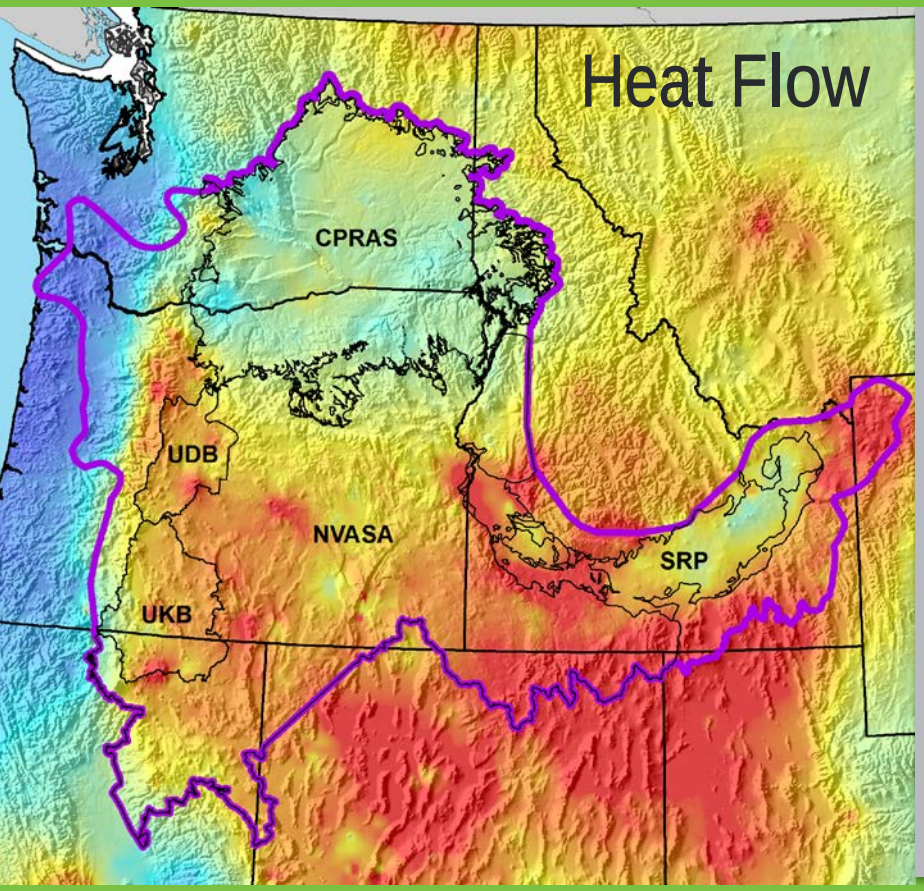
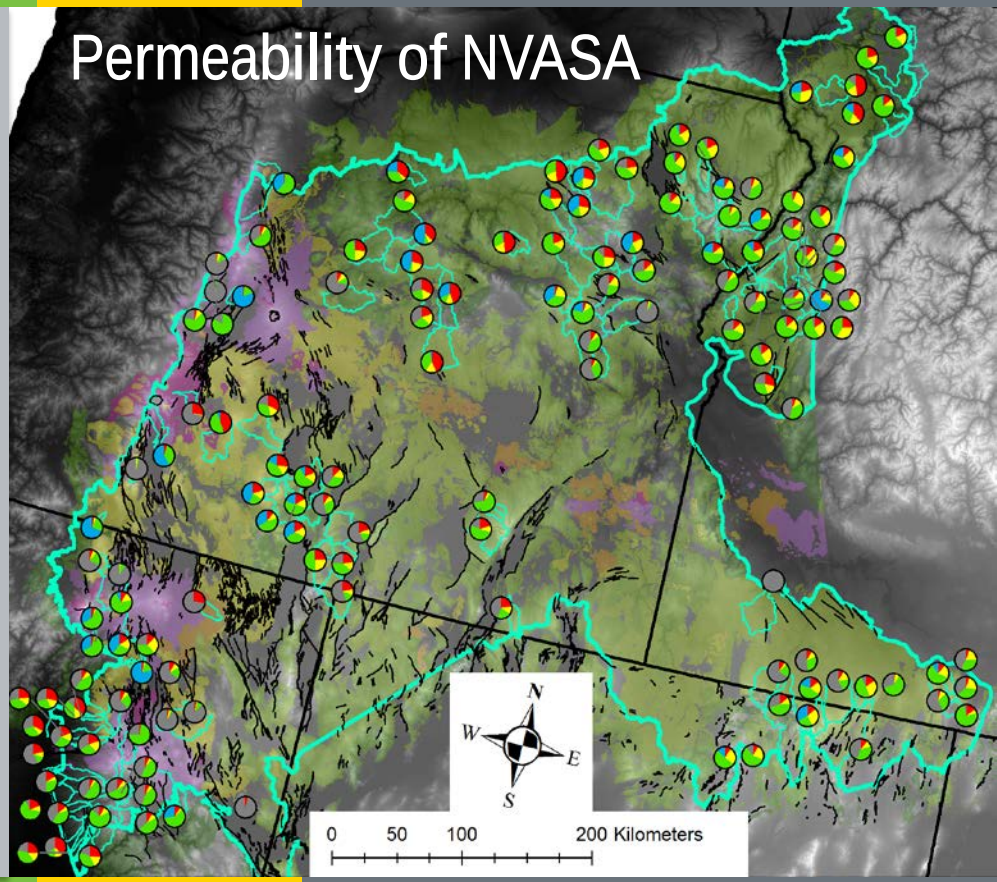




Northwest Volcanic Geothermal Province Studies

Project Officer: Eric Hass/Mike Weathers

Total Project Funding: $200,000

November 15, 2017

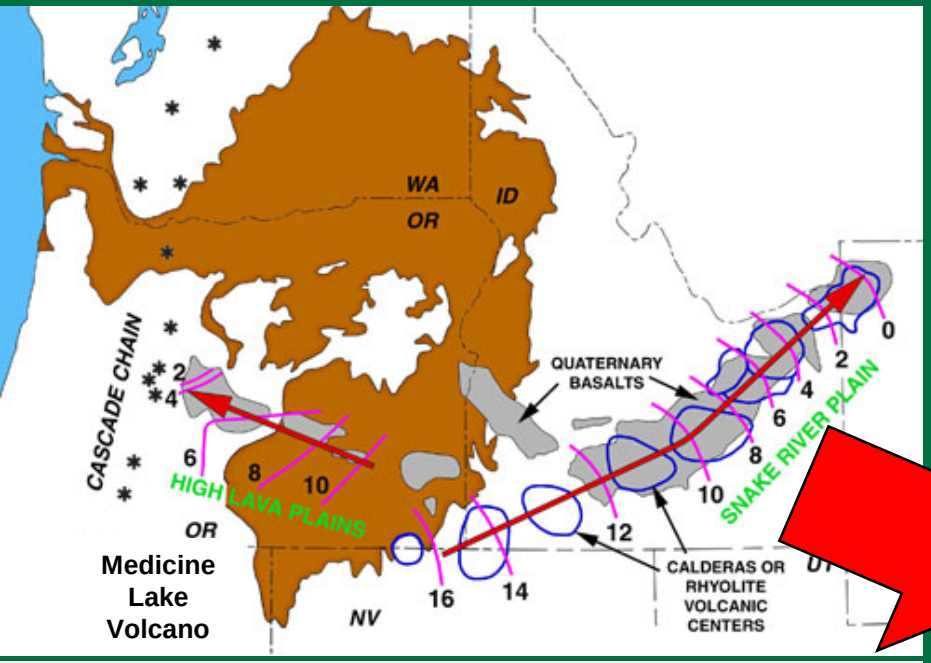
Principal Investigator

Erick R. Burns

U.S. Geological Survey

Track Name: Play Fairway

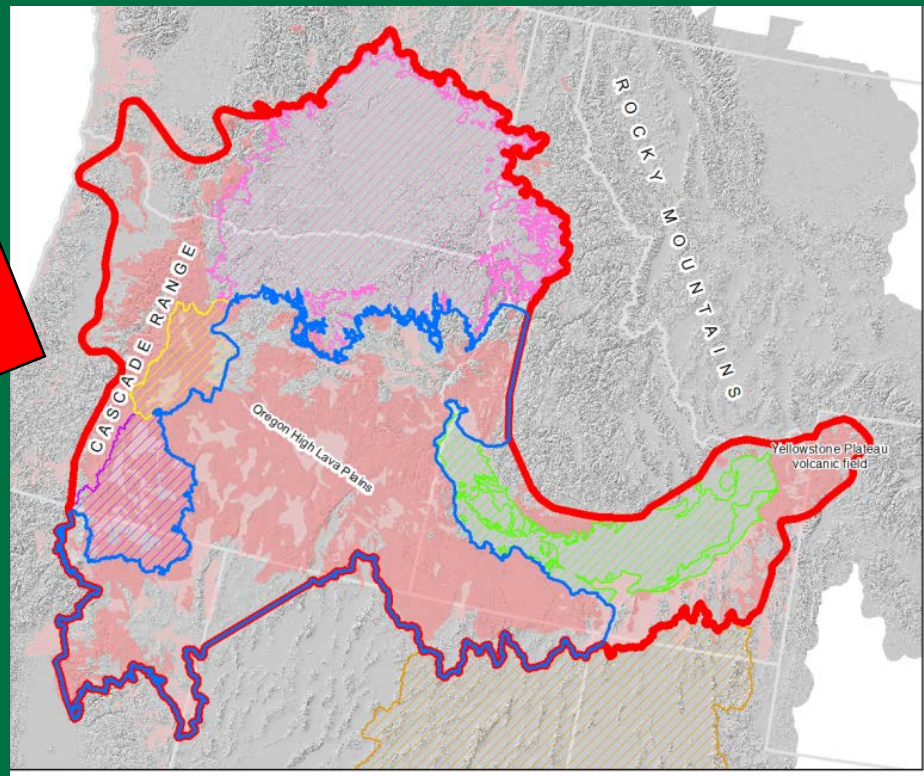
Northwest Volcanic Province (NVP)



From Camp and Ross
(http://www.mantleplumes.org/RadVolcMigrations.html)

Volcanic History

Permeability patterns in this area are often dominated by volcanic deposits

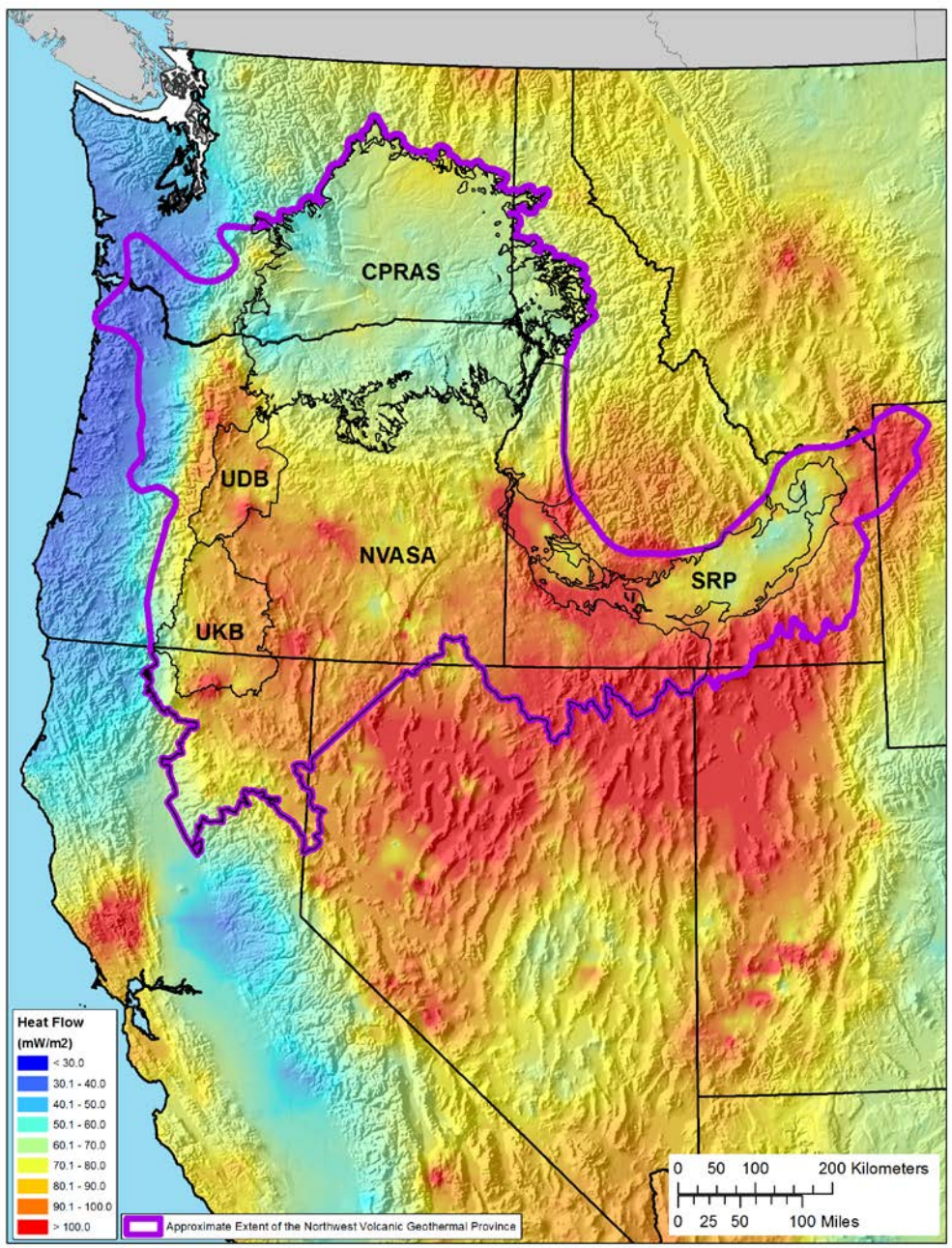


USGS

Relevance to Industry Needs and GTO Objectives

The overarching objective is to improve geothermal prospectivity in the Northwest Volcanic Province (NVP)

- Can we improve maps of estimated geothermal resources?
- Can we identify permeability patterns that improve geothermal prospectivity?
- Despite much of the NVP being basin-and-range, there are more successes in Nevada than in similar terrains in the NVP. Why?

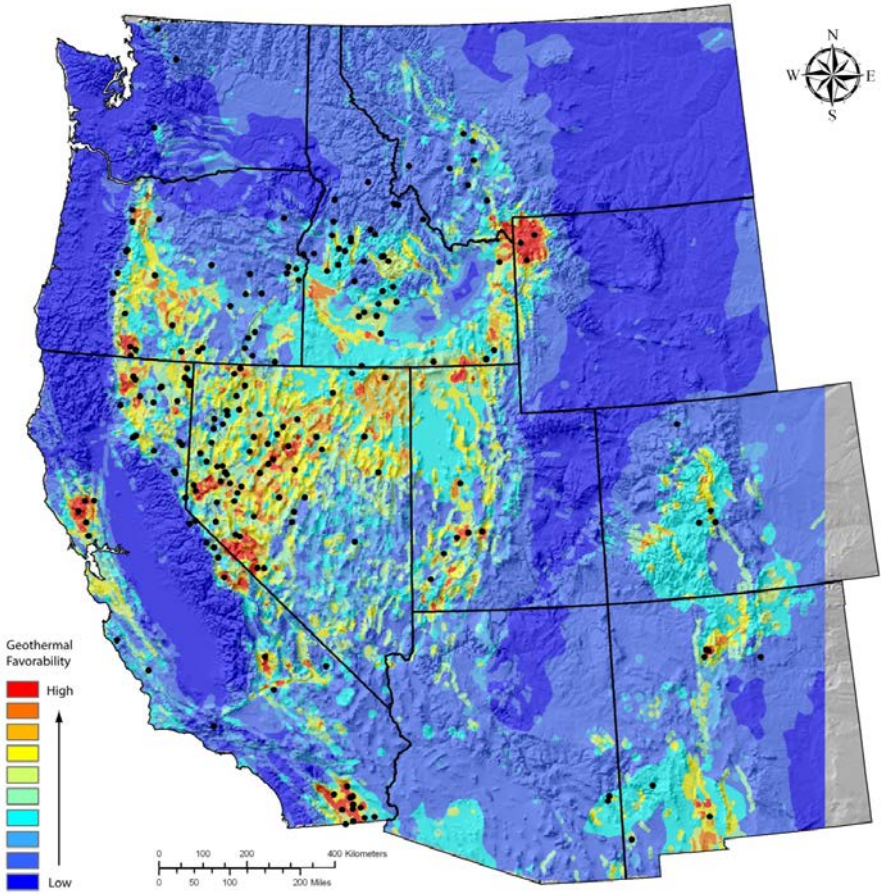


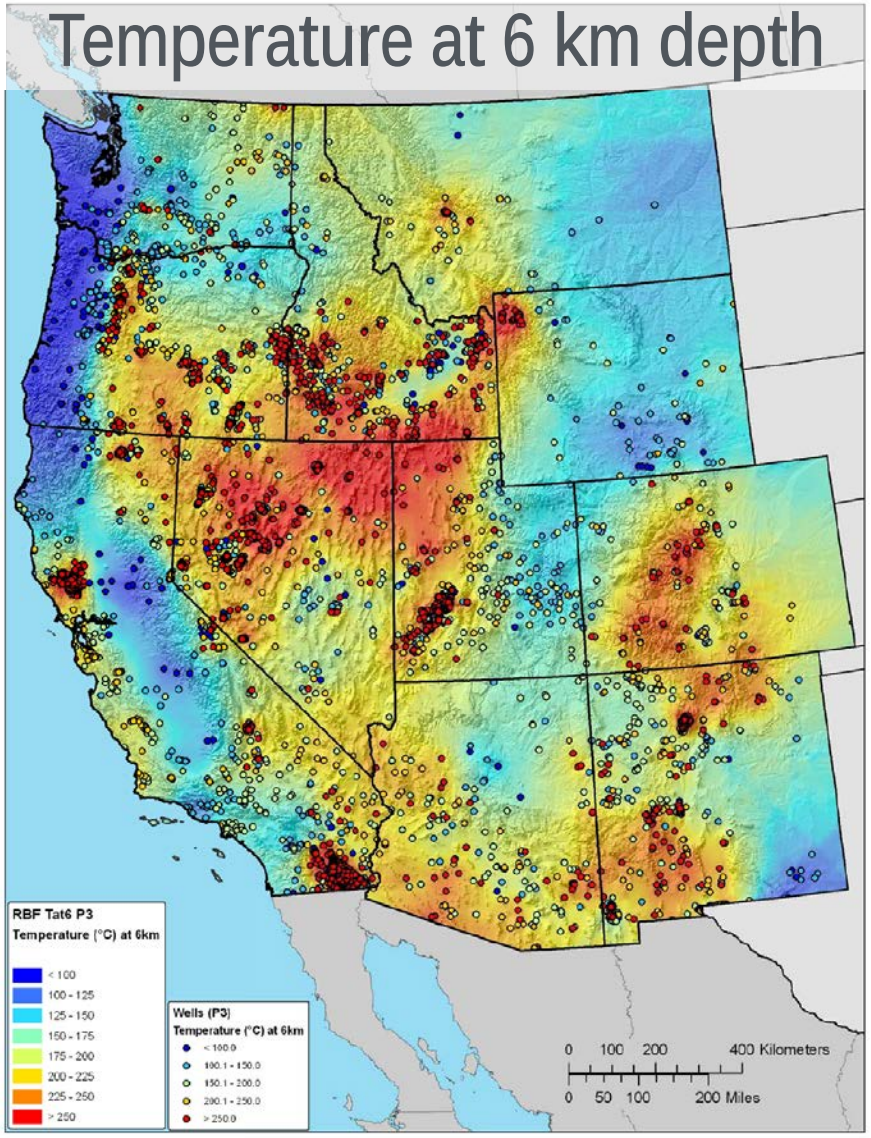
Heat flow map was constructed using the methods of Williams & DeAngelo (2008).

Relevance to Industry Needs and GTO Objectives

Hydrothermal favorability versus Enhanced Geothermal Systems (EGS)

(Williams and DeAngelo [2008, 2011], Williams and others [2008a,b, 2009], and Williams [2010a,b])



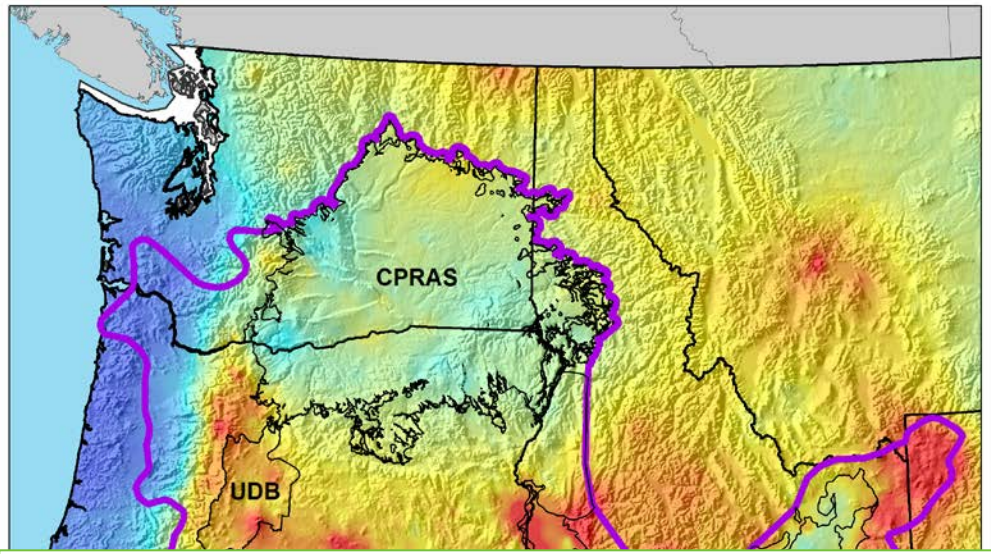


Relevance to Industry Needs and GTO Objectives

Heat is swept away by forced convection associated with regional groundwater flow driven by meteoric recharge

- Heat flow estimates collected within and above the aquifer system bias heat flow estimates.
- Hydrothermal discharge can be at the land surface, subaqueous, or subterranean. The last two can result in blind geothermal systems.
- Shallow and deep groundwater flow rates are important for understanding depth to the geothermal resource.

Heat flow map was constructed using the methods of Williams & DeAngelo (2008).



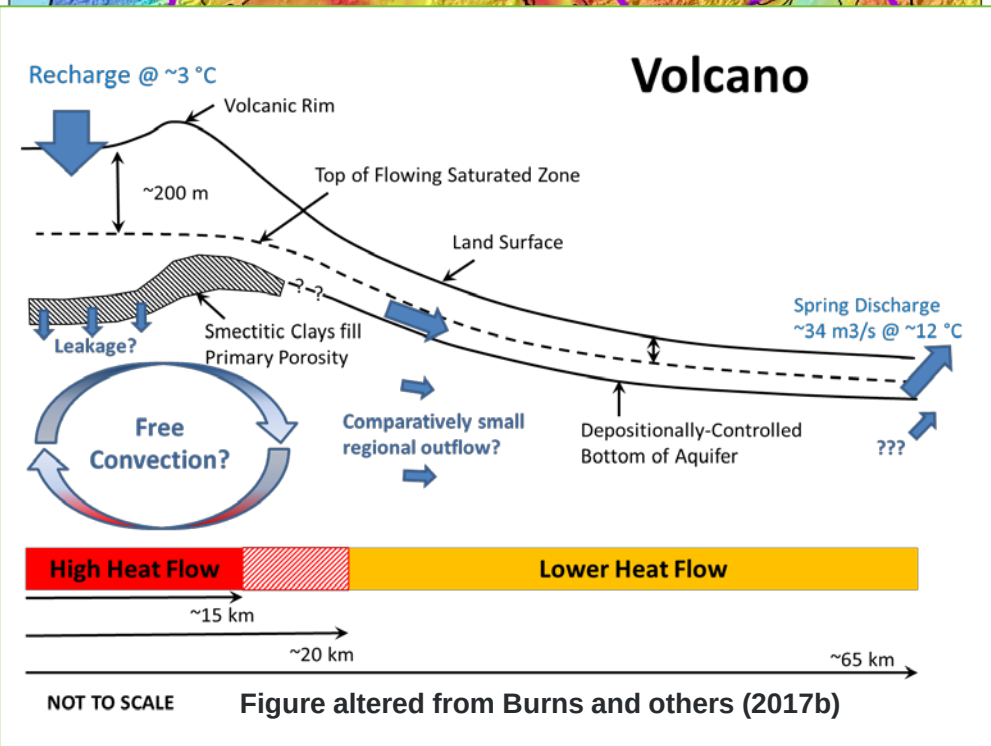
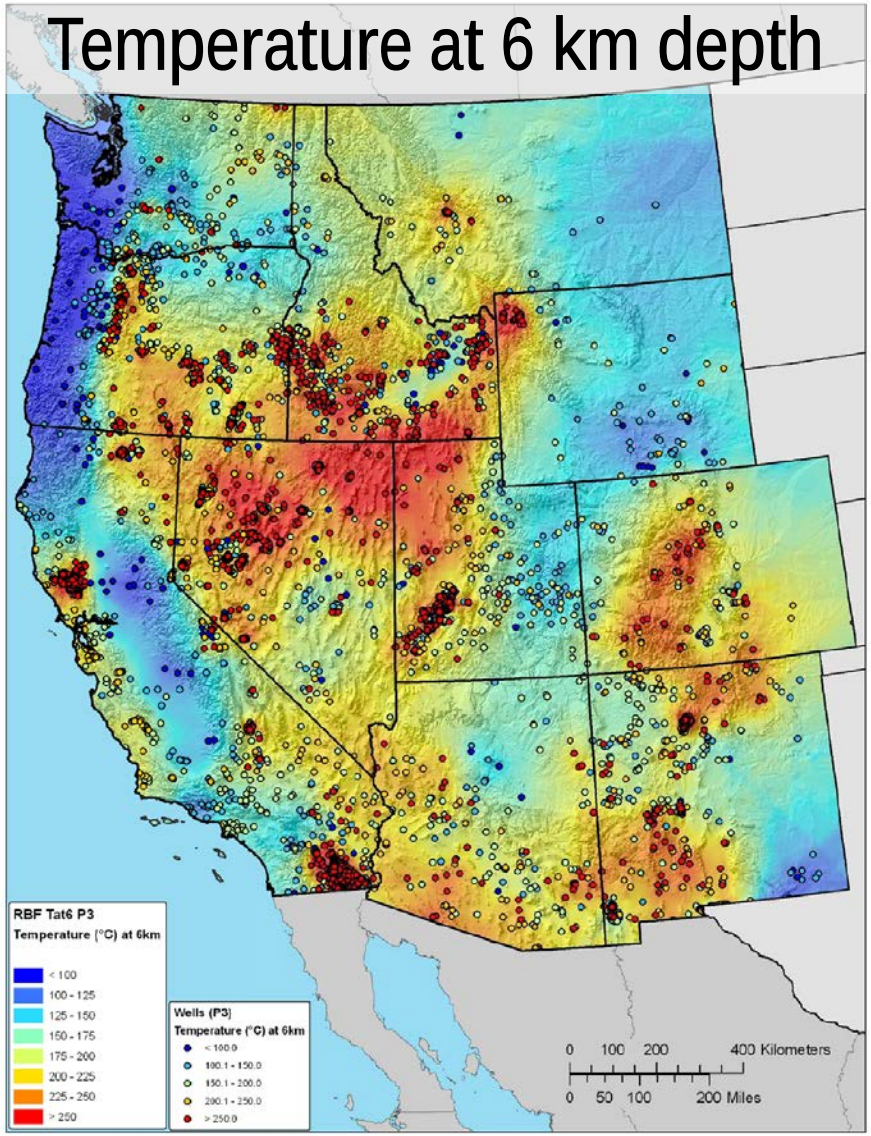


Figure altered from Burns and others (2017b)

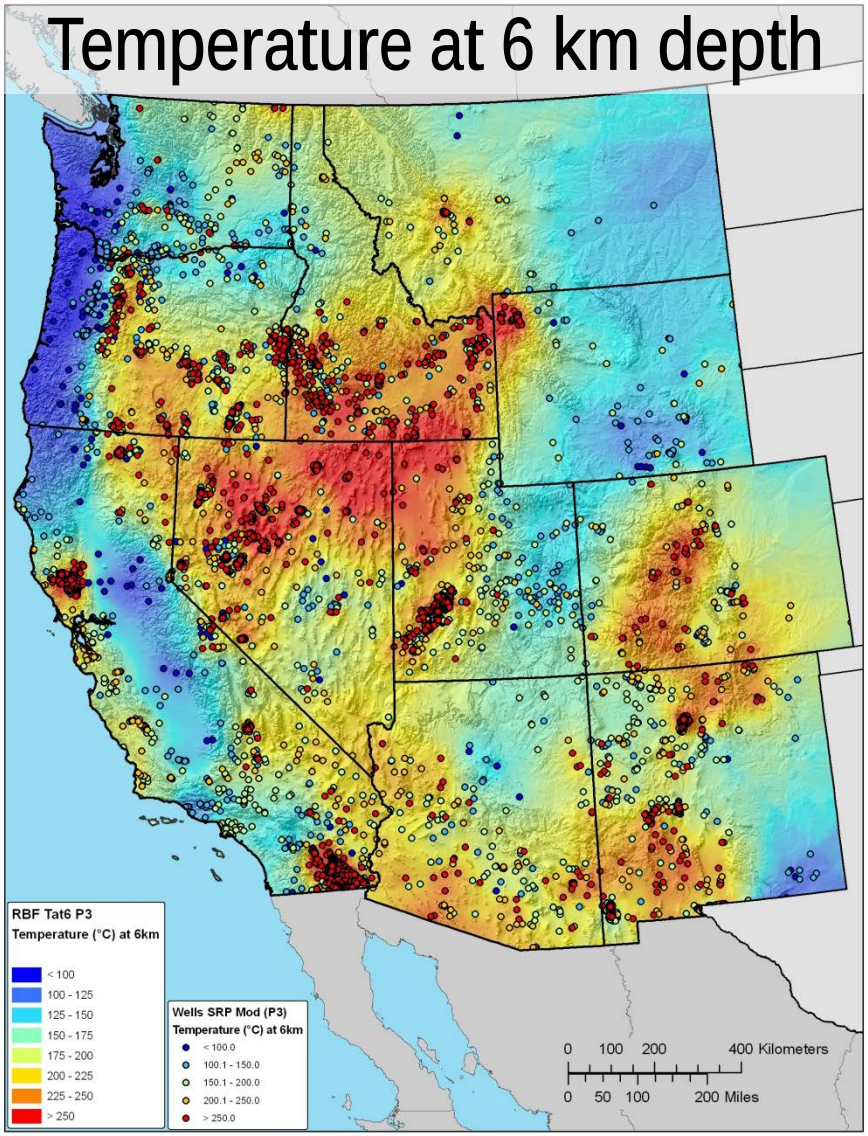
Modified from Williams' (2011) GRC presentation

Effect of Eastern Snake River Plain Modifications *(i.e., correct for measurements that are biased by groundwater)*

Temperature at 6 km depth



Temperature at 6 km depth



Relevance to Industry Needs and GTO Objectives

This project in part of larger research arc

- Previous USGS efforts supported jointly by USDOE GTO and USGS ERP
  - Regional maps of heat flow and geothermal resource estimation (e.g., Williams and DeAngelo [2008, 2011], Williams and others [2008a,b, 2009], and Williams [2010a,b]))
  - Identification/evaluation of resource estimate bias due to advective heat transport (e.g., Burns and others, 2015, 2016a), and some refined analyses of the geothermal resource in areas of bias, showing likely increased resources (Burns and others, 2016a,b)
- Current research is jointly funded by USDOE GTO, the USGS Energy Resources Program (ERP), and the USGS Water Availability and Use Science Program (WAUSP)
  - Focuses largely on the Northwest Volcanic Aquifer Study Area (NVASA, hydrologically understudied sub-region within the NVP)
  - USDOE and USGS ERP resources are also directed towards taking results from study of the NVASA for feedback into Play Fairway studies within the larger NVP
- Future research to improve geothermal resource maps will continue under USGS ERP and WAUSP, and continued support by USDOE would be appreciated

Relevance to Industry Needs and GTO Objectives

Why joint-study of groundwater and geothermal heat flow?

- Groundwater sweeps a tremendous amount of heat away, altering heat flow patterns and thermal gradient measurements. Understanding groundwater flow can allow for correction of measurement bias.
  - Can we develop additional variables to improve prospectivity through geostatistical analysis (e.g., weights of evidence approach)?
- Heat can be used as a tracer of groundwater flow, constraining our understanding of water resources.
- Permeability in shallow strata is an analog for deep permeability, but hydrothermal alteration must be accounted for. Identify patterns that can correlate with blind hydrothermal systems.
- Water is a necessary resource for geothermal energy development, so assessing this water availability will allow informed decisions when procuring water rights for power production.

Methods/Approach

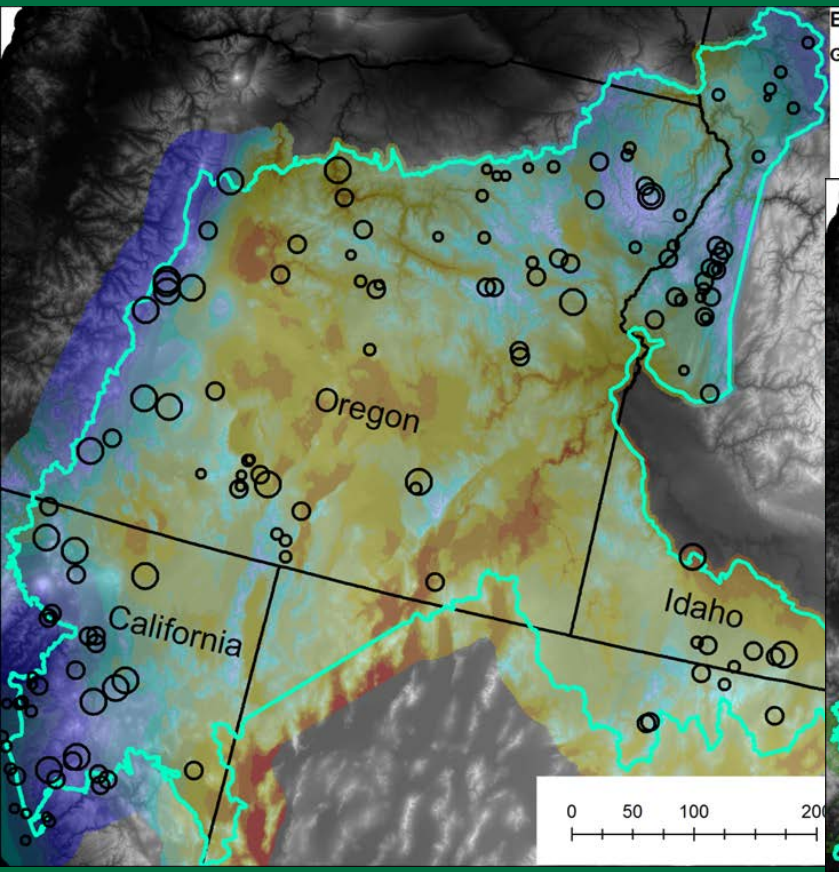
- Geologic/Hydrogeologic/Geothermal Framework Map Compilation
  - A thematic digital mosaic of state geologic maps has been compiled, reinterpreted, and improved for the purposes of identifying geologic patterns correlated to geothermal and water resources. Volcanic ages and composition are correlated with thermal history and heat source emplacement within the crust. Also, there are correlations between age of volcanic units and permeability, with a reduction in permeability as alteration to clay occurs over geologic time.
- Geothermal Database Compilation/Preparation
  - Construction of a geothermal database to allow statistical analysis of existing heat flow data in the context of the new geologic, hydrologic, and geothermal framework.

Methods/Approach (continued)

- Statistical Analyses and Derivative Maps
  - Correlations and associated causative relations between geology and groundwater flow are being established to improve understanding of geothermal and water resource potential. A series of maps and reports are being produced that summarizes study findings, and that will serve as the foundation for continued studies of geothermal resources of the region. The maps will form the foundation for future phases of study where a geothermal framework is created that accounts for thermal history of the province and advection of heat by groundwater.
- Feedback with Phase 2 and 3 Play-Fairway studies
  - As geophysical surveys and other play-fairway study tasks are completed for the southern WA Cascades and for the Snake River Plain, the information gained are evaluated and compared against NVASA study findings

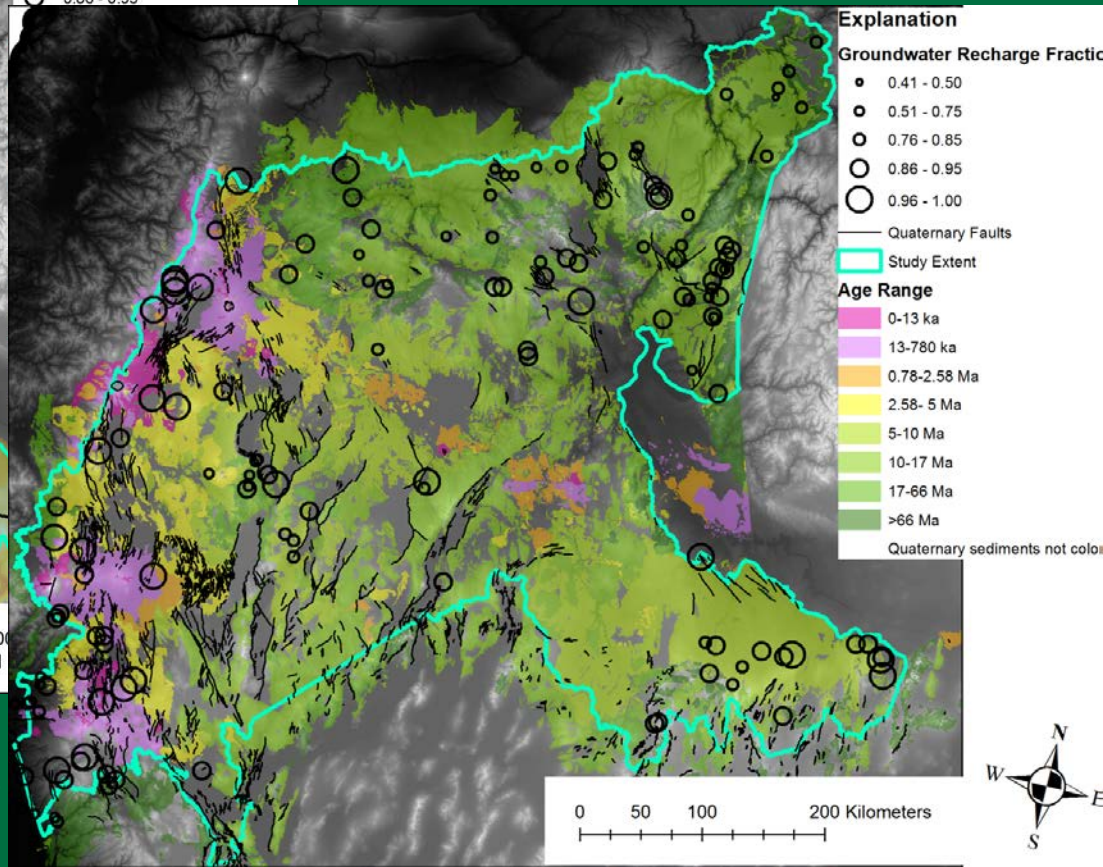
Young volcanics (<2.58 Ma) are correlated with regional-scale permeability

Precipitation



Geologic Age

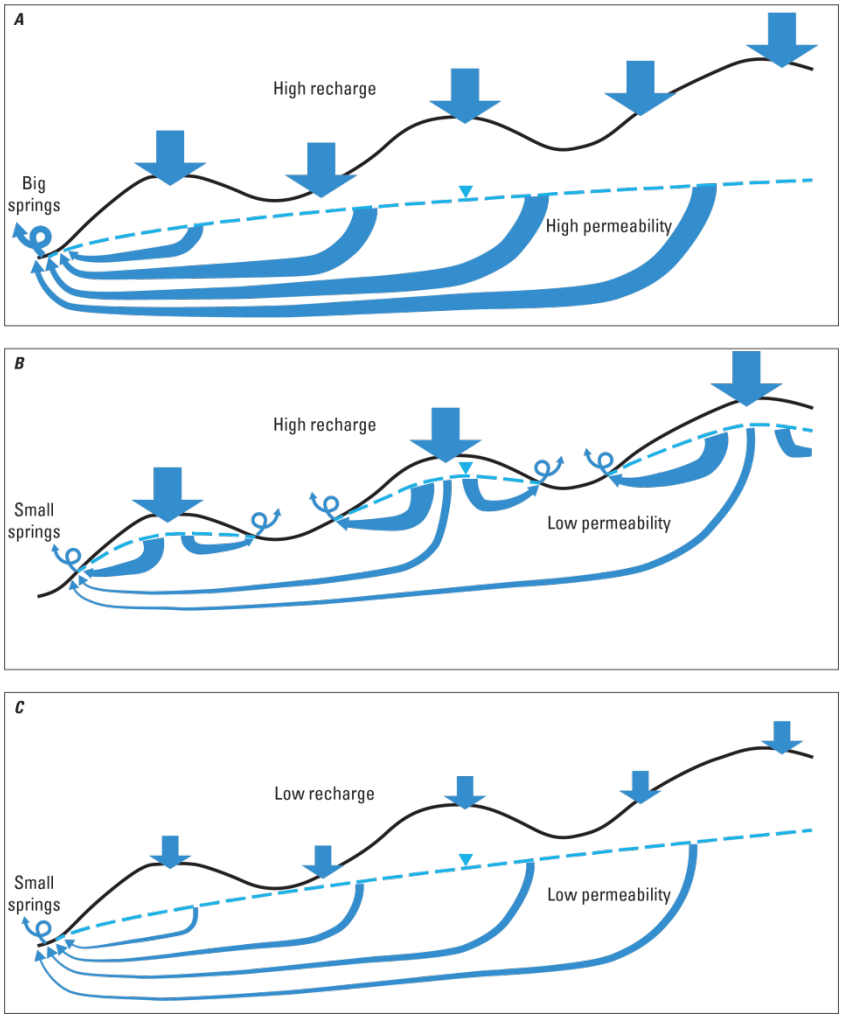
(Sherrod and Keith, 2017)



USGS

Figs 2 and 3 from Burns and others (2017a)

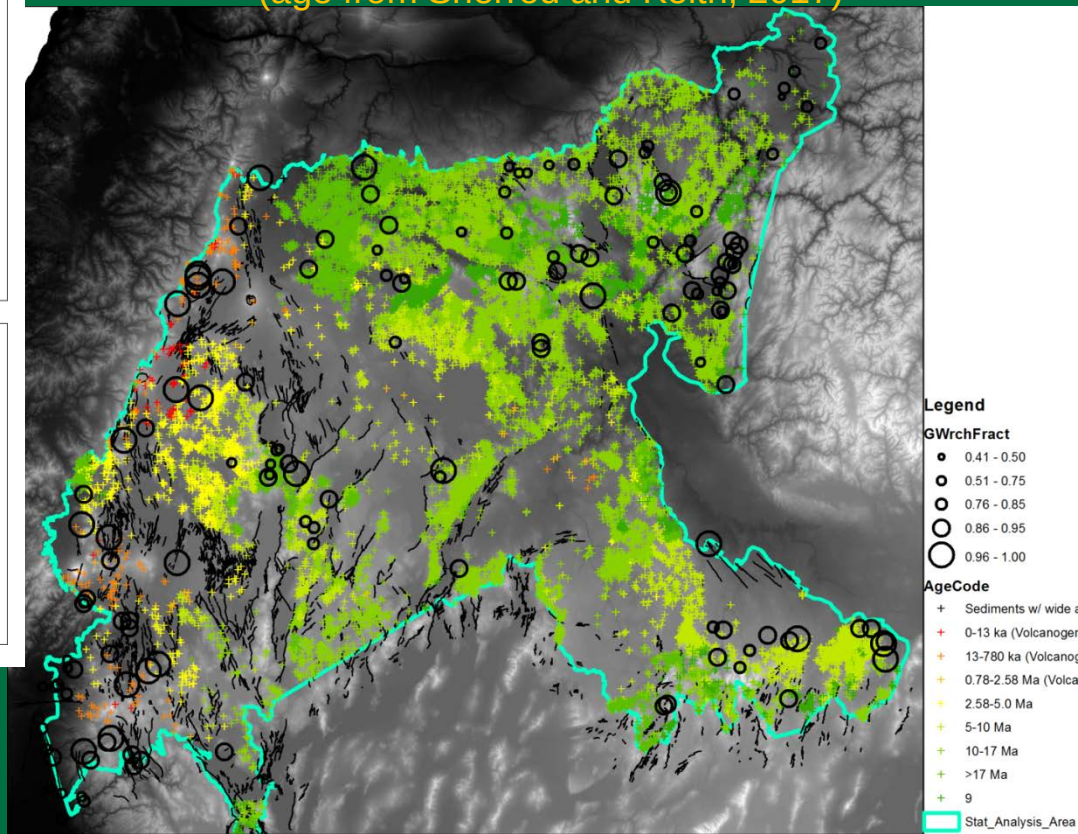
Spring density is a proxy for flowpath length



Springs conceptual diagram

Spring density colored by geologic age

(age from Sherrod and Keith, 2017)



USGS

Figs 1 and 4 from Burns and others (2017a)

Technical Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The seven items in this table are reiterated from the Milestones and Deliverables from the Agreement.

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Multi-State Geologic Map Compilation covering NVASA (Milestone)	Construction of map(s) and new interpretation/grouping for statistical analysis. Re-interpretation of existing geologic maps into age/composition groups that are appropriate for analysis of correlation with hydrogeology and geothermal potential.	November 2016
Thematic Interpretation of Geology for NVASA (Publication)	USGS-published multi-state geologic dataset with 4 new interpretive themes (age, composition, lithology, hydrologic groups) to support statistical analyses of groundwater and geothermal resources.	Bureau-approved Sep 2017, so is now citeable
Geothermal Database Compilation for NVASA (Milestone)	Successful collection of available geothermal data and evaluation of quality of data to assess how it may be used during statistical analyses.	Preliminary complete Feb 2017, iterative refinement
Statistical Analysis of Permeability & Groundwater Flow within NVASA (Milestone)	Establishment of correlations between age/composition and various additional metrics of regional groundwater flow	Ongoing. Started ahead of schedule (May 2017).
Hydrogeologic Framework Maps (Anticipated Publication)	Generalized hydrogeologic framework map showing the distribution of geologic units that control regional groundwater flow patterns, which influence geothermal heat flow	In Progress (Due Date is Dec 2017)
Summary Report/Article (Anticipated Publication)	Documentation of statistical analysis resulting in development of the hydrogeologic framework	In Progress (Due Date is Dec 2017)
Geothermal Industry Publication & Presentation	GRC Paper summarizing thematic interpretation of geology and implications for the geothermal resource potential of the region	Oct 2017 GRC Annual Meeting

+ one extra… Burns and others (2017b)

Research Collaboration and Technology Transfer

- Engaging with SRP and WA Play-Fairway studies.
- Published new USGS maps with refined/improved categorization of volcanic age and composition for the region (plus additional categories)
- Presentation of conceptual models of permeability at GRC conference.
- Models and tools are archived and published:
  - Medicine Lake Volcano model (Burns et al. 2017b) is archived by USGS. This model uses a Python tool (freely available as electronic supplementary material from the journal [Burns et al., 2016] or from USGS).
- Fourteen related presentations during the period-of-performance (see Project Summary document for the list)

Future Directions

- Key activities for the rest of the period of performance (ends Jan 2018).
  - Complete the statistical analysis of permeability patterns related to geologic controls (first draft of publication anticipated Dec 2017)
  - Complete interpretive maps of permeability patterns (i.e., hydrogeologic framework; first draft anticipated Dec 2017)
- The future depends on continued support by USGS ERP and WAUSP (and DOE GTO?), but the FY18-20 plan is:
  - Continued regional analysis, including using the newly compiled geothermal database and new maps of permeability. In particular, can we develop new variables with explanatory power to refine geothermal resource maps?
  - Initiate a focus area study for the region between Medicine Lake Volcano and Lassen Peak, including numerical modeling of 3D heat and fluid flow.
  - Piggy-back geothermal study components onto a groundwater focus area study of the Harney Basin (this groundwater study is funded under a separate USGS program, in cooperation with the State of Oregon)
  - Synthesize the above focus area studies with the continued regional analysis

Summary Slide

- As part of ongoing joint DOE/USGS research, additional data are being compiled and analyzed under the current project to improve prospectivity of geothermal resources and to improve regional estimates of geothermal resource potential
  - Developed a new multi-state thematic map with updated and improved interpretation of volcanic history within the NVP (i.e., thermal history)
  - Interpreted permeability patterns within the study area and described implications for geothermal resource development
  - Compiled a geothermal database for continued future analysis
  - In progress for publication…
    - Statistical analysis of permeability as a function of geology
    - Interpretative maps of hydrogeologic sub-regions related to modes of permeability and resulting advective heat transport patterns

References

- Burns, E.R., Gannett, M.W., Sherrod, D.R., Keith, M.K., Curtis, J.A., Bartolino, J.R., Engott, J.A., Scandella, B.P., Stern, M.A., and Flint, A.L. (2017a) *Geothermal Implications of a Refined Composition-Age Geologic Map for the Volcanic Terranes of Southeast Oregon, Northeast California, and Southwest Idaho, USA*, GRC Transactions, Vol. 41.
- Burns, E.R., Ingebritsen, S.E., Manga, M., and Williams, C.F. (2016a) *Evaluating Geothermal and Hydrogeologic Controls on Regional Groundwater Temperature Distribution*, Water Resources Research, DOI: 10.1002/2015WR018204.
- Burns, E.R., Williams, C.F., Ingebritsen, S.E., Voss, C.I., Spane, F.A., and DeAngelo, J. (2015) *Understanding Heat and Groundwater Flow through Continental Flood Basalt Provinces: Insights Gained from Alternative Models of Permeability/Depth Relationships for the Columbia Plateau, USA*, Geofluids 15, (2015), 120–138, doi: 10.1111/gfl.12095.
- Burns, E.R., Williams, C.F., Tolan, T., and Kaven, J.O. (2016b) *Are the Columbia River Basalts, Columbia Plateau, Oregon and Washington, USA, a Viable Geothermal Target? A Preliminary Analysis*, PROCEEDINGS, v41, Forty-first Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 22-24, 2016.
- Burns, E.R., Zhu, Y., Zhan, H., Manga, M., Williams, C. F., Ingebritsen, S. E., and Dunham, J. B. (2017b) *Thermal effect of climate change on groundwater-fed ecosystems*, Water Resour. Res., 53, 3341–3351, http://dx.doi.org/10.1002/2016WR020007.
- Sherrod, D.R., and Keith, M.K. (2017) *Geologic Map Showing Distribution, Composition, and Age of Cenozoic Volcanic Rocks of the Pacific Northwest Volcanic Aquifer System Study Area*, U.S. Geological Survey Data Series 2017-XXXX, (2017, in review, IP-085787), XX p., XX sheets, http://dx.doi.org/10.3133/ofr20XXXXXX.
- Williams, C.F., and DeAngelo, J. (2008) *Mapping geothermal potential in the western United States*. Transactions of the Geothermal Resources Council, 32, 181–8.
- Williams, C.F., and DeAngelo, J. (2011) *Evaluation of approaches and associated uncertainties in the estimation of temperatures in the upper crust of the Western United States*, Trans. Geoth. Resources Council, v. 35.
- Williams, C.F. (2010a) *Challenges in the assessment and classification of Enhanced/Engineered Geothermal Systems resources*, Trans. Geoth. Resources Council, v. 34, p. 485-490.
- Williams, C.F. (2010b) *Thermal energy recovery from Enhanced Geothermal Systems – evaluating the potential from deep, high-temperature resources*, Proceedings, 35th Workshop on Geothermal Reservoir Engineering, Stanford University, 7p.
- Williams, C.F., Reed, M.J, DeAngelo, J., and Galanis, S.P., Jr. (2009) *Quantifying the undiscovered geothermal resources of the United States*, Trans. Geoth. Resources Council, v. 33, p. 995-1003.
- Williams, C.F., Reed, M.J., Mariner, R.H., DeAngelo, J., Galanis, S.P., Jr. (2008a), *Assessment of moderate- and high-temperature geothermal resources of the United States*: U.S. Geological Survey Fact Sheet 2008-3082, 4 p.
- Williams, C.F., Reed, M.J., and Mariner, R.H. (2008b), *A review of methods applied by the U.S. Geological Survey in the assessment of identified geothermal resources*: U.S. Geological Survey Open-File Report 2008-1296, 27 p.