Geothermal Play-Fairway Analysis of Washington State Prospects

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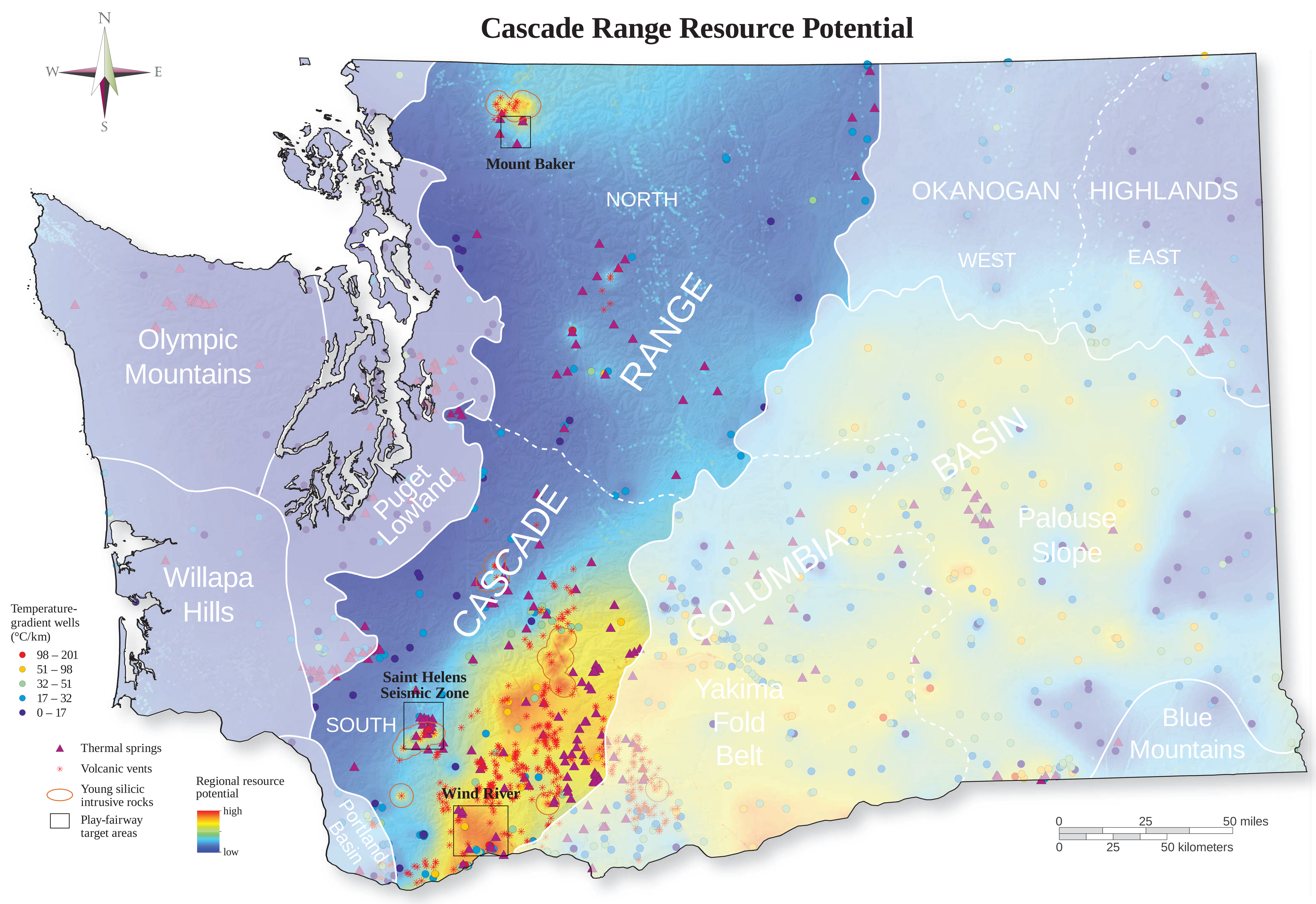
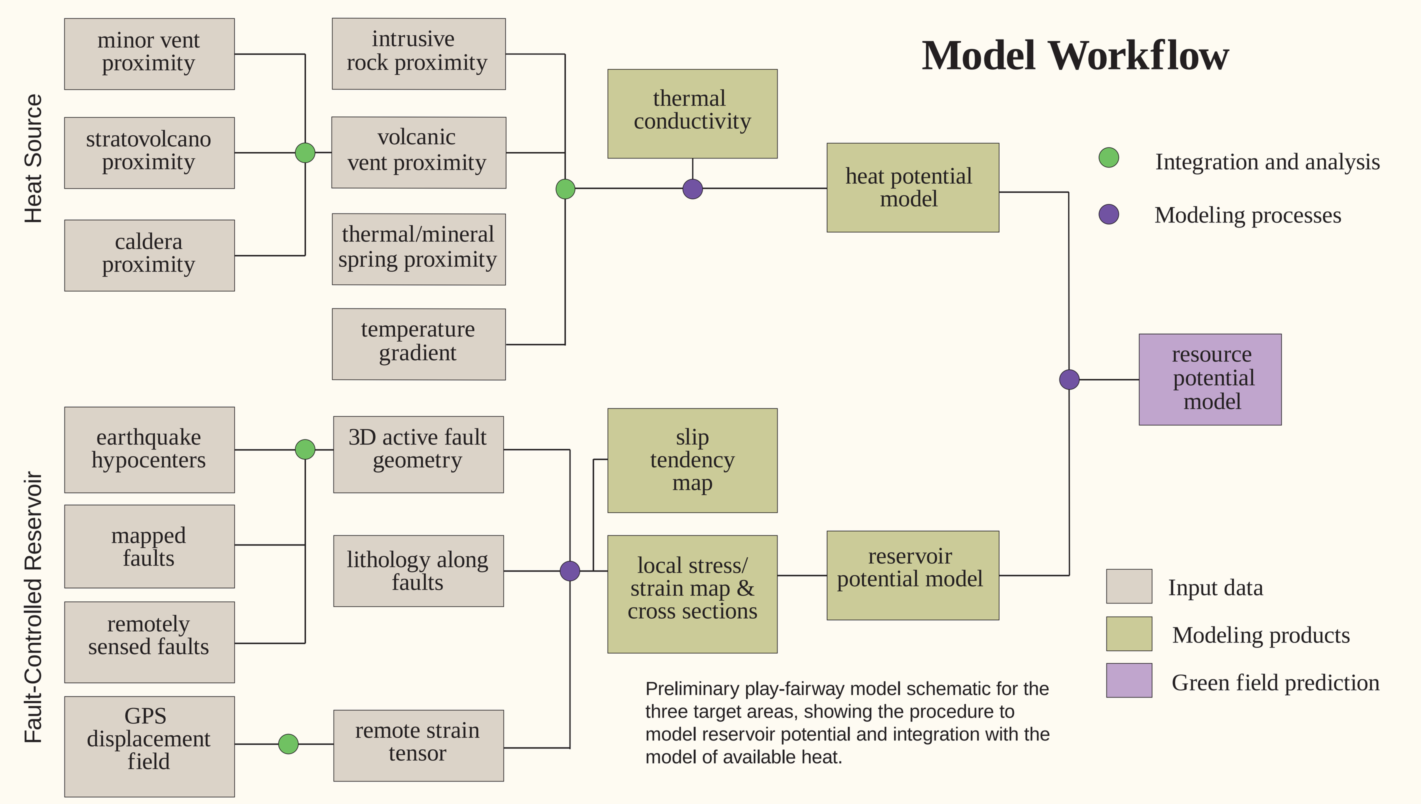
Cascade Range Resource Potential



