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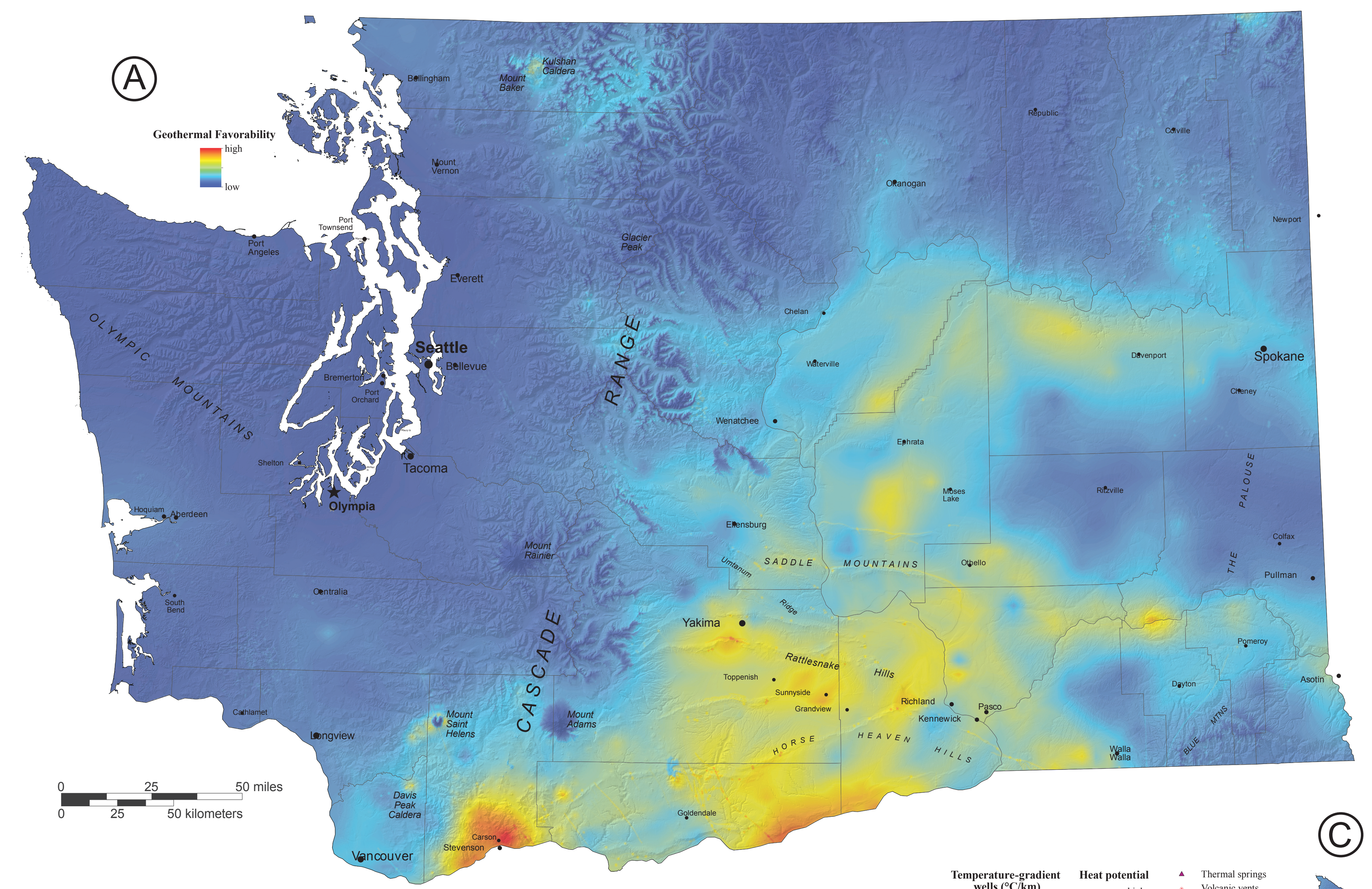
Geothermal Favorability Model of Washington State

by Darrick E. Boschmann, Jessica L. Czajkowski, and Jeffrey D. Bowman

Geothermal Favorability Model



Geothermal Favorability Model Structure

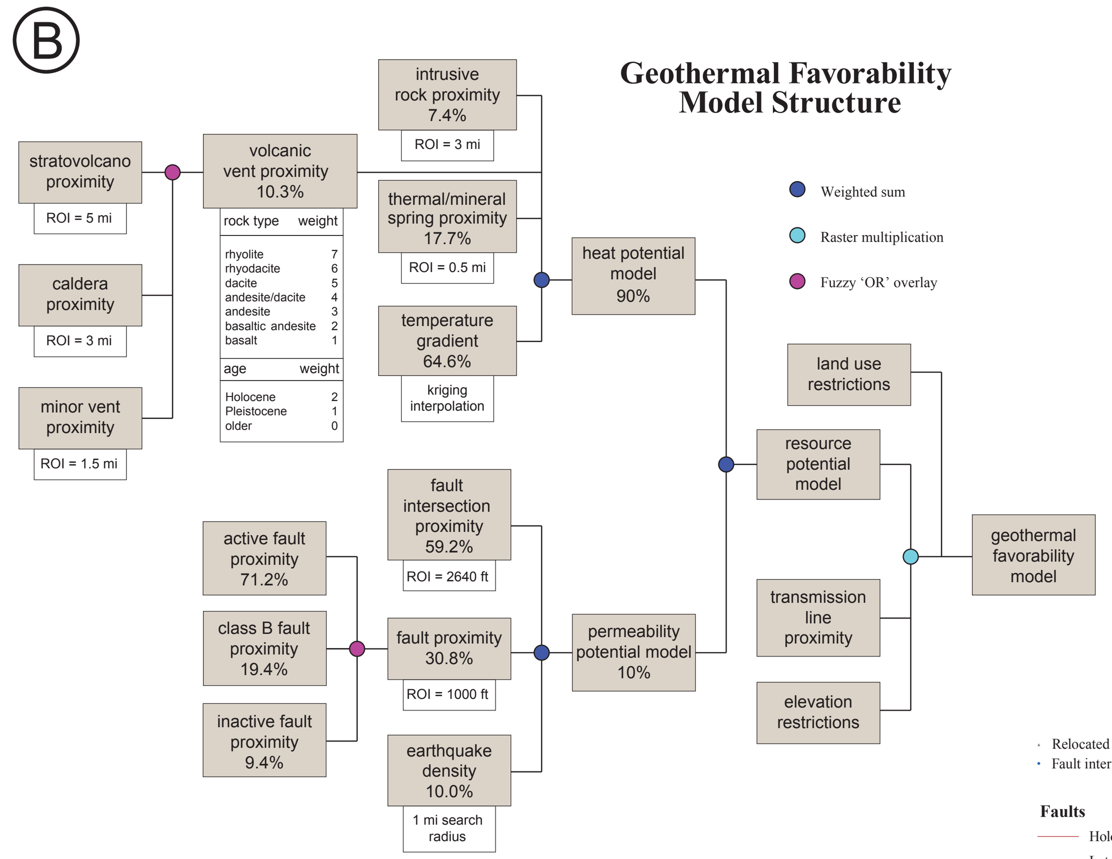


Figure B. General structure of the geothermal favorability model of Washington State, including intermediate raster data, thematic models, and favorability input models, model processes (purple, cyan, and magenta circles), classification schemes, radius of influence (ROI), and analytic hierarchy process (AHP) weights (percent). Vector input data not shown.

BACKGROUND

In the early phases of geothermal exploration, many important geological details are unknown. A regional exploration model based on available data and exploratory principles can identify areas where it would be most beneficial to obtain more detailed data.

In 2011, the U.S. Department of Energy funded a three-year effort by state geological surveys to compile and collect all varieties of new and existing geothermal-related data and information for inclusion in the National Geothermal Data System (NGDS; geothermaldata.org). In support of this effort, the Washington State Department of Natural Resources (DNR), Division of Geology and Earth Resources (DGER), developed and (or) revised numerous datasets of existing geothermal and geological data in Washington State.

GEOTHERMAL FAVORABILITY MODELING

Using newly compiled and collected data, a Geographic Information System (GIS)-based analysis of spatial datasets was used to determine the spatial association between various geologic and thermal features, infrastructure, and land-use to gain a broad understanding of geothermal resource potential and favorability in Washington State.

The geothermal favorability model of Washington State was constructed by performing multiple iterative ArcGIS processes (density and proximity analyses, interpolation, and data combination) on volcanic vents, young silicic intrusive rock bodies, thermal/mineral springs, temperature gradients in wells, faults, earthquakes, electric transmission lines, and elevation (Figs. C–G).

The Analytical Hierarchy Process (Saaty, 2008) was used during all modeling steps to ensure consistent and appropriate weighting of data layers.

RESULTS

The geothermal favorability model shows relatively high favorability in localized areas of the Columbia Basin as well as areas within the South Cascades (Figs. A and I). The model also illustrates the challenges of developing geothermal resources in Washington State—most areas of the state with potential resources (Fig. F) are remote, with little infrastructure or accessibility. Proximity to transmission lines (not shown), elevation (Fig. G), and land-use restrictions (Fig. H) significantly impact geothermal favorability, rendering potential resource areas unfavorable for exploration and (or) development, including most of the thermal areas along the crest of the Cascade Range (Fig. I). However, the potential for local, small-scale geothermal power production remains an option for some remote locations.

The widespread low-temperature geothermal resources in the Columbia Basin and elsewhere have considerable potential for direct-use applications in district heating, agriculture, and industry.

The modeling incorporates the most complete and accurate data compilations to date, but is nevertheless limited by the quantity, quality, and sparse or irregular distribution of available data.

FUTURE WORK

A geothermal play-fairway U.S. Department of Energy grant was recently awarded to the Washington Division of Geology and Earth Resources and our collaborative partners, AltaRock, the U.S. Forest Service, Temple University, and BOS Technologies. Work has begun to produce detailed resource potential maps for several prospects along the Washington State Cascade Range, including the Wind River valley (area 5), the southeast flank of Mount Baker (area 1), and the Mount St. Helens seismic zone (area 4). Refinement of the model will include:

- Resampling of data not already included in the state-wide model (Fig. J)
- Resampling of the data already collected at a higher resolution
- Model simulations and data processing to incorporate additional variable weighting and a modified radius of influence scheme within the existing statewide scheme,
- Using two new techniques to model fault permeability, such as three-dimensional stress/strain analysis on faults and mapping GPS-derived velocities and strain rates.

All three plays have current geothermal lease holders with plans for exploration and are developable if sufficient resources are found.

The main products of play-fairway analyses at the three geothermal plays in Washington State are:

- 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
- The assessment of reservoir potential
- Maps and cross sections of fault slip tendency and displacement will also be produced to indicate the potential for the faults themselves to act as fluid conduits, or in locations of inhibited/small slip, to act as fluid barriers that compartmentalize the reservoir.

Integration of this assessment of reservoir potential with the heat model will generate the geothermal resource potential model. In addition for each play, recommendations will be made for the most cost-effective exploration activities to test and(or) better constrain the fault models.

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Heat Potential Model

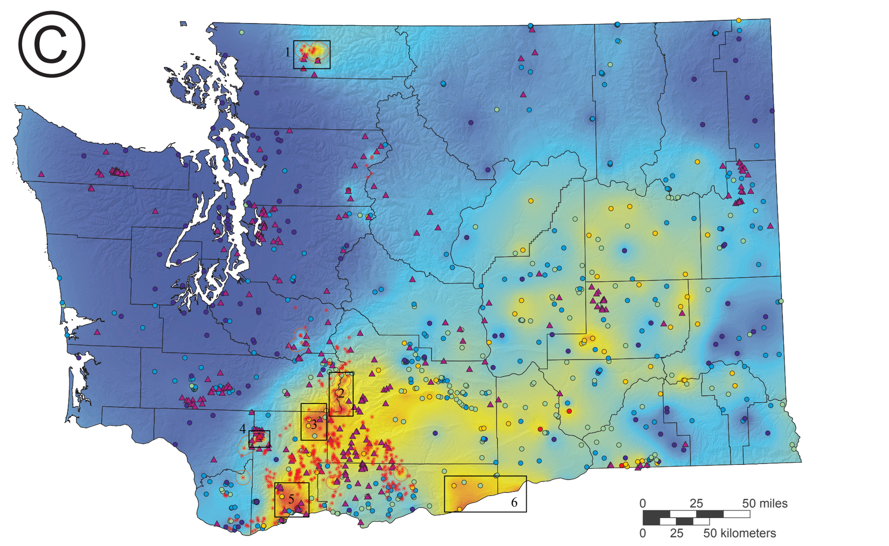

Figure C. Crustal heat at depths accessible by modern drilling technologies is a basic requirement for development of geothermal resources. The geothermal heat potential model represents the modeled shallow crustal heat potential in Washington State based on the spatial distribution of temperature gradient, thermal/mineral springs, volcanic vents, and young intrusive rocks. The highest modeled heat potential is in the southern Cascade Range, with isolated areas of elevated heat potential in the North Cascades and a broad region of scattered moderate potential across much of the Columbia Basin. Areas west of the Cascade Range, including the Puget Lowland and Olympic Mountains, generally have the lowest modeled heat potential. Areas of interest: area **1**, Mount Baker/Kulshan Caldera; area **2**, Goat Rocks; area **3**, East Canyon Ridge; area **4**, Mount St. Helens; area **5**, Wind River; and area **6**, Roosevelt.

Resource Potential Model

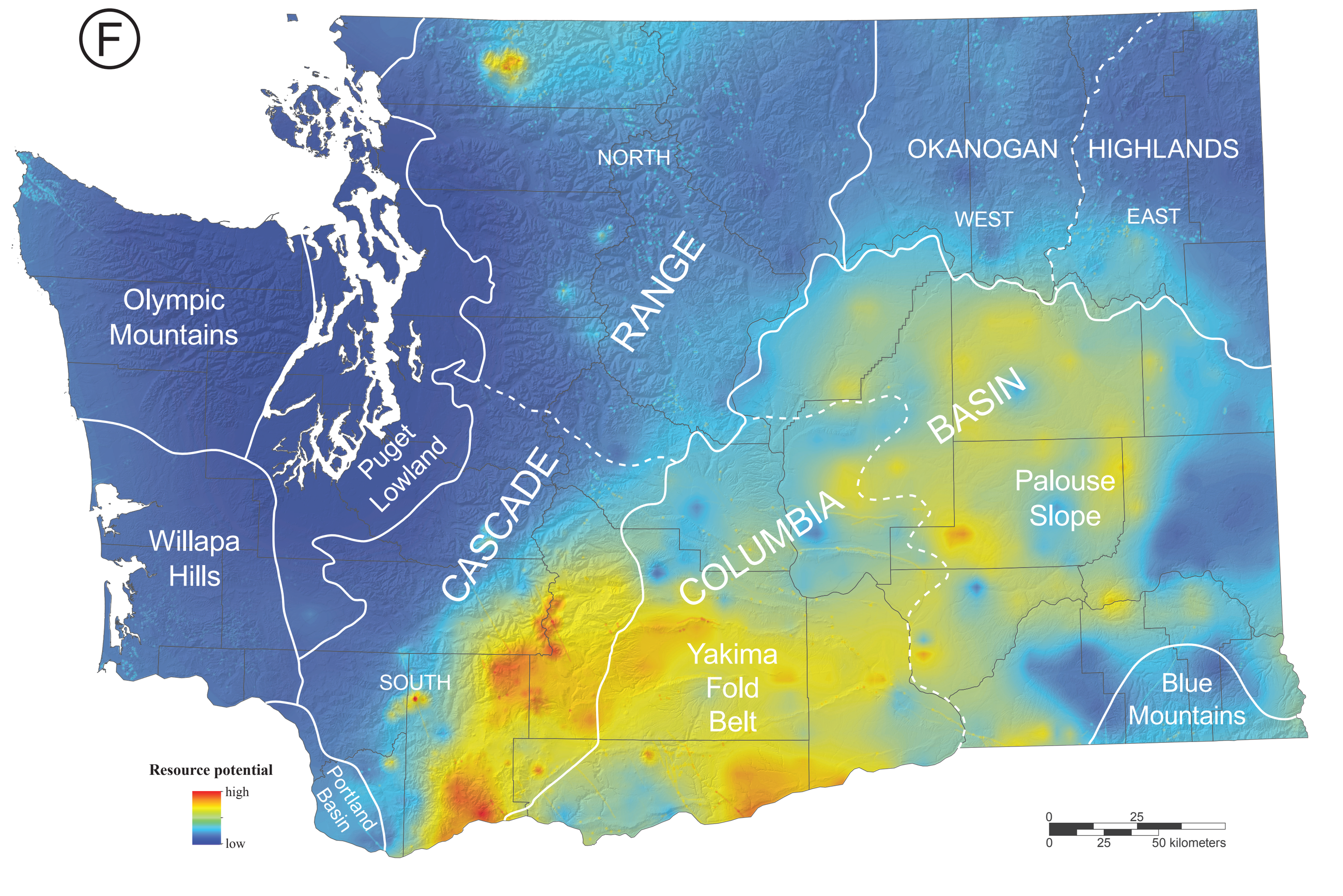

Figure F. The resource potential model represents the relative geothermal potential in Washington State based on the permeability and heat potential models. The model is intended to highlight areas of elevated potential for the presence of moderate- to high-temperature geothermal systems. This model represents geothermal resource potential without consideration of regulatory restrictions, land-management restrictions, or economic viability. The general trend of the resource potential model is similar to that of the heat potential model. Locally, areas with elevated modeled permeability potential moderately increase the relative resource potential.

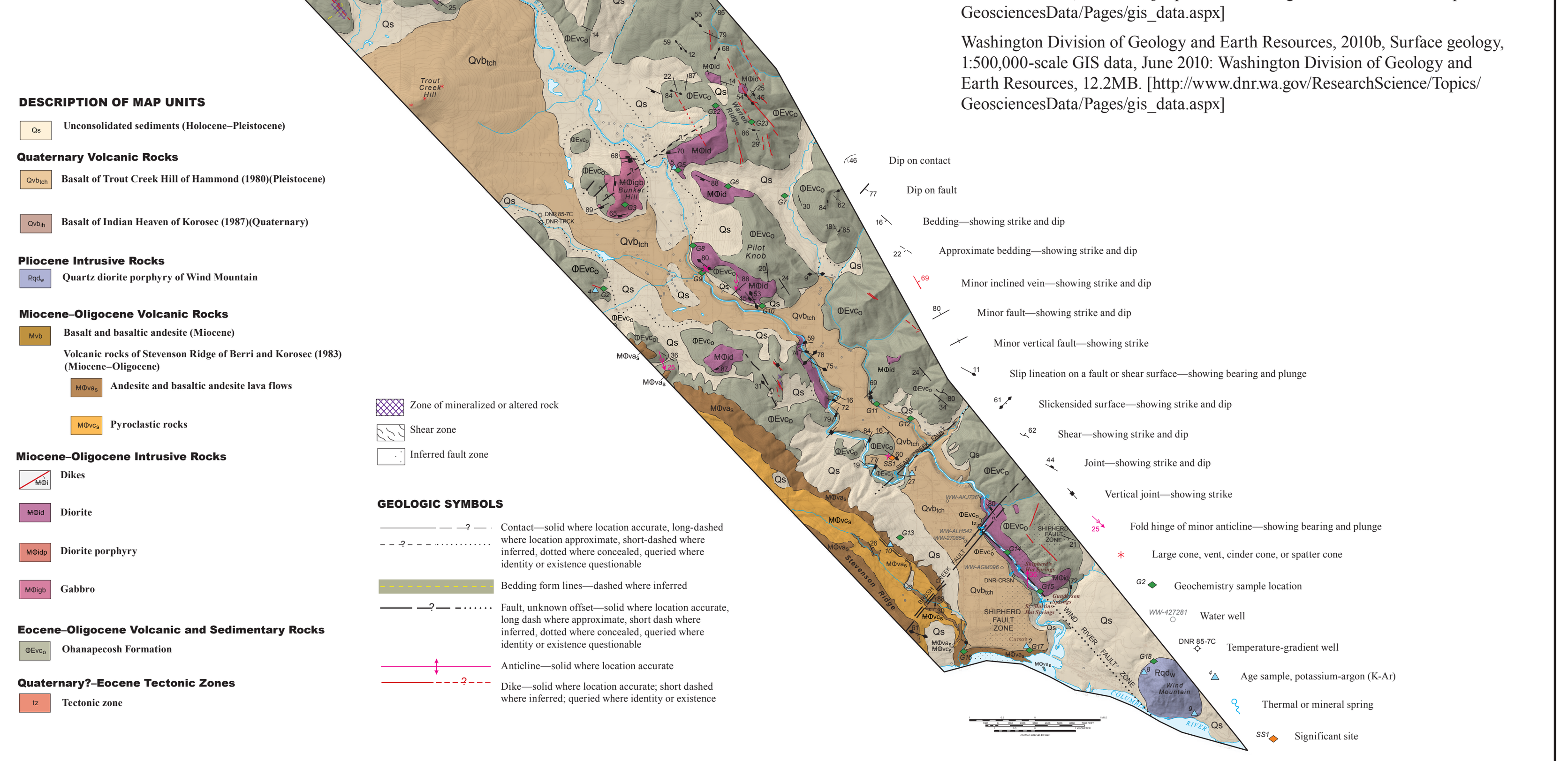

Figure J. Detailed play-fairway analyses of smaller geothermal prospects will rely heavily on detailed mapping. The Wind River valley area (area 5 on Fig. C) will be evaluated based on new data and detailed data (Czajkowski and others, 2014). Fault traces and detailed structural data gathered during geologic mapping will be used to model three-dimensional stress and strain. Figure modified from Czajkowski and others (2014).

Permeability Potential Model Input Data

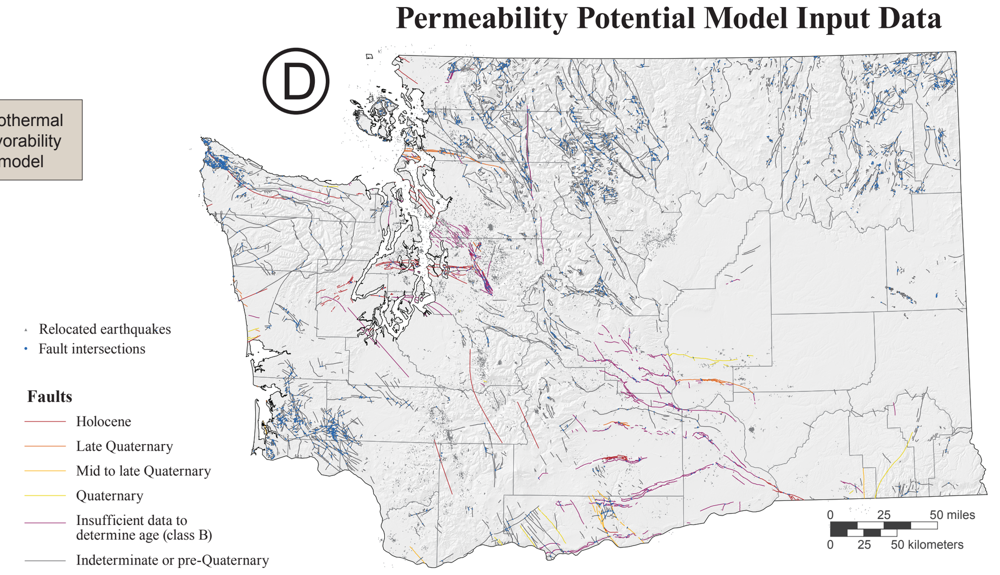

Figure D. The permeability potential model uses input data including faults, fault intersections, and earthquake locations. Fault data consist of mapped faults compiled from 1:250,000-scale, 1:100,000-scale, and active fault digital data (Washington Division of Geology and Earth Resources, 2010a,b; Bowman and Czajkowski, 2014). The earthquake density calculation was performed on relocated earthquakes greater than magnitude 1 and at less than 30 km depth (Bowman and Czajkowski, 2014).

Permeability Potential Model

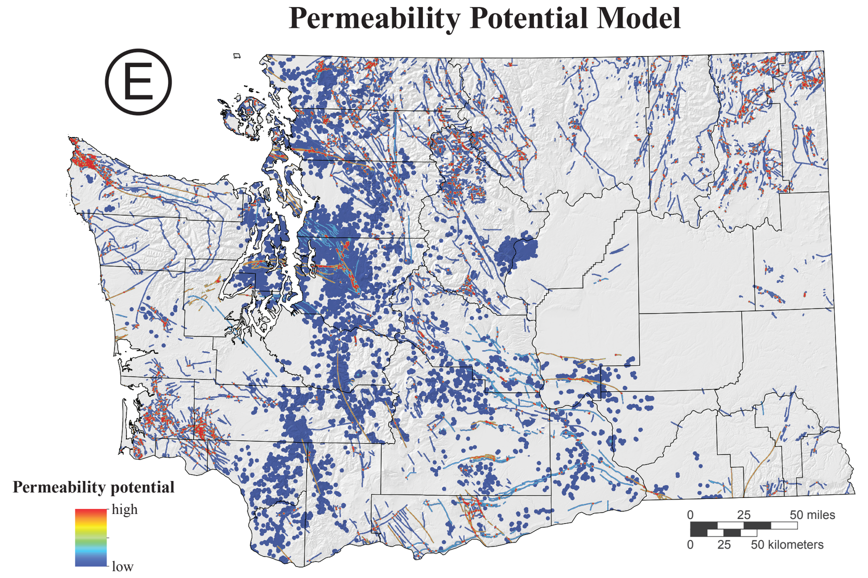

Figure E. Conventional geothermal-resource production requires significant reservoir permeability to enable thermal fluids to migrate freely through a reservoir and into the wellbore. The permeability potential model is based on the spatial distribution of known faults, fault intersections, and recorded seismic activity. The highest modeled permeability potential is found in areas of dense fault intersection, such as the northwest corner of the Olympic Peninsula and the southern Willapa Hills. Mapped fault-density variation is likely due in part to the scale and scope of fault mapping as well as the variable emphasis placed on faults by different investigators. Broad regions with recorded seismic activity are distributed widely along the western front of the Cascade Range, with isolated high-density regions across much of the state.

Elevation Restrictions

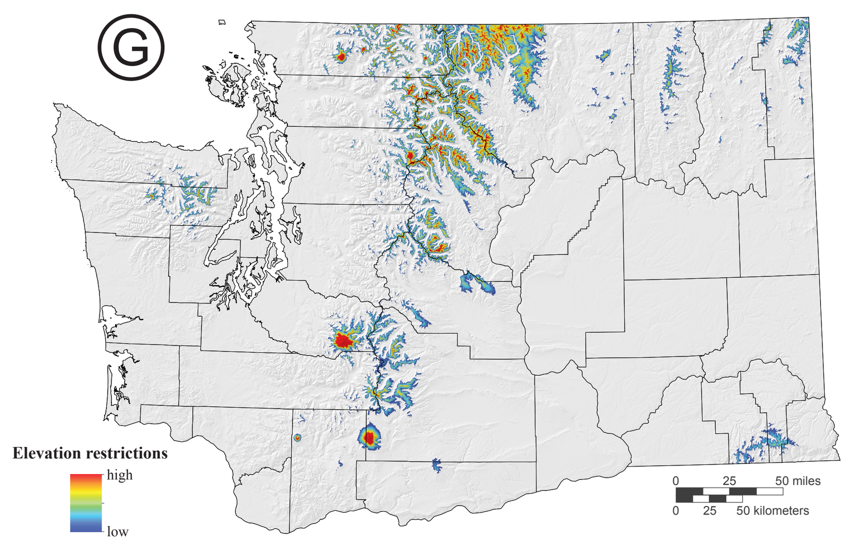

Figure G. High elevations can be restrictive to development because of logistic and climatic conditions, especially in the Cascade Range where annual snowfall can exceed 80 feet at elevations as low as 4,200 feet (Leffler and others, 2001). Most high-elevation areas are also remote, have little existing infrastructure, and may be inaccessible during several months of the year. Many areas thought to have high heat flow, such as Mount St. Helens volcano, a "Known Geothermal Resource Area" (KGRA)(Burkhardt and others, 1980), are at high elevations, making these areas challenging for geothermal-resource development. While extreme elevation and climate do not necessarily preclude development of geothermal resources, the model assumes favorability will decline with increasing elevation above 5,000 feet, and that elevations above 8,000 feet will prohibit any development activity.

Land-Use Restrictions

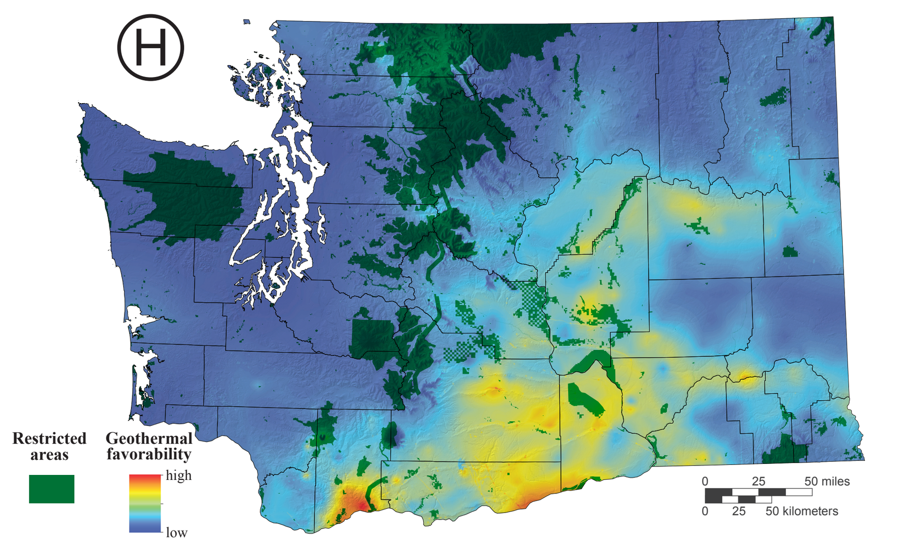

Figure H. Land-use restrictions include public and private lands managed for the conservation of biological diversity and other natural, recreational, and cultural uses that may, through legal or other effective means, restrict the exploration and development of geothermal resources. These lands include national parks, national wilderness areas, wildlife refuges, private conservations lands, and areas of critical environmental concern. Land-use restricted areas are widespread in the Cascade Range, especially in the North Cascades where much of the uplands is designated federal wilderness area. The South Cascades and Olympic Mountains also have significant land-use restrictions, and widely distributed restrictive parcels are located throughout the state. In total, just over 10,000 square miles (~14%) of land in Washington State are designated as restrictive for the purposes of this report. Much of this land is located in areas with elevated resource potential, and thus, land-use restrictions are a major obstacle for exploration and development of geothermal resources in Washington State.

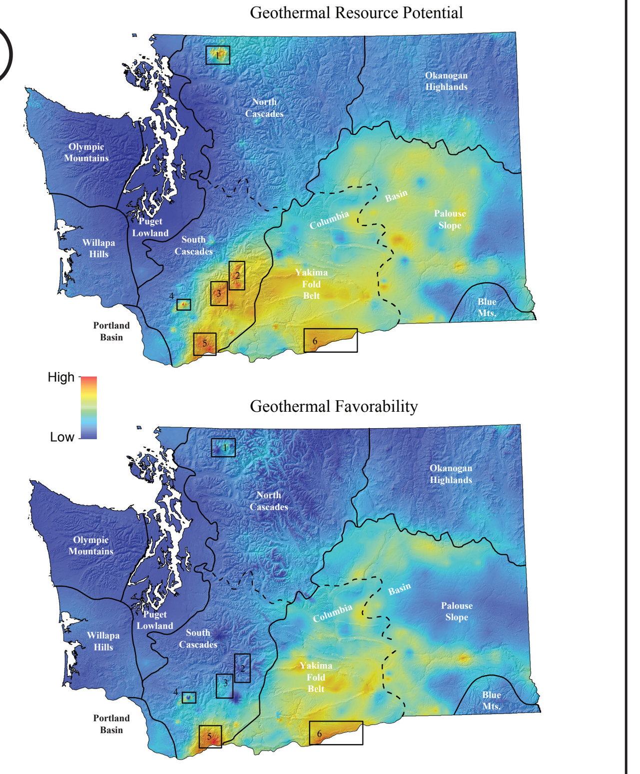

Figure I. Comparison of the geothermal resource potential model to geothermal favorability. Once distance to transmission lines and elevation restrictions are applied to the geothermal resource potential model, geothermal favorability in several areas is either moderately reduced, as in the Mount Baker(1) and Mount St. Helens (4) areas, or significantly reduced in areas like the Goat Rocks Wilderness (2) and East Canyon Ridge (4). Other areas, such as the Wind River valley (5) or the Roosevelt area (6) along the Columbia River lie at lower elevations in close proximity to the eletrical grid, resulting in no loss of geothermal favorability.