Geothermal Play–Fairway Analysis of Washington State Prospects

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Abstract

Analysis of existing geologic, geophysical, and geochemical data revealed areas with elevated heat and permeability, defining three promising plays along the central axis of the magmatic arc of Washington State: Mount St. Helens, Wind River valley, and Mount Baker. These areas are geothermal 'fairways', or locations with high geothermal resource potential based on modeling.

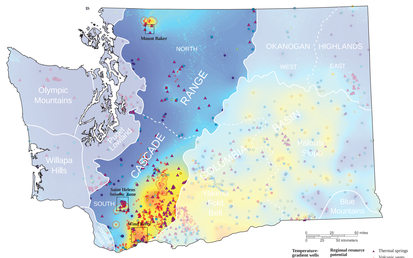
This project applies innovative data analyses (Poly3D) in conjunction with methods proven in previous geothermal favorability studies (ArcGIS and MATLAB) to extract new value from existing public data. Heat and permeability potential models for each play are weighted using the Analytical Hierarchy Process, and combined to map geothermal resource potential and locations for further data collection at each site.

Heat potential is based on: (1) temperature gradients, (2) volcanic vents, (3) Quaternary intrusive rocks, (4) spring temperature, and (5) spring geothermometry.

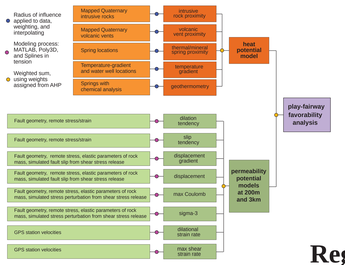
Permeability potential is based on: (1) slip and (2) dilation tendency on mapped and seismic faults (3) maximum shear strain rate, and (4) dilatational strain rate at the surface, (5) modeled fault displacement distribution, and (6) displacement gradient, (7) shear, and (8) tensile fracture density, and (9) local geology and geophysical data.

This information is vital for revealing the small scale heat and permeability potential of each study area, locating areas of undiscovered or untapped resources, and reducing the risk and cost involved in greenfield exploration and development. Analysis of the three play areas shows promise for geothermal development. Uncertainty modeling will help guide future exploration plans.

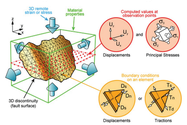
Cascade Range Resource Potential



Model Workflow

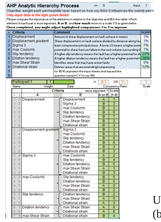


Innovative Poly3D Analysis



Poly3D software (Thomas, 1993), using boundary conditions derived from GPS strain rates (see right), is used to model fault displacement to determine where fault damage zones enhance permeability. Maximum Coulomb stress and σ3 are used to estimate fracture density in the volume surrounding the faults.

AHP Decision-Making

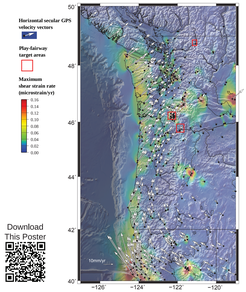


During processing of input layers and when combining input layers into the heat and permeability models, the Analytical Heirarchy Process (AHP) is used to assign weights representing the relative importance of that layer with respect to the others. The AHP is a structured technique used for organizing and analyzing complex decisions based on psychology and math.

Uncertainty and Risk Assessment

Uncertainty was assessed by assigning values of data quality (based on relevant data quality parameters and spatial accuracy) for each input dataset (heat and permeability), and then modeling a radially decreasing certainty value within the given radius of influence for each dataset. Sensitivity analysis is used as a proxy for risk—it was generated for permeability layers by modeling two end member fault geometries and determining where the permeability potential model changed the most. The risk assessment is useful for determining areas where future data gathering and modeling efforts will be focused to improve the resource potential model and reduce the risk of drilling a bad well.

Regional Strain



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Future Work

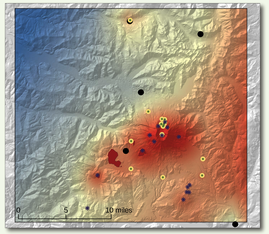
Heat and permeability potential modeling and uncertainty analyses delineated favorable areas located on developable land that would benefit from further exploration. Proposed exploration methods include:

- Magnetotelluric surveys
- LIDAR, scarp ID, and field checking
- Detailed geologic mapping
- Temperature–gradient drilling
- Aeromagnetic survey
- Seismic surveys (active and passive)

	MSHSZ	WRV	MB
	✓	✓	✓
	✓		✓
	✓		✓
			✓
		✓	
	✓	✓	✓

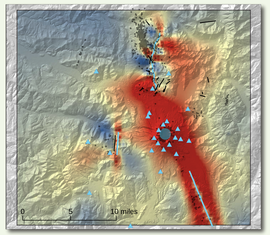
Saint Helens Seismic Zone

Heat Potential



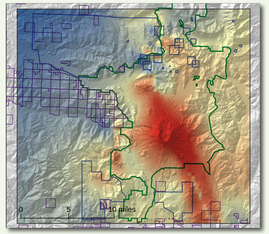
The Saint Helens seismic zone fairway is a convection-dominated volcanic system with an active magmatic heat source, with magmatic and fault-controlled hydrothermal fluid circulation. The volcano is the heat source for numerous hot springs and fumaroles, as well as several warm temperature-gradient measurments.