The geothermal resource potential model of Washington State was developed by Boschmann and others (2014) to represent the relative geothermal potential based on permeability and heat-potential modeling. Datasets were imported into a Geographic Information System (GIS), and multi-criteria analyses were run using the Analytic Hierarchy Process (AHP; Saaty, 2008) to determine the spatial association between various geologic and thermal features. The model is intended to highlight areas of elevated potential for the presence of moderate- to high-temperature geothermal systems without consideration of regulatory restrictions, land-management restrictions, or economic viability. The modeling identified several areas along the Cascade Range crest that warrant further attention: the Wind River valley, areas surrounding the Saint Helens seismic zone, and the southeast flank of Mount Baker.

Model Workflow



Preliminary play-fairway model schematic for the three target areas, showing the procedure to model reservoir potential and integration with the model of available heat.

BACKGROUND

In the Pacific Northwest region of the U.S., geothermal resource of the Cascades is largely undeveloped—direct use of geothermal heat near Klamath Falls, Oregon, and the Neal Hot Springs power plant near Vale, Oregon being the exception. Part of the difficulty of finding and developing geothermal resources in the Cascades is related to the complex pattern of crustal deformation (McCaffrey and others, 2007) caused by the same plate convergence that produces the magmatic arc and heats the crust. Other challenges include dense vegetation, glacial veneers, and extreme precipitation that erode heat at very shallow depth and surficial alteration.

PROJECT GOAL

The play type with the highest geothermal favorability in Washington State is found adjacent to active faults near the central axis of the magmatic arc. The play-fairway is provided by the natural permeability generated along faults and associated fractures. These structures can provide vertical pathways capable of tapping deep heat sources related to magmatism as well as large fracture networks to host the geothermal fluids in a viable reservoir.

Three areas representative of this play type have high geothermal favorability on the statewide map and have active faults: the Wind River valley; the Saint Helens seismic zone north of the volcanic monument; and the southeast flank of Mount Baker. All three plays have geothermal lease holders with plans for exploration and are developable if sufficient resources are found.

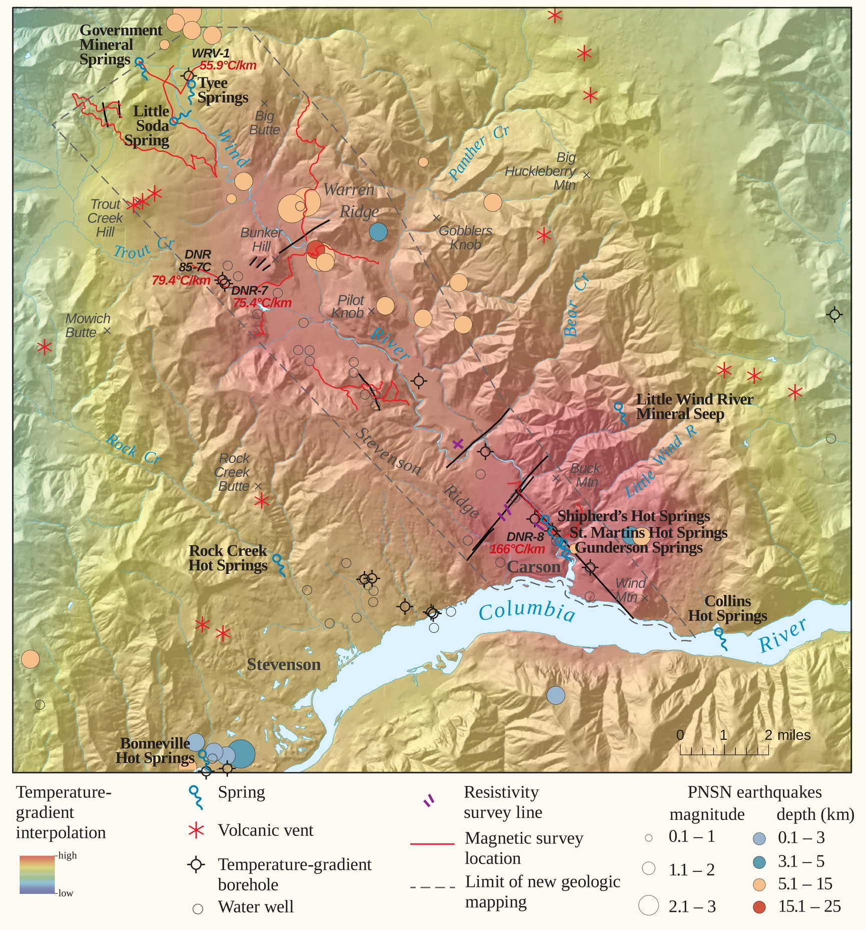
This project will:

1) refine the existing resource potential model in the target areas using new, innovative, and higher resolution data.
2) develop local, play-scale models that incorporate improved data with the mechanical constraints on reservoir potential.

DESIRED OUTCOME

Detailed geothermal resource modeling using these techniques will be the first of its kind in Washington State and will lift the restrictions to exploration originating from limited or irregular data collection, high amounts of vegetative cover, precipitation, and snowpack. The modeling of reservoir potential provides a new approach to quantitative fairway analysis of fault-controlled reservoirs and risk assessment in regards to targeting discovery wells. This analysis provides a basis for defining the reservoir potential necessary to describe the recoverable geothermal resource.

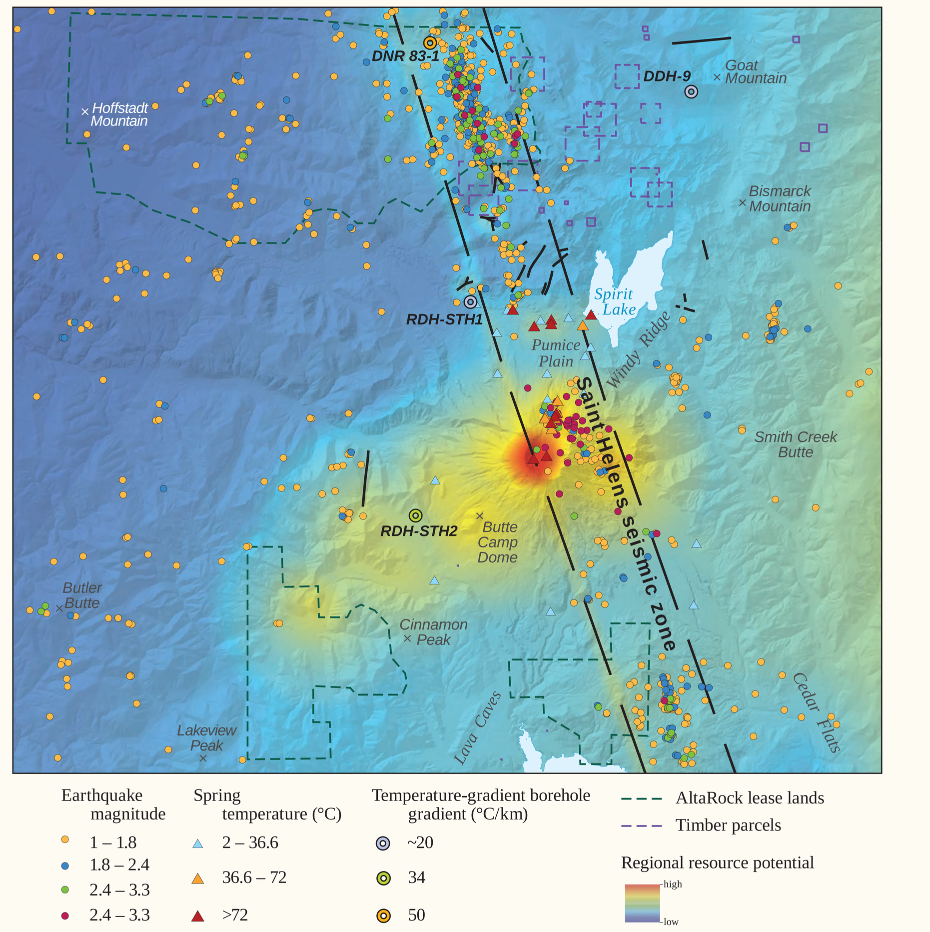
Wind River



The Wind River valley, a northwest-trending valley draining southeastward into the Columbia River Gorge shows the highest modeled resource potential in the state. The valley lies along trend with newly discovered faults in Oregon that have recently been the object of preliminary geophysical exploration for geothermal resources (Cashman and others, 2013).

