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A Review of Shallow Temperature Surveys for Geothermal Exploration in the Great Basin and their Contributions to Resource Conceptual Models

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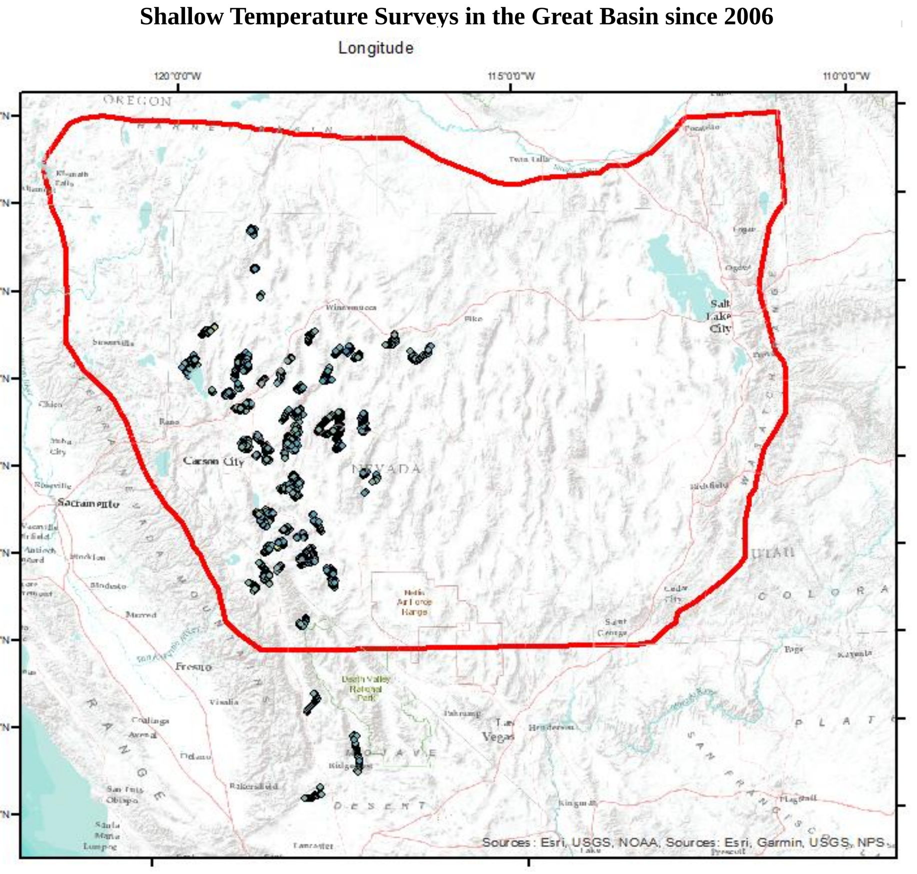
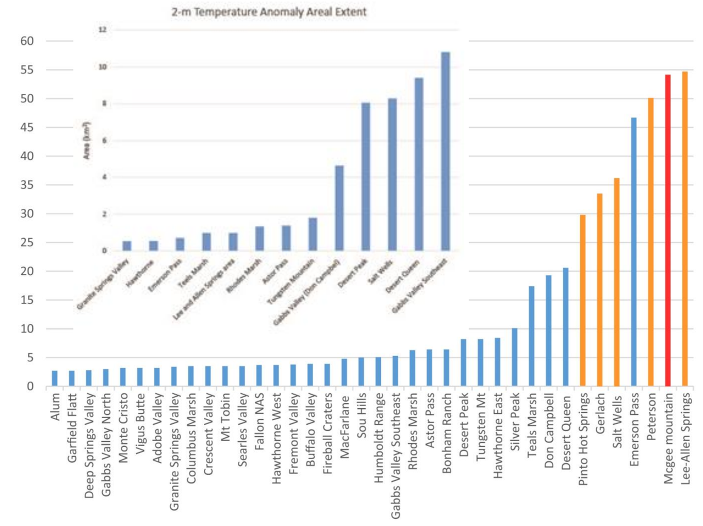
Abstract

Over the past 40+ years, shallow (2-meter) temperature surveys have been employed in the Great Basin region of the western United States for the exploration of geothermal energy resources. This technique has proven to be effective for mapping the extent of shallow thermal anomalies due to geothermal upwelling and outflow in arid environments, particularly where shallow, cold groundwater does not mask the thermal signatures. Several approaches have been developed to increase the effectiveness of these surveys, related to survey equipment design, survey grid geometry, and advanced processing techniques, such as correcting for the effects of seasonal temperature cycles, variations in albedo, thermal conductivity, and elevation. In this poster, we present a compilation of regional 2-meter temperature data assembled for the INGENIOUS project funded by the U.S. DOE. We review several examples of shallow temperature surveys and discuss their contribution to geothermal conceptual models at those locations. We also present the results of a new 2-meter temperature survey from 2021 collected for the INGENIOUS project at a "blind" geothermal prospect: Granite Springs Valley, NV. At Granite Springs Valley (GSV), we collected 85 shallow temperature measurements between June and July 2021. At this location we observed a subtle thermal anomaly with temperatures about 2.5-3 °C above background. Along with supplemental data from shallow temperature gradient wells, geologic mapping, and geophysics, we provide a case study demonstrating how to incorporate these data into the geothermal conceptual model for GSV. In addition to the new case study, we also reviewed the past uses of the technique, and how the method is incorporated into conceptual models, by providing information about the possible upflow and outflow locations of geothermal fluids. Lastly, we reviewed the compiled data at a regional scale to investigate the magnitude of a typical geothermal anomaly at sites with confirmed geothermal activity, and the typical dimensions of a shallow thermal anomaly in map view.

Survey Compilation Summary

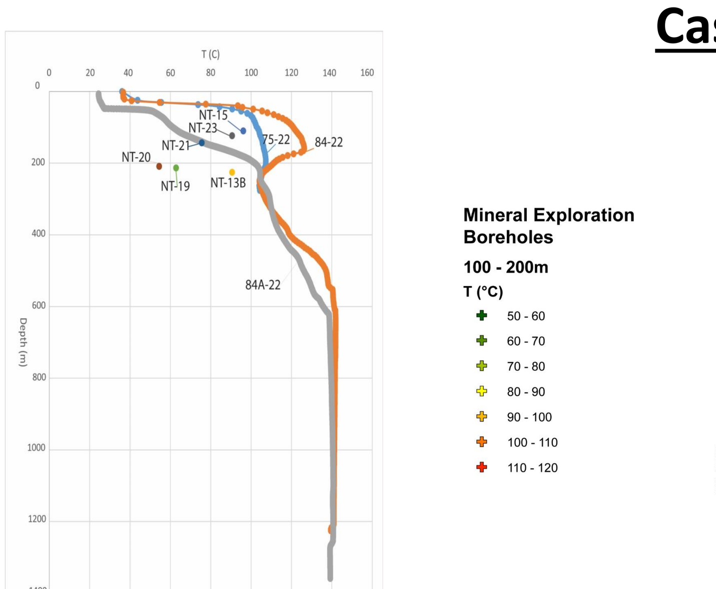
Shallow Temperature Surveys in the Great Basin since 2006

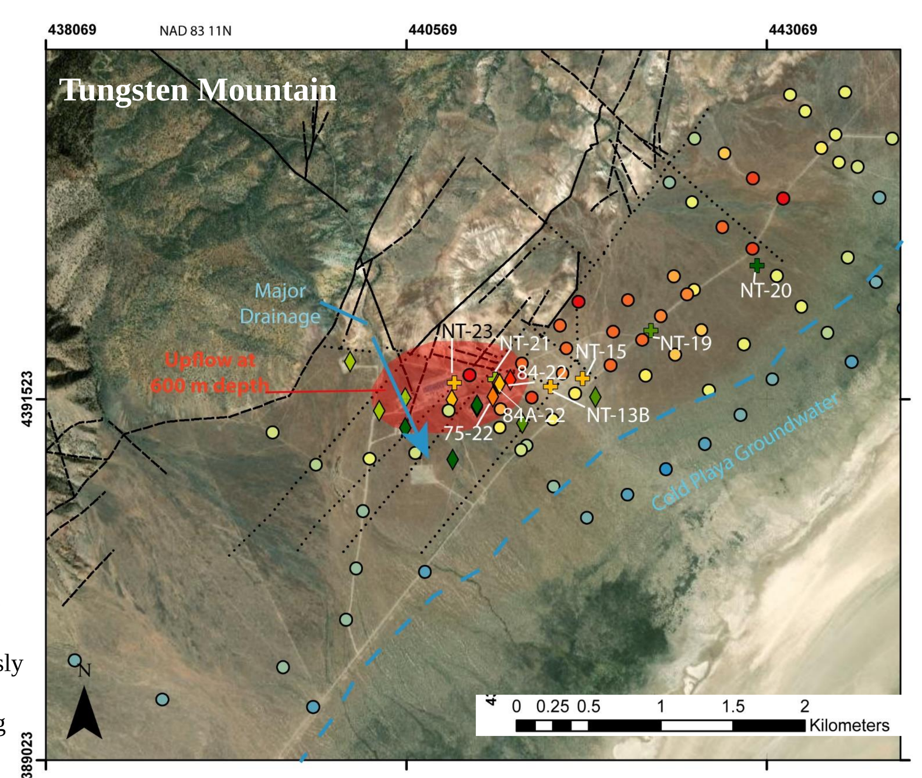


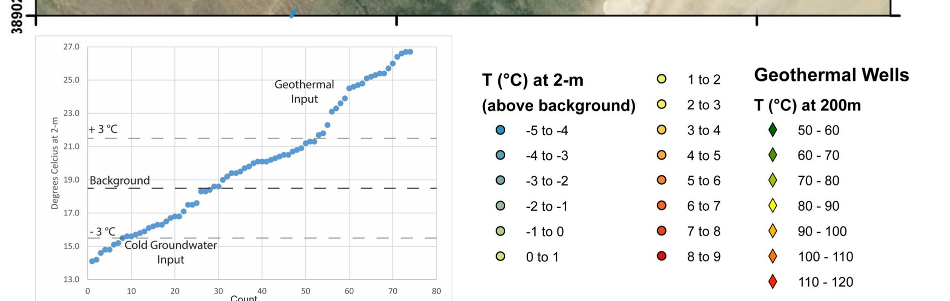


- 3801+ 2-m measurement locations
- 60+ survey areas
- Key role in discovering several blind systems: Teels Marsh, Rhodes Marsh, southwest Columbus marsh, East Hawthorne, Emerson Pass, Gabbs Valley SE, and more
- Typical thermal anomalies range from 3-8 °C, but, with shallow outflow and low-conductivity sediments, can be 20 °C
- Near hot springs or fumaroles, 2-m anomalies can be as high as 55 °C above background
- 2-m thermal anomalies range from <1 – 10 km² in area

Case Studies



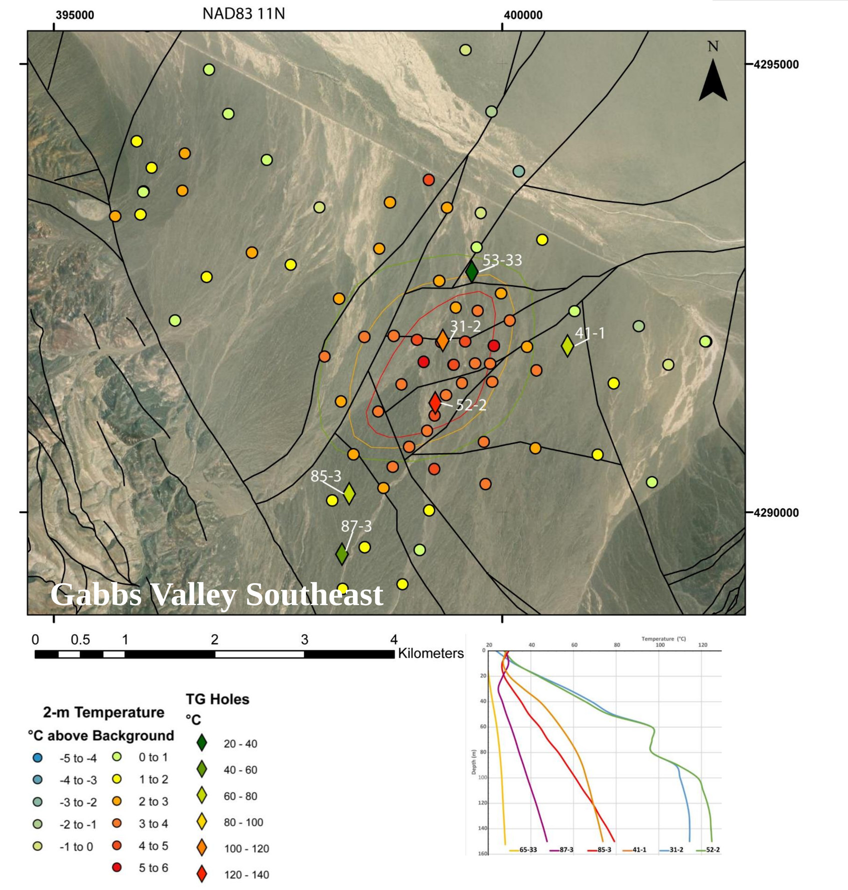




Tungsten Mountain:

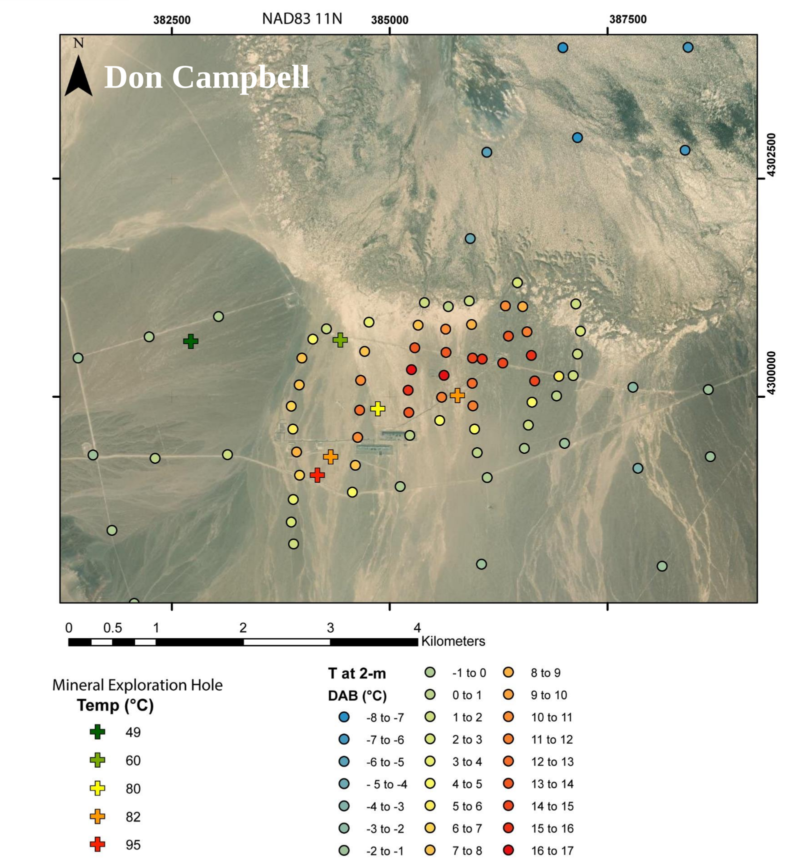
- The thermal anomaly at Tungsten Mountain was discovered in 2005-2006 by gold exploration holes (<300 m)
- In 2007, Kratt et al. (2008) identified a 5-km long zone of anomalously high 2-m temperatures
- In 2011, Ormat Nevada Inc. conducted additional exploration drilling → geothermal power production (online in 2017) 37 MWe installed capacity) (Delwiche et al., 2018)
- Primary upflow (red area) occurs at the intersection of NE and W-SW trending faults within the basement rocks
- A shallow outflow plume (125 °C at 150 m) is the source of the temperature anomaly
- Cold groundwater from an adjacent drainage inferred to suppress the shallow temperature to the W, and cold groundwater in the playa is thought to suppress the shallow temperature to the SE (Kratt et al., 2008)

Case Studies



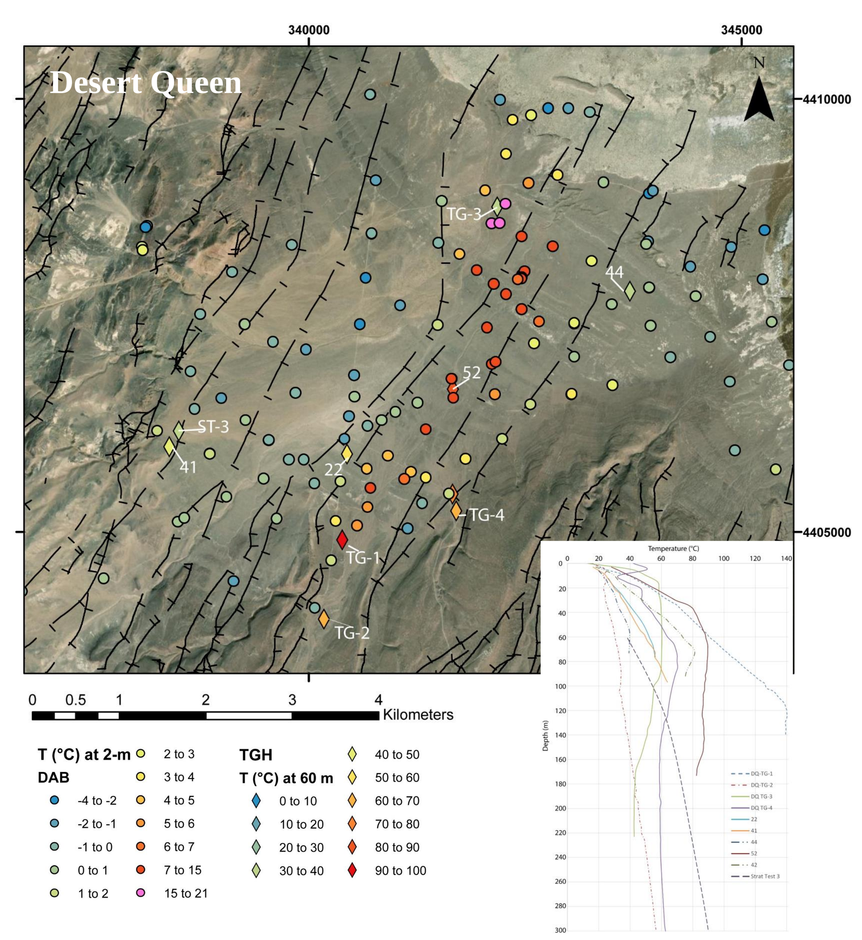
Gabbs Valley Southeast

- One of 4 shallow temperature anomalies in Gabbs valley discovered in 2016 by the 2-m survey during the Nevada Play Fairway project
- Geologic mapping and geophysical surveys revealed a fault intersection within a broader displacement transfer zone which underlie the shallow thermal anomaly
- Six temperature gradient wells were drilled, and identified a 125 °C near-isothermal zone at 110 m
- Craig et al. (2021) developed a resource conceptual model and power density estimates following the methods of Cumming (2016) and Wilmarth et al., (2020)
- The 2-m temperature survey was utilized to infer the geometry of the shallow outflow plume and the most probable location of upflow