Permeability Potential



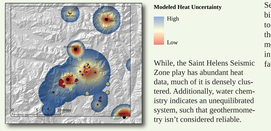
Mount St. Helens is located along a 100-km-long dense zone of earthquakes, which have predominantly strike-slip focal mechanisms on north-striking fault planes. Areas with high fracture density and high deformation provide a percolating fracture network, high porosity, and large heat exchange volumes.

Heat and Permeability at 3 km



Areas of overlapping heat and permeability potential are closely tied to steeply dipping faults along the shear zone. Future exploration efforts will be focused where permeability potential is collocated with heat potential outside of the National Volcanic Monument and within existing geothermal lease areas.

Model Uncertainty and Risk Analysis

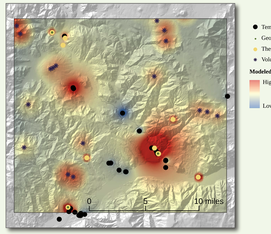


While, the Saint Helens Seismic Zone play has abundant heat data, much of it is densely clustered. Additionally, water chemistry indicates an unequilibrated system, such that geothermometry isn't considered reliable.

Sensitivity analysis of permeability inputs based on changes to fault geometry shows that the highest sensitivity in our model lies in the area where we infer a system of deep splayed faults.

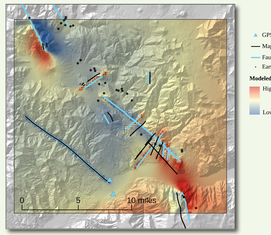
Wind River Valley

Heat Potential



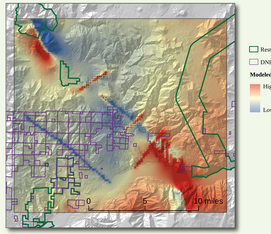
The Wind River valley lies along the Cascade volcanic arc, but is not situated alongside an active volcano. Many volcanic vents, springs, and warm temperature -gradient wells suggest the possibility of: 1) undetected shallowly buried instrusives or 2) remnant heat from a 334 ka lava flow. Spring geochemistry does not suggest a magmatic fluid source.

Permeability Potential



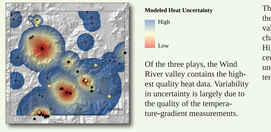
Faults and dilational fault intersections in this area act as conduits for heated meteoric water percolating through a network of fractures proximal to the faults.

Heat and Permeability at 3 km



Areas of collocated heat and permeability potential are closely tied to hot springs at the dilational intersections of steeply dipping faults. Infrastructure in this area is conducive to development and there are less restricted lands than the other two play areas, yet no geothermal lease lands are available as of yet.

Model Uncertainty and Risk Analysis

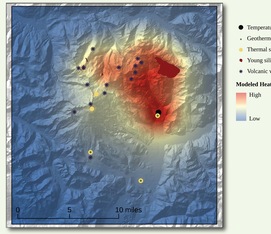


Of the three plays, the Wind River valley contains the highest quality heat data. Variability in uncertainty is largely due to the quality of the temperature-gradient measurements.

The areas adjacent to faults in the southern Wind River valley are the least sensitive to changes in fault geometry. Highly sensitive area in the center of the map due to spatial uncertainty of a major fault termination.

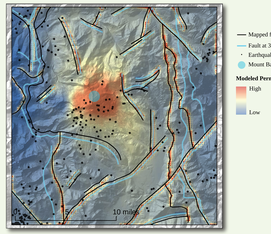
Mount Baker

Heat Potential



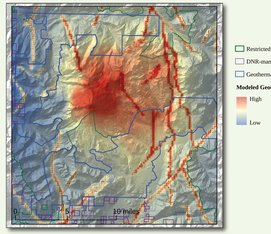
Mount Baker play is a convection dominated volcanic system with an active magmatic heat source, with magmatic and fault-controlled hyrothermal fluid circulation. The volcano and the numerous vents in Kulshan Caldera are the heat source for several fumaroles and springs, as well as the hottest temperature-gradient well in the state.

Permeability Potential



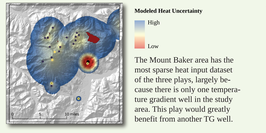
Faults in the Mount Baker area have not been studied in detail, and many mapped faults are inactive. Yet, preliminary LIDAR data suggests there are several intersecting structures near Baker Hot Sprigns that have not been mapped. If present, these faults are likely conduits for geothermal fluids. Elevated gas and heat flux cause localized strain two orders of magnitude greater than tectonic strain.

Heat and Permeability at 3 km



The most favorable area with collocated and accessible heat and permeable potential lie in the area surrounding Baker Hot Springs. Lineament analysis, seismic surveys, tomography, and MT may better constrain fault locations and geometry as well as identify zones of alteration.

Model Uncertainty and Risk Analysis



The Mount Baker area has the most sparse heat input dataset of the three plays, largely because there is only one temperature gradient well in the study area. This play would greatly benefit from another TG well.

The Mount Baker Mogi source strain rate is highly uncertain (420+-140 nanostrain/yr). Additional constraints upon strain were modeled from line length changes between electronic distance meters installed around Mt Baker.