Several temperature-gradient boreholes drilled in the early 1980s revealed elevated gradients within this valley. In addition, numerous water wells at the southern end of the valley document warm water (Berri and Korosec, 1983). Based on the presence of thermal and mineral springs, relatively young intrusives, moderate seismicity, and warmer water found along the valley's axis, some workers postulate that a valley-parallel structure channels high heat flow from cooling intrusives at depth within and along the length of this valley. Recent detailed mapping provides evidence for several newly mapped faults, which likely offset middle Pleistocene basalt flows. Their presence is further supported by deflections and anomalies in electrical resistivity and ground-based magnetic survey profiles across these zones. There are numerous thermal and mineral springs and seeps within this valley, found at the intersections of strands of the Shipherd and Wind River fault zones along and within the southern Wind River canyon (Czajkowski and others, 2014).

Saint Helens Seismic Zone

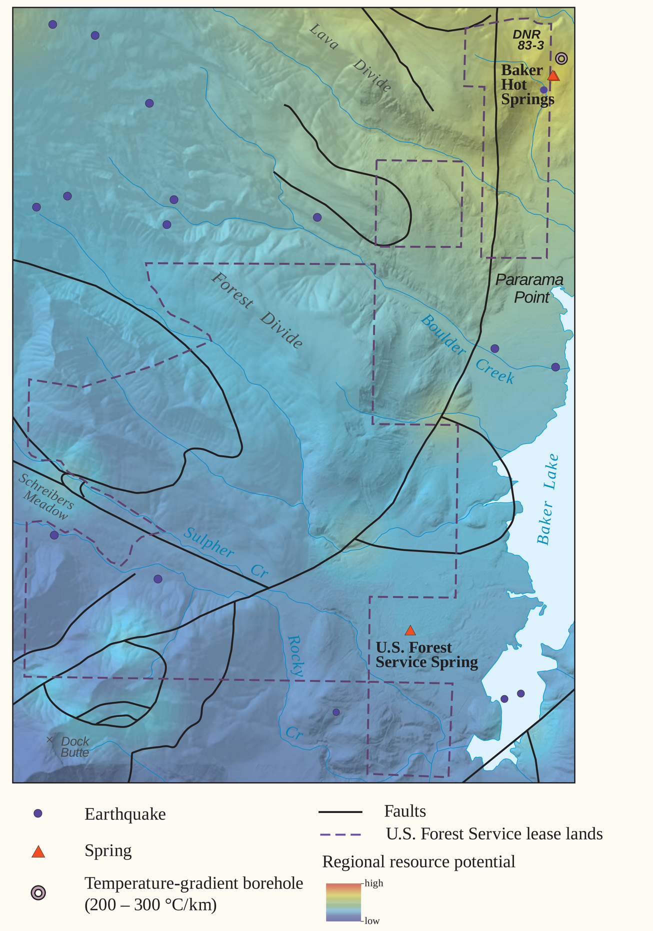


Mount St. Helens lies within Mount St. Helens National Volcanic Monument and is a designated Known Geothermal Resource Area (Burkhardt and others, 1980). The volcano is the site of ongoing geothermal activity, with numerous hot springs and fumaroles at the central crater, along the north flank, and in the Pumice Plain north of the 1980 flank collapse of the volcano. Geothermometer estimates of source temperatures range between 155°C and 185°C (Shevenell and Goff, 1995).

