 2015
M4: Will have completed evaluation of composite common risk segment (CCRS) maps and ranking of geothermal plays and prospects, and selection of geothermal prospects for Phase 2 evaluation.	Expected completion 30 September 2015
Phase 2 Go/NoGo: Final Report and Phase 2 Proposal.	September/October 2015

The project will generate a final report that contains a summary of the data sets utilized, the play types identified and their critical elements, the data matrices that were developed to constrain each critical element, a series of CRS and CCRS maps, and the identification of potential geothermal prospects based on this analysis. The report will also contain proposed activities for Phase 2, including key data gaps for the identified prospect area(s) and an exploration work plan to fill those gaps.

Our project is proceeding as scheduled, with no performance or technical variances.

Mandatory Summary Slide

- Project has assembled a substantial data base for the SRP, including geology, structure, geophysical surveys (seismic, gravity, magnetic, MT), and geochemistry (water, rock), and land use.
- We have developed matrices that utilize geologic, geophysical, and geochemical observations to evaluate the likelihood of encountering critical play elements (heat, permeability, and seal) for each distinct play type.
- We are developing techniques to automate the processing of evidence layers *quantitatively* in Arc GIS, and to then combine these into CRS and CCRS maps. These include algorithms for assessing risk in data confidence as well as resource attribute quality.
- Our preliminary assessment suggests that important undiscovered geothermal resources are located in several areas, including the western SRP, at lineament intersections in the central SRP, and along the margins of the eastern SRP.
- Our project contributes directly to GTO's goal of accelerating near-term growth in hydrothermal power production by lowering risks and identifying new prospects in a greenfield geothermal area.

Additional Information

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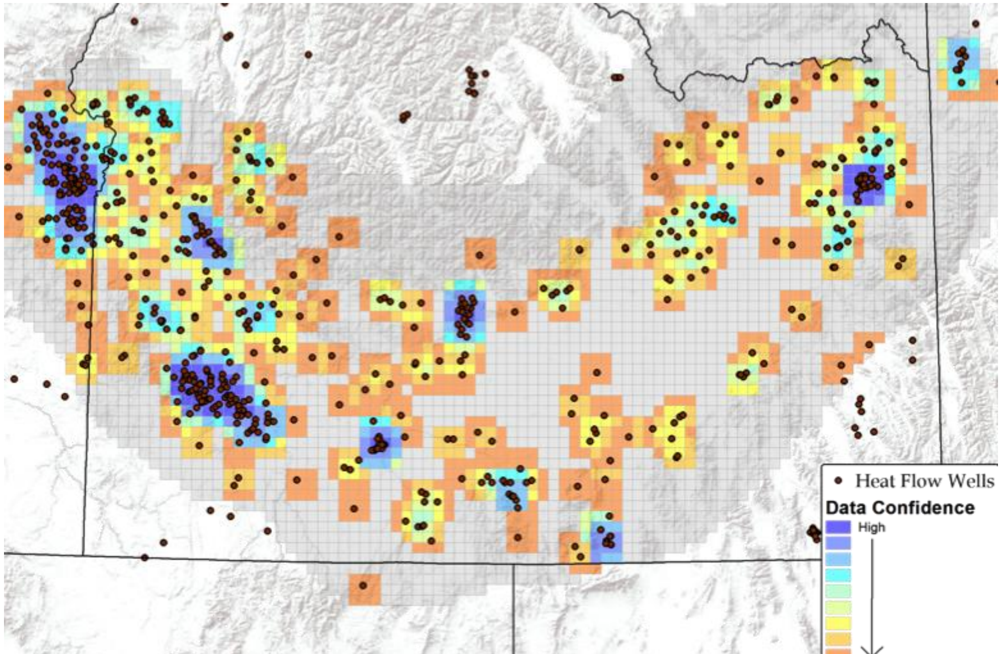
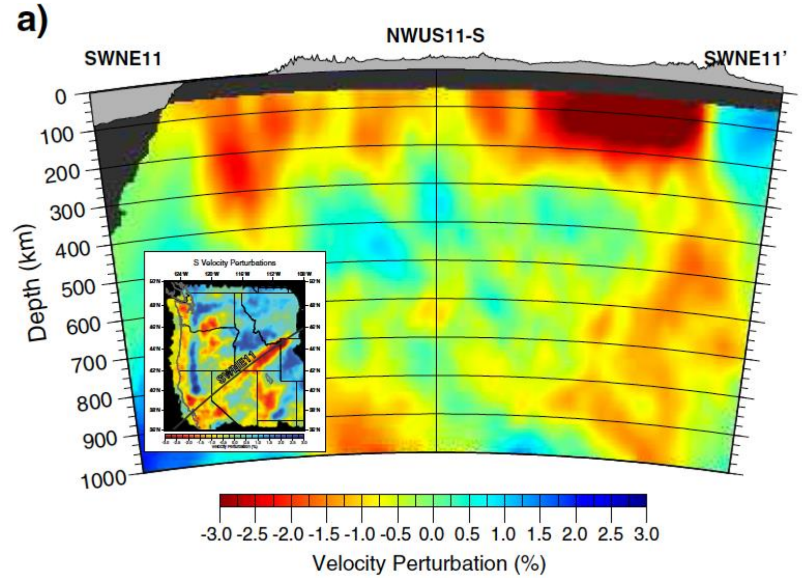
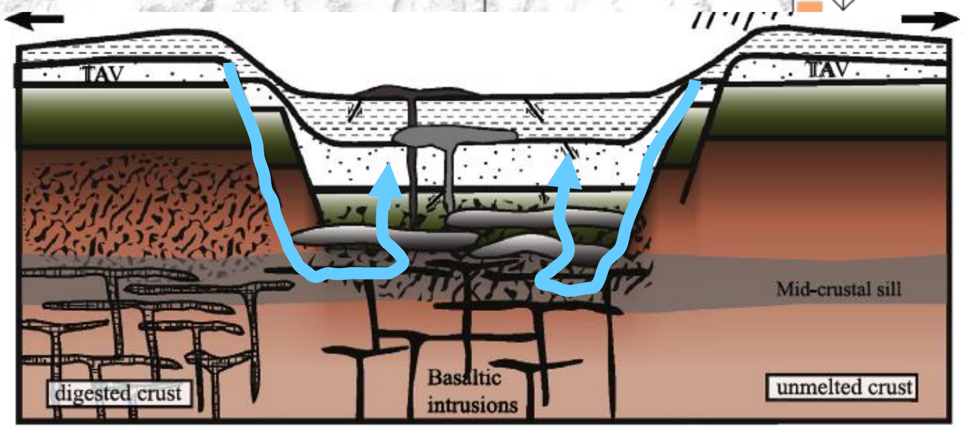




Upper left: Example of preliminary data confidence risk map for heat flow data, based on the distribution of wells (data points). Grid count of wells in nearest neighbor cells, unweighted. Revised scripts will be based on distances to nearest and next-nearest neighbors.

Upper right: Perturbation of S-wave velocity below the SRP from Earthscope Transportable array. The -3% Vs below the SRP reflects high temperatures and incipient melt from 200 km depth to the base of the crust. It is the hottest mantle region in the continental USA.

Left: Conceptual model for geothermal system sustained by long-term influx of basaltic sills into crust, which provides a thermal profile similar to silicic intrusions.



Conceptual Model of Geothermal System Related to Basalt Sill Complex