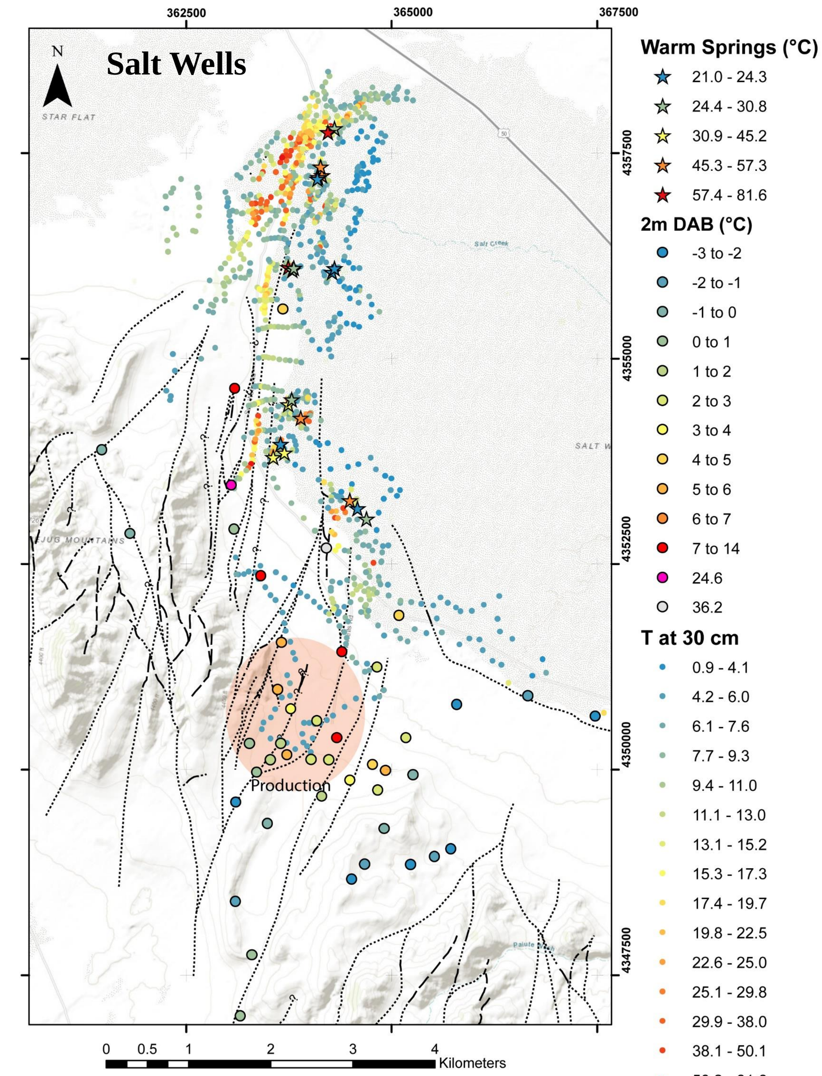
Don A. Campbell

- Operated by Ormat Nevada, Inc, a blind geothermal system originally identified by several mineral exploration holes
- Kratt et al. (2010) performed a 2-m survey that identified a thermal anomaly ~ 4km km long with temperatures as high as 17 °C above background
- Exploration drilling by Ormat in 2010 measured temperatures as high as 130 °C at 60 m., along with argillic and siliceous alteration (Orenstein and Delwiche, 2014)
- ORC units have a combined 47.5 MWe nameplate capacity as of 2020 (Muntean et al., 2021)



Desert Queen

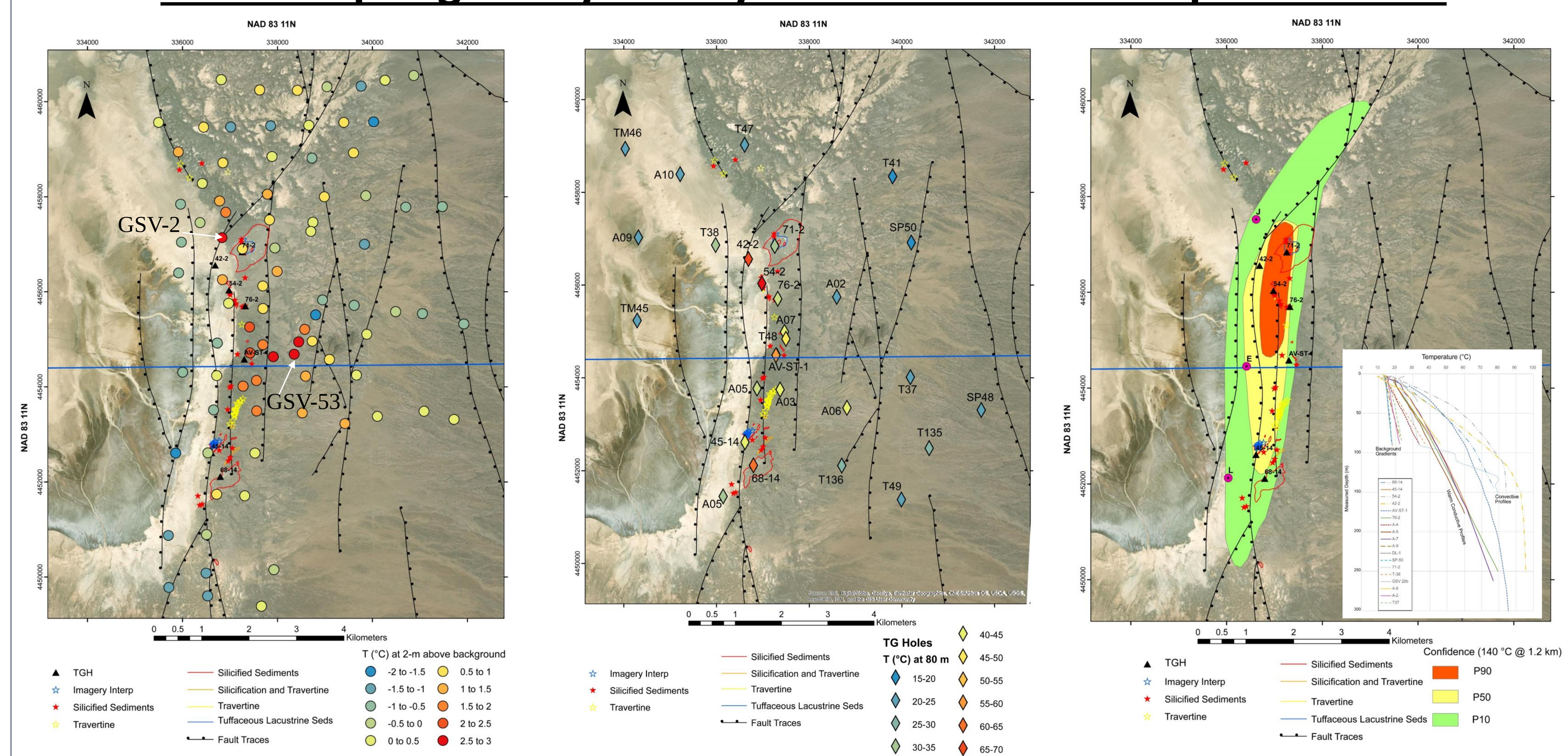
- Early TGH drilling identified a relatively shallow thermal outflow plume at 60 m depth → Sladek and Coolbaugh (2013) tested and develop 2-m temperature techniques here
- Two shallow thermal anomalies were identified (2006 – 2009)
  - West: broad area with 2 °C above background
  - East: long and narrow with temperatures up to 20.6 °C above background (~5 km long x 2 km wide) making it one of the largest shallow thermal anomalies identified to date
- Recent geologic mapping by Dellerman (2021) who also performed local-scale play fairway analysis
- The primary structure inferred to control geothermal upwelling is the horse-tailing terminations and step-over between the Desert Queen fault to the northwest and the Power-Line fault to the southeast, corresponding to the highest measured temperature near at TG-1
- 2-m temperature anomaly is inferred to represent the outflow plume from a source near TG-1



Salt Wells

- Geothermal power plant began production in 2009, and as of 2020 is producing 7.7 MWe net with fluid production temperatures between 120-140 °C (Muntean et al., 2021), but max BHT recorded in the area is 181 °C at 2591 m.
- TGH drilling since the 1970s identified a 12-km long thermal anomaly
- Complex system of normal fault terminations, accommodation zones, and stepovers, with fault termination splays most associated with current thermal anomaly (Hinz et al., 2014; University of Nevada, 2014)
- 30-cm temperature probe measurements identified several thermal anomalies but were confined to areas with a near-surface water table (Coolbaugh et al., 2006)
- 2-m temperature survey targeting southern portion of field identified thermal anomalies that were not detected at 30 cm (Skord et al., 2011; 2012).
- The two hottest 2-m points are in the northern portion of the survey within 0.5 km of mapped hot springs and adjacent to 30 cm anomalies.

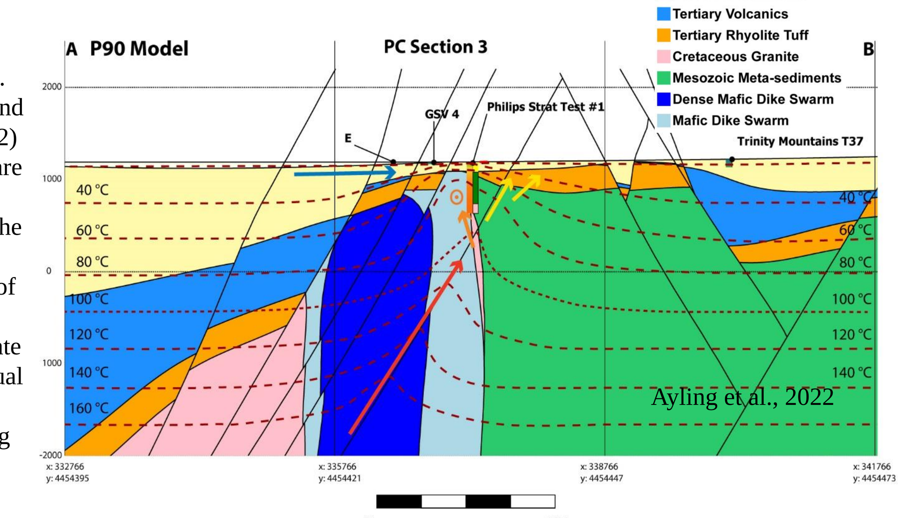
Granite Spring Valley Survey and Resource Conceptual Model



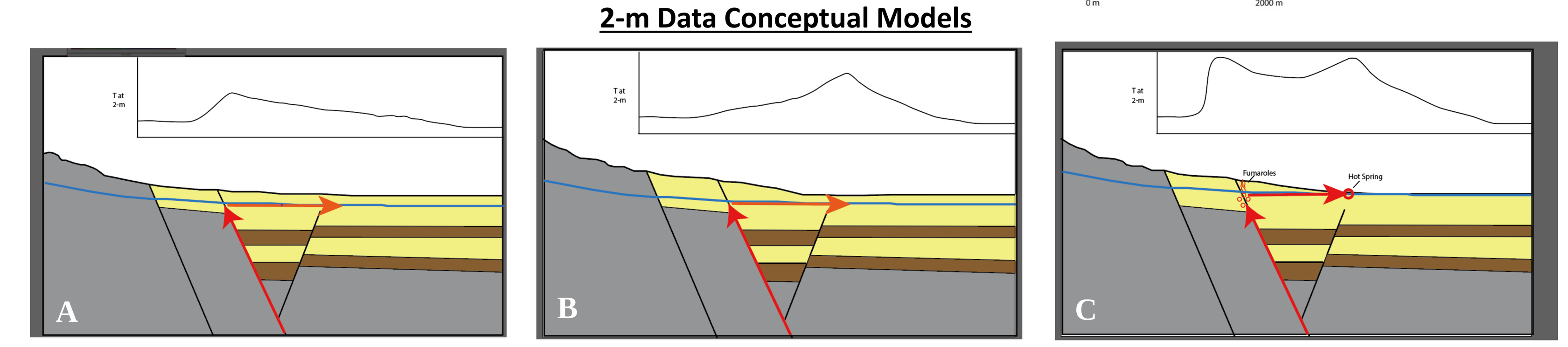
Granite Springs Valley

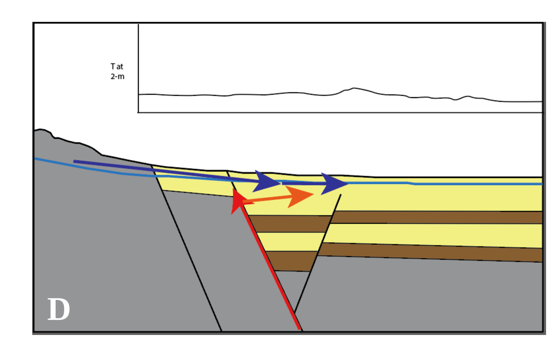
The Granite Springs Valley site is currently under detailed study as part of the INGENIOUS project following temperature gradient drilling in the NV Play Fairway project (2018). New data acquisition at the site includes a 2-m temperature survey conducted between June and August 2021. Additional accomplishments include reinterpretation and integration of detailed geologic and geophysical data into a 3-D geologic model, and integration of this 3-D model, temperature, geochemistry, paleo-geothermal deposits and hydrologic data into a resource conceptual model of the system (Ayling et al., 2022).

Due to the relative depth of the resource, and the effects of shallow cold groundwater, the 2-m temperature anomaly is relatively subdued compared to other 2-m survey (maximum measured temperature ~3 °C above background). Two shallow thermal anomalies were identified, one near GSV-2, and the second near GSV-53. The anomaly near GSV-2 is adjacent to the hottest TG hole (42-2) and is likely related to thermal outflow. Shallow temperatures west of GSV-2 are likely suppressed due to the presence of shallow cold groundwater near the surface of the Adobe Flat playa, and to the north due to a major drainage into the basin. The anomaly near GSV-53 was unexpected due to its presence up hydrologic gradient from the inferred controlling structures based on analysis of TGH data. One possible interpretation is that there is additional fracture permeability in a damage zone due to faulting allowing thermal fluids to migrate into the center of the inferred horst block. In the preliminary resource conceptual model, the 2-m temperature measurements were interpreted to represent the shallow portion of the geothermal system and were used to infer the controlling structures.



2-m Data Conceptual Models





Figures adapted from Richards and Blackwell (2002) and Skord et al. (2011)

A. Simplest case: shallow thermal anomaly is observed, highest temperatures correspond to the location of the primary upflow.
B. Common case: depth to the thermal outflow plume controls the magnitude of the 2-m temperature anomaly, warmest temperatures are observed up to several km from inferred upflow point (Desert Queen).
C. Active geothermal manifestations produces very high shallow temperatures due to convective heat transfer (Salt Wells, McGee Mountain, Lee-Allen and Gerlach hot springs)
D. Shallow cold groundwater masks a blind geothermal system. No negative examples are given, Tungsten Mountain → thermal anomaly is partially concealed (see TM section).

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Acknowledgements

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