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Characterization and Analysis of a Potential Hidden Geothermal Resource in the Jersey Summit Area, North-Central, Nevada

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ABSTRACT

The Great Basin region (GBR) in the western U.S. is known for prolific geothermal activity and has substantial geothermal resource potential due to its favorable tectonic setting. However, most of the geothermal systems in this region are probably hidden, with no surface manifestations such as hot springs or steam vents. These hidden systems can be challenging to discover using traditional exploration methods, prompting new multidisciplinary approaches that are able to increase the ability to detect these untapped resources while decreasing the overall risk associated with geothermal exploration. For this study, we aim to better characterize hidden geothermal systems in the GBR using detailed structural analyses of designated field sites. Here, we focus on the Jersey Summit area, which includes southern Buffalo Valley and northern Jersey Valley in north-central Nevada. This site has been identified as having high potential for a hidden system based on an abundance of Quaternary faults and the presence of a major accommodation zone between the southward terminating, east-dipping Buffalo Valley normal fault zone and northward terminating, west-dipping Jersey Valley normal fault zone. Our objectives are to integrate multiple geological, geophysical, and geochemical datasets to establish the stratigraphic and structural framework of the Jersey Summit area, delineate the geometry and kinematics of the Quaternary fault systems, identify particularly favorable structural settings within the broader accommodation zone, define locations of thermal anomalies, and assign the most favorable targets for future temperature gradient drilling. Detailed geologic mapping incorporating new high-resolution lidar data, structural analysis, and 2-m temperature surveys were employed to identify the most highly prospective areas. These data suggest two particularly promising areas: 1) a broad left step-over in the southern part of the Buffalo Valley fault zone, and 2) a complex fault intersection between terminating strands of both the Buffalo Valley and Jersey Valley fault zones as well as a major east-striking, down-to-the south fault that transects the Tobin Range and projects into the accommodation zone toward a small left step in the northernmost segment of the Jersey Valley fault zone.

1. INTRODUCTION

The Great Basin region (GBR) of the Basin and Range province in the western U.S. has prolonged periods of Cenozoic extensional faulting and crustal thinning. It encompasses portions of Nevada, western Utah, southern Idaho, southeastern Oregon, and eastern California (Figure 1). In many areas, extension has continued through the Quaternary, resulting in increased geothermal gradients ranging from ~25°C/km to >70°C/km (Faulds et al., 2004; Coolbaugh et al., 2005; Blackwell et al., 2011). Faults generally control primary permeability pathways of geothermal systems (Caine et al., 1996; Micklethwaite and Cox, 2004), with permeability favoring areas of structural complexity (Curewitz and Karson, 1997; Blackwell et al., 1999; Faulds et al., 2004, 2012, 2015). This combination of high geothermal gradients and active faulting facilitates prolific geothermal activity throughout the GBR, allowing it to host numerous geothermal operations. Currently, the region produces ~1 gigawatt (GW) of geothermal energy (Robins et al., 2021). However, estimates suggest ~10 GWe of undiscovered geothermal resource potential lies within the GBR (Williams et al., 2008).

For decades, geothermal exploration has focused on areas with surface manifestations. In recent years, exploration efforts are shifting to hidden resources, as they present a largely untapped market. A hidden geothermal system has no surface manifestations of geothermal activity (e.g., warm/hot springs, fumaroles, mud pots, etc.). Despite abundant Quaternary faults in the GBR, ~39% of known geothermal systems are hidden with estimates suggesting that up to 75% of all geothermal resources in the region are hidden (Coolbaugh et al., 2007). This geothermal potential is greatest in areas that contain favorable structural settings characterized by increased structural complexity. Faulds and Hinz (2015) characterized and inventoried 426 known geothermal systems (>37°C) across the extensional to transtensional terrane of the Great Basin. This dataset was later refined for the state of Nevada (Faulds et al., 2021). Eight types of favorable structural settings were defined in these studies (Figure 2). Out of these eight settings, six accommodate the vast majority of known geothermal systems in the GBR, with hybrid systems (i.e., more than one favorable structural setting) generating additional structural complexity that can further enhance permeability (Faulds et al., 2013). However, the obscure nature of these hidden systems presents a challenge for exploration and new discoveries.

Thus, a multidisciplinary approach incorporating geological, geophysical, and geochemical datasets referred to as "play fairway analysis" has been under development to detect these hidden resources (e.g., Faulds et al., 2015, 2019; Siler et al, 2017; Wannamaker et al., 2017). The primary objective of implementing the play fairway methodology is to decrease exploration risk and enhance the probability of discovering valuable resources. The United States Department of Energy (DOE) launched the Geothermal Play Fairway Analysis (PFA) initiative in 2014 to examine and assess various approaches to geothermal exploration. One of the PFA studies analyzed about 1/3 of

Nevada and resulted in the assessment of several hundred favorable structural settings that would be most prospective for geothermal activity with several particularly promising sites examined in detail, which resulted in the discovery of two hidden systems (e.g., Faulds et al., 2019; Craig et al., 2021). The INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) project, funded in 2021 by the DOE, builds on the PFA approach, with an emphasis on hidden geothermal systems. Rather than only Nevada, however, INGNEIOUS incorporates the entire GBR with the central objective to expedite the discovery of economically viable hidden geothermal resources, while simultaneously mitigