Subsurface Characterization of Thermal Springs in Cascade Range and Olympic Mountains, WA using Multiple Mineral Equilibria Geothermometry

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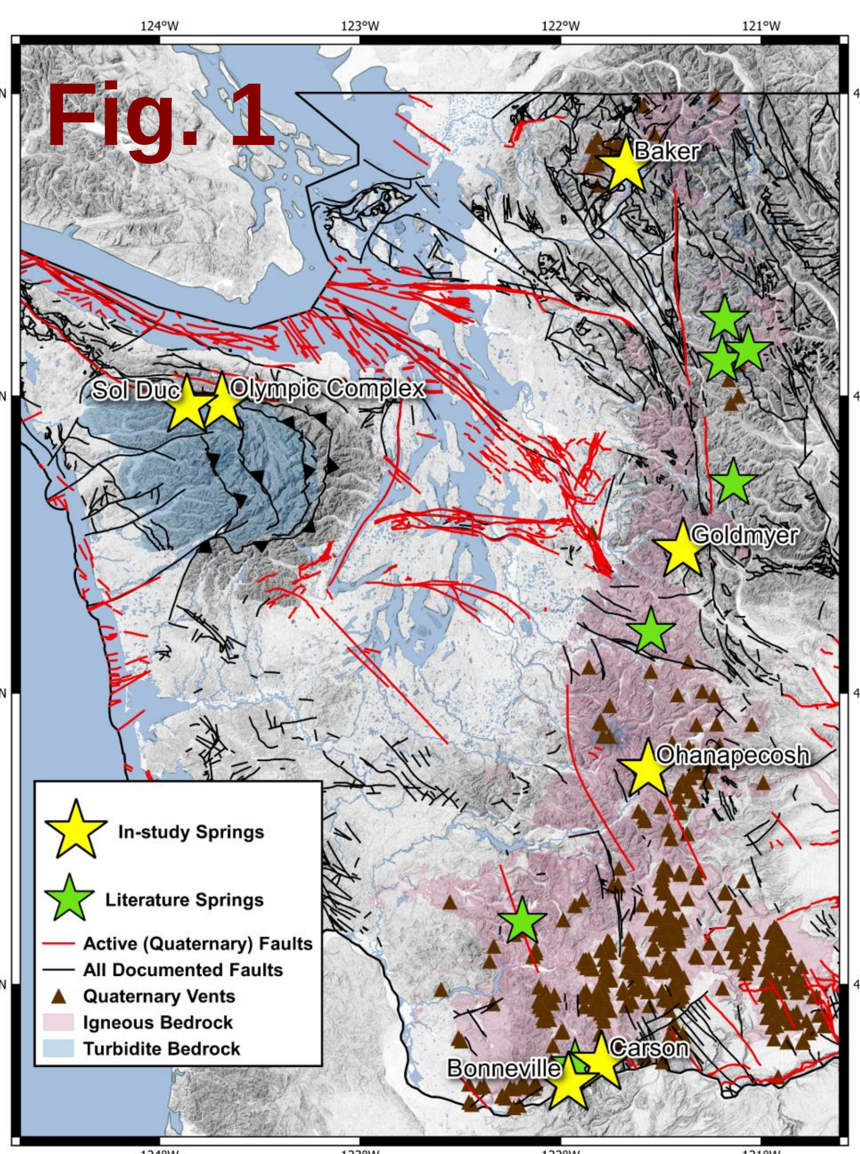
Abstract

This study aims to characterize the geothermal fluid flow paths of thermal springs in the Washington Cascades and Olympics through mineral-fluid equilibria, the geologic settings, and fluid discharge rates. All calculations were done through SOLVEQ.

The geothermal fluids feeding the Cascade springs appear to undertake an indirect or variable path to the surface, as reflected by their variable flow rates, greater temperature difference between surface and reservoir, and by evidence of mineral-water disequilibria. On the other hand, the more fully-equilibrated, stronger-discharging Olympic waters appear to have cooled to a lesser extent during upflow through subvertical, thrust-imbricated turbidites, which provide a more direct connection between the reservoir and the springs.

Study Area: Geology and Background



GIS Data Source: https://test-fortress.wa.gov/dnr/protectiongisqa/GeologyV2/portal/

Refer to **Fig. 1**

- Yellow stars denote sampled sites
- Some literature springs are incorporated to obtain better representation of Cascade springs

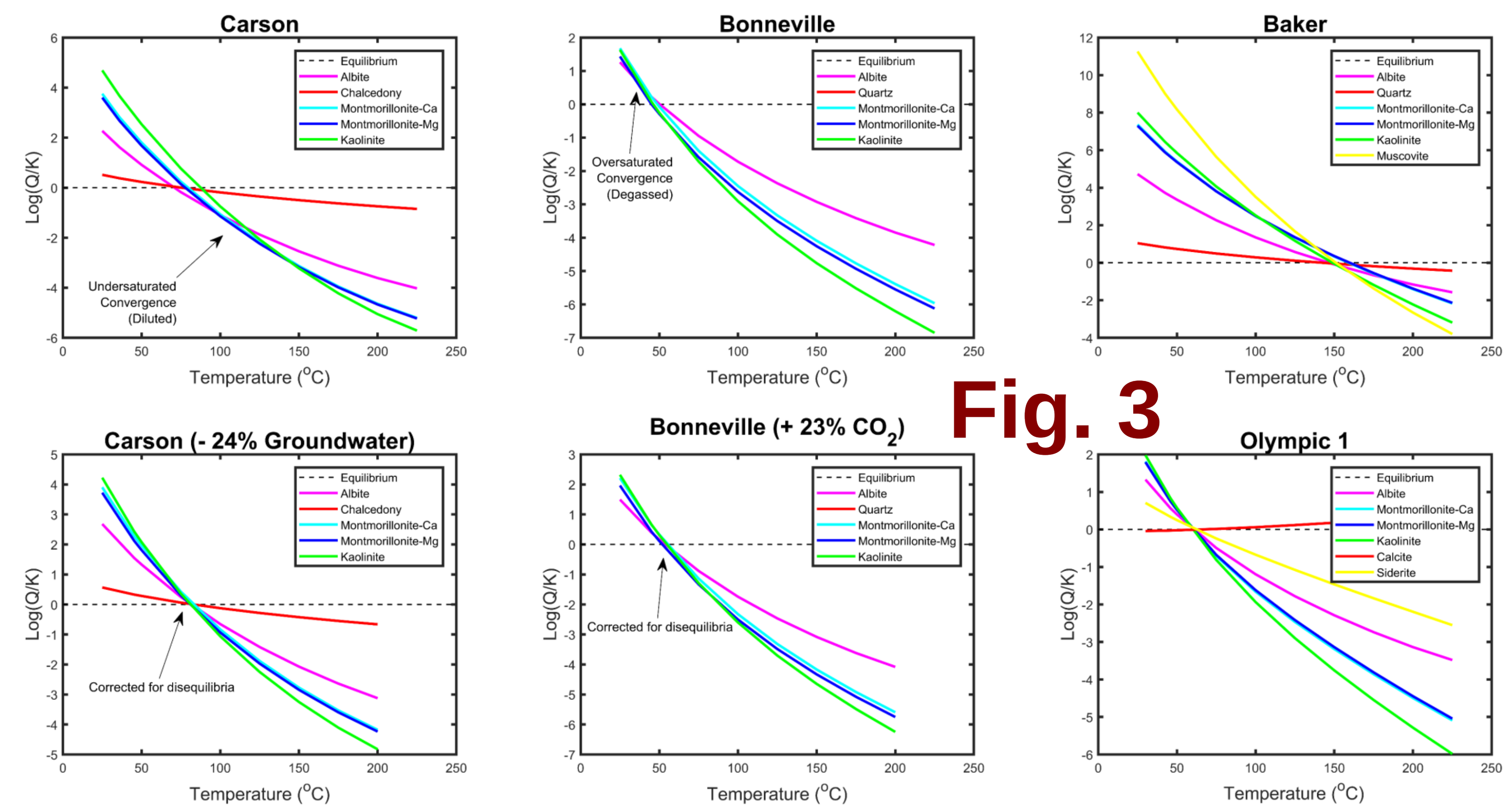
Cascades

- Predominantly igneous hostrock
- Structurally complex, but may not have much recent activity to facilitate permeability
- Vents are widespread but more concentrated in southern part, where extrusion rates are higher

Olympics

- Marine sedimentary (turbidites w/ carbonates, metasediments)
- Surrounded by active faults
- All thermal springs are featured in this study and are hosted by Pre-Quaternary subvertical faults

Some photos from sampling and lab work:



Conclusions: Flow Paths and Spring-Reservoir Connectivity

Cascades = more indirect connection to subsurface

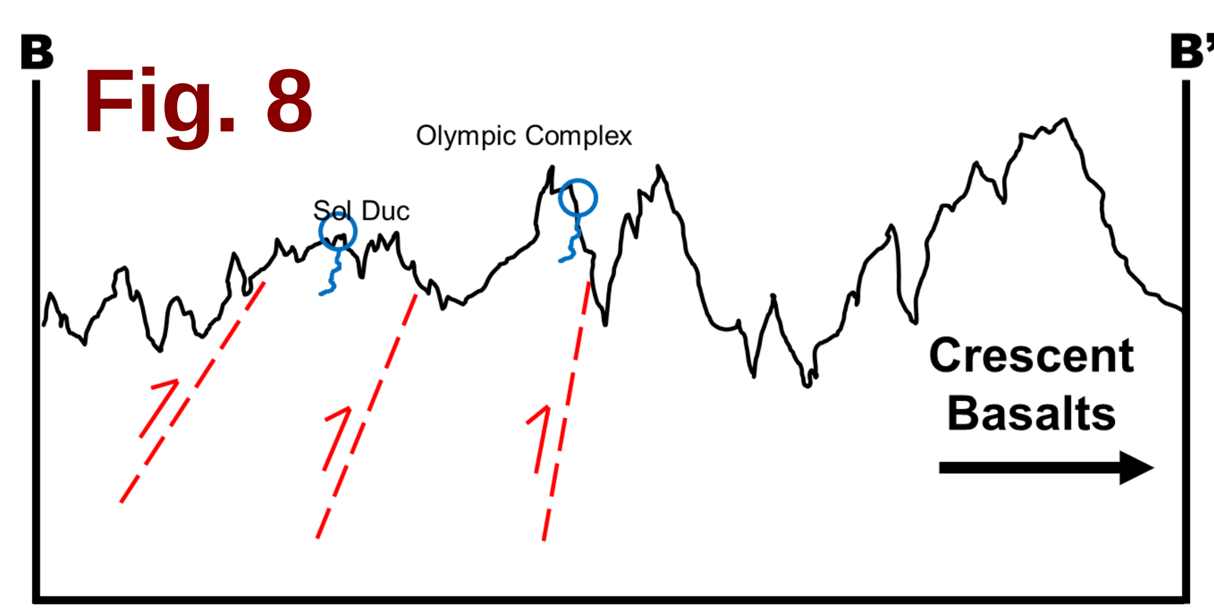
- Slow flow rates, disequilibria, larger temperature differences **(Figs. 3-6)**
- Flow paths controlled and may be complicated by fracture network made by young intrusions **(Figs. 1 and 7)**
- Springs in southern Cascades may be undertaking most variable pathway – furthest from equilibrium **(Fig. 6)**

Olympics = more directly linked to reservoir

- Faster flow rates, fully-equilibrated, relatively small temperature differences **(Figs. 3-6)**
- Permeability control (widely-spaced, subvertical, imbricated thrusts) is more 'straightforward' **(Figs. 1 and 8)**

Future Work

- Ground-truth initial work by looking at other geothermal systems with known constraints (shallow vs deep, low-temp vs high-temp, two-phase vs liquid, etc.)
- Improve conceptual models with better structural constraints, especially knowledge of northwestern Cascade intra-arc tectonics



Data and Results: Geothermometry

- Water chemistry from previous work (Golla and Tepper, 2017)
- Springs range from upflow-outflow types **(Fig. 2)**
- Multiple Mineral Equilibria (MME) estimates generally fall within ranges projected by most conventional geothermometers **(Fig. 3)**
- Note that MME investigations pertains to *last* rock-water equilibration/reaction **(Fig. 3)**
- The average difference between reservoir and discharge temperatures is greater in the Cascades ($\bar{x}_{difference}$: 53 °C vs 27 °C; **Figs. 4 and 5**)
- Carson, Bonneville, and some other Cascade waters show evidence of chemical evolution since ascent; undersaturation = dilution; oversaturation = degassing **(Figs. 3 and 6)**
- Relative to Olympic waters, Cascade springs have significantly weaker discharge/flow rates **(Fig. 6)**

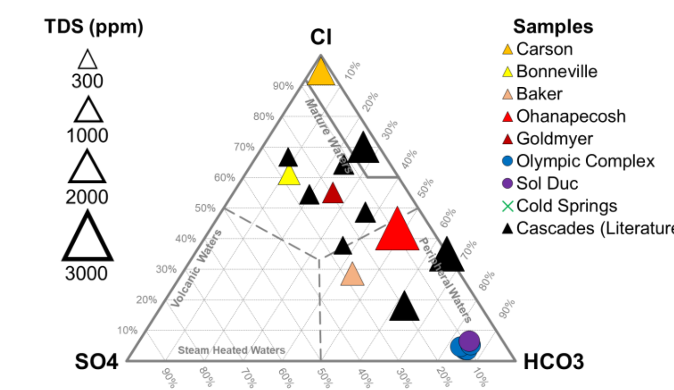
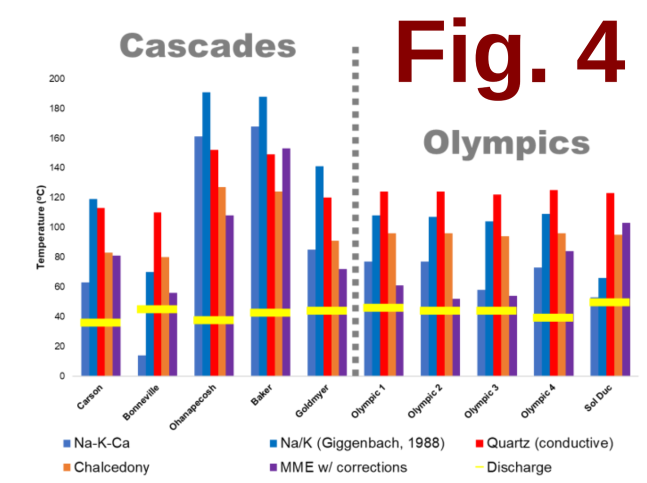
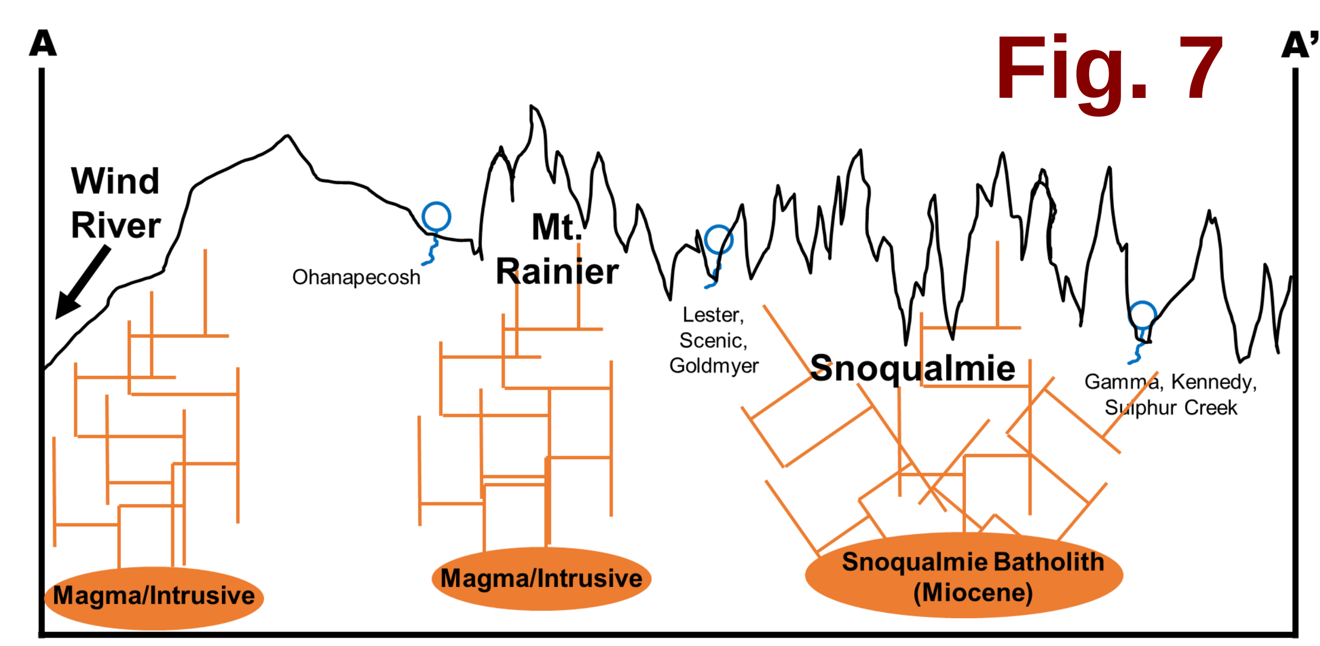


Fig. 2





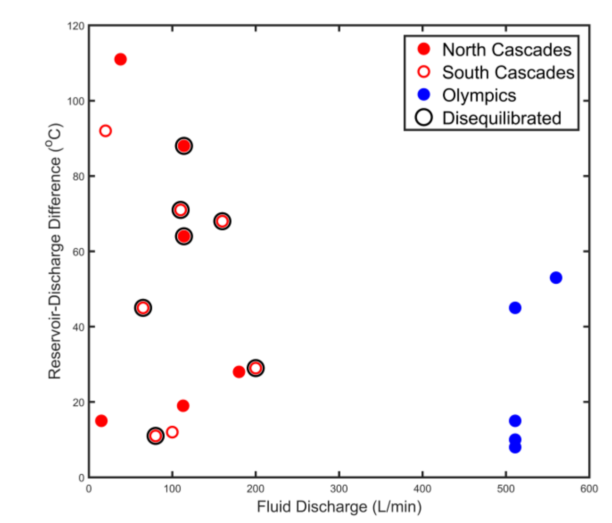
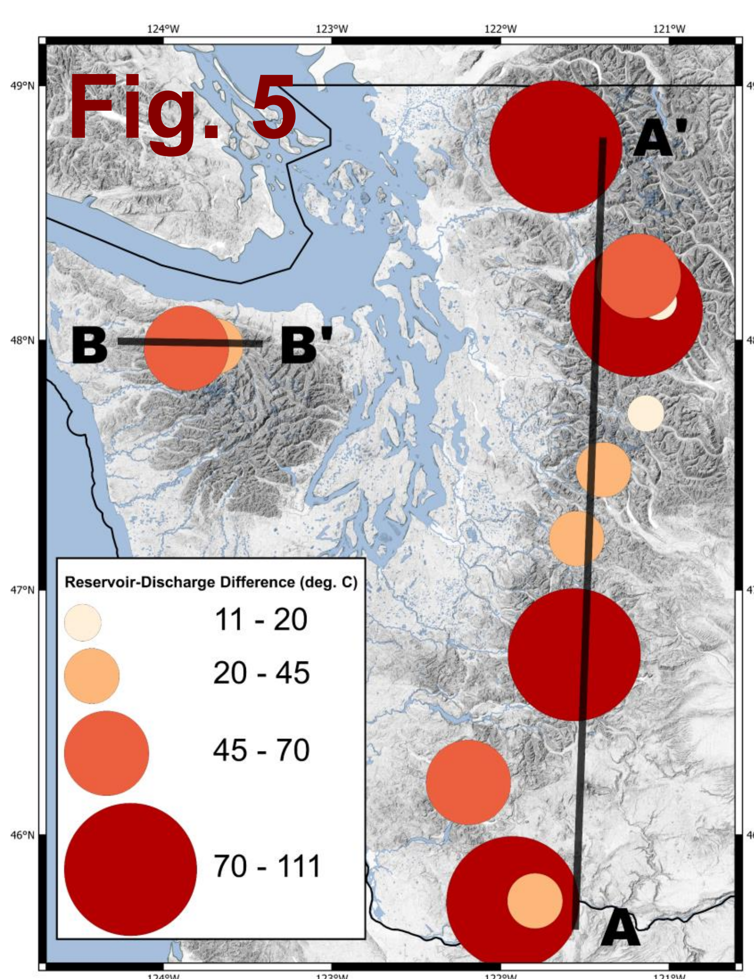


Fig. 6



Acknowledgements

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