The play lies at the northern end of the Saint Helens seismic zone (SHZ)(Weaver and others, 1987), a well-defined northwest-trending fault zone expressed as a linear band of concentrated seismicity that crosses the volcano and extends both north and south outside the Volcanic Monument. A DNR temperature-gradient borehole drilled near the Green River Soda Spring, where the SHZ crosses the Green River, detected a gradient of 50°C/km.

Lands outside the volcanic monument are privately held by timber companies or managed by the Department of Natural Resources and the U.S. Forest Service (not shown), making these lands attractive exploration targets. Despite these factors, the area remains virtually unexplored.

Mount Baker

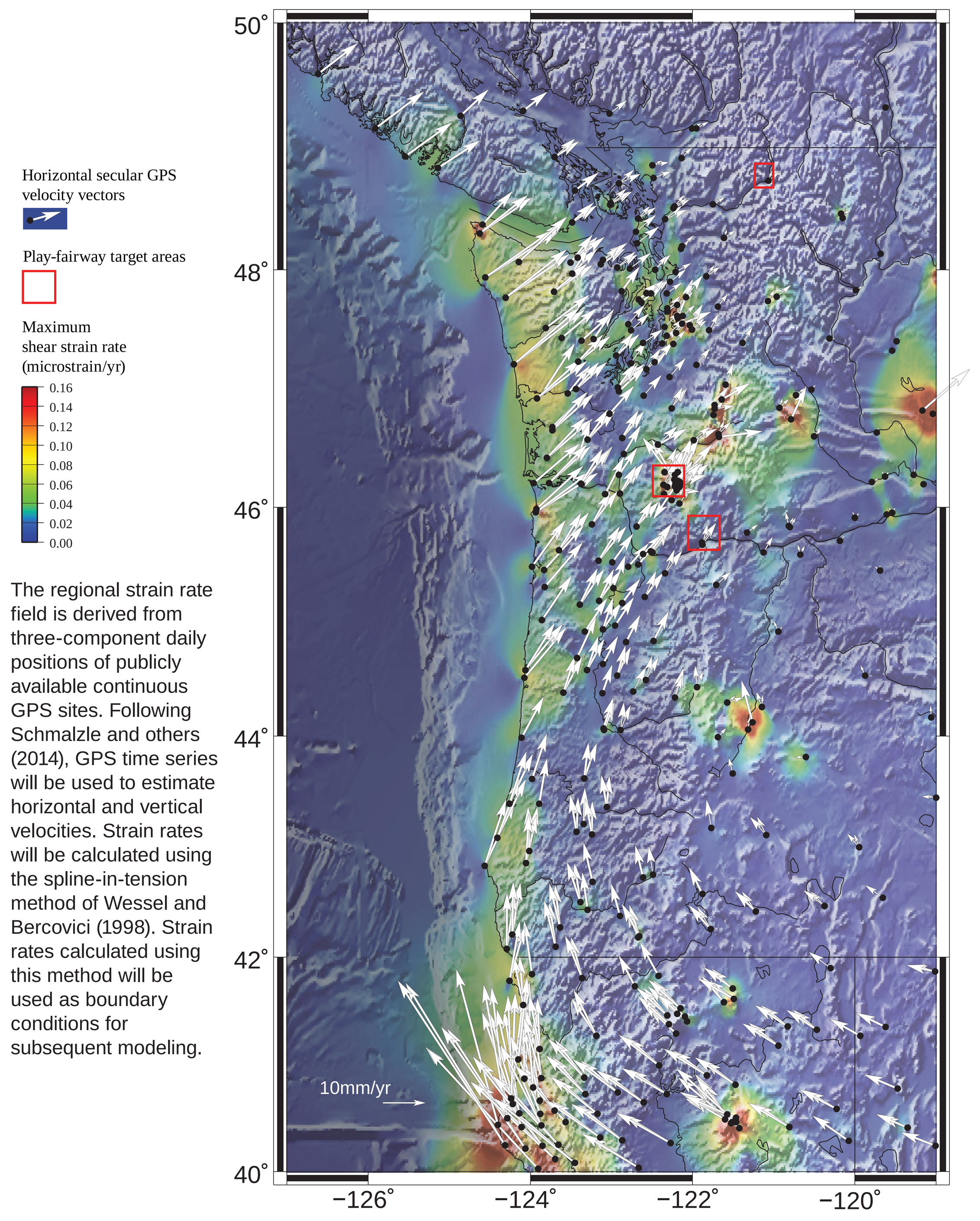


The Mount Baker area has received some attention due to the presence of thermal features and young volcanic centers, yet remains relatively unexplored. Exploration activities have included spring water sampling, geophysical surveys, soil mercury measurements, and one temperature-gradient borehole (Korosec,1984).

Chemical geothermometry of Baker Hot Springs suggests that the reservoir equilibrium temperature of this system may range as high as 150 to 170°C (Korosec, 1984). DNR 83-3, a 140-m-deep temperature-gradient well was drilled near Baker Hot Springs and had a geothermal gradient between 200 and 309°C/km.

Although faults are not as well characterized as the other two plays, geologic maps and geomorphology indicate that the hot spring occurs along a major fault that defines the Baker Lake valley.

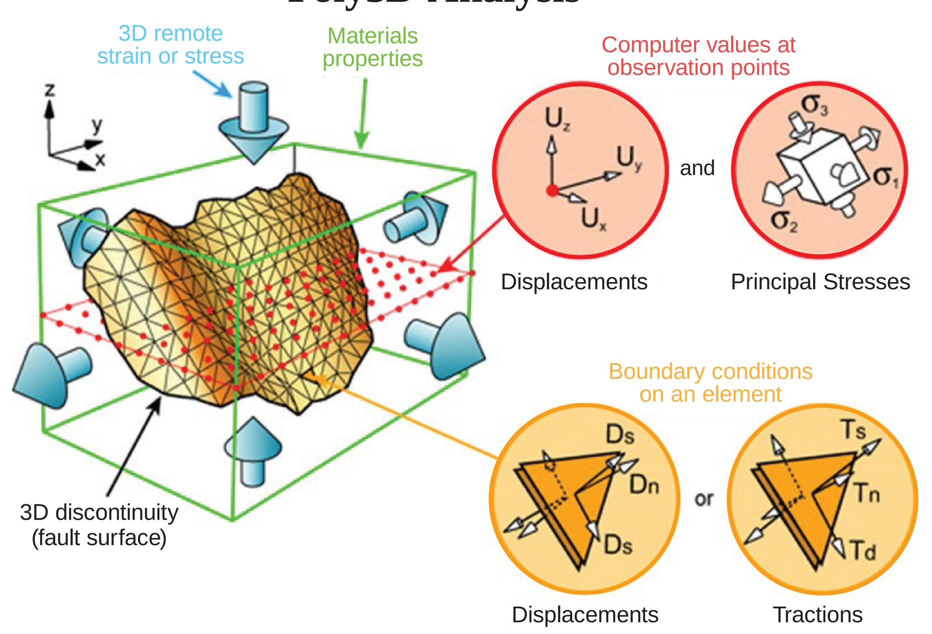
Regional Strain



The regional strain rate field is derived from three-component daily positions of publicly available continuous GPS sites. Following Schmalzle and others (2014), GPS time series will be used to estimate horizontal and vertical velocities. Strain rates will be calculated using the spline-in-tension method of Wessel and Bercovici (1998). Strain rates calculated using this method will be used as boundary conditions for subsequent modeling.

Poly3D Analysis

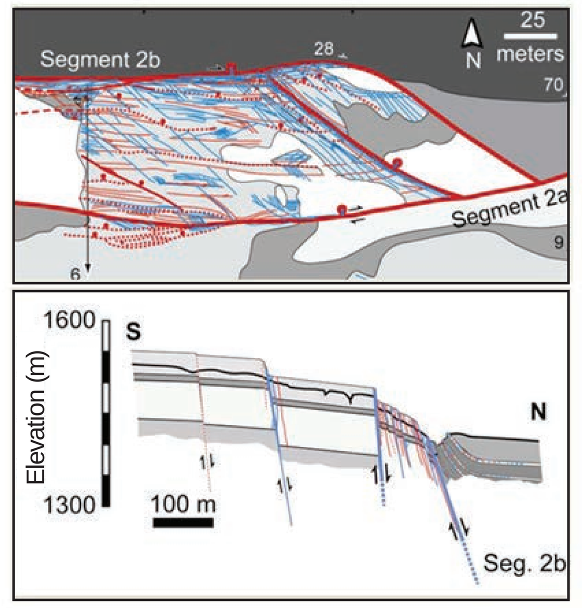
Poly3D (Thomas, 1993) uses the boundary element method to model quasi-static fault slip and deformation in the surrounding model volume in a homogeneous, isotropic linear elastic full or half-space. Faults are discretized into an array of triangular elements, which allows the construction of complex, realistic fault geometries (Swyer and Davatzes, 2013). Poly3D can be used to predict the location and orientation of secondary fractures around faults. Figure on right reproduced from Maerten and others (2002); far right figure adapted from Davatzes and others (2005).



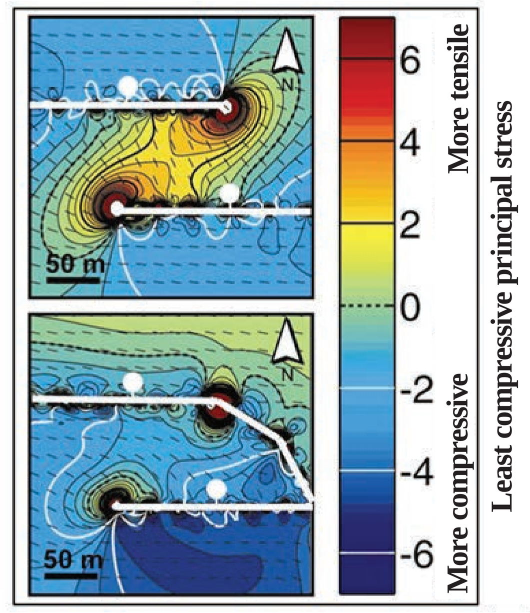
RESERVOIR POTENTIAL MODELING

- The strain rate field surrounding faults can provide insights to where geothermal reservoirs are found.
- GPS-derived strain rate field used with a mechanical fault model to generate crustal fault slip and estimate the likelihood areservoir exists, and if so, estimate its vertical extent and volume.
- Poly3D (Thomas, 1993) will be used to model quasi-static fault slip and deformation in a homogeneous, isotropic linear elastic half-space. Fault geometry constrained with remotely sensed data, detailed geologic maps/cross sections, and seismicity (Swyer and Davatzes, 2013).
- Fracture density estimated based on maximum Coulomb shear stress. A critical density consistent with a percolating fracture network will be used to define viable reservoirs and the depth of fluid circulation as a source of heat to support a geothermal reservoir.

Field Data



Simulation



PERMEABILITY ANALYSIS PRODUCTS

- Maps of GPS-derived velocities and strain rates
- Maps and cross sections of model-derived Coulomb stress that show regions favorable to fracture and fault slip that promote fluid flow
- Assessment of the uncertainty in the model predictions
- Assessment of reservoir potential
- Maps and cross sections of fault slip tendency and displacement indicating the potential for the faults to act as fluid conduits, or in regions of inhibited/small slip, to act as fluid barriers
- Integrating this assessment of reservoir potential with the heat model leads to the development of the geothermal resource potential model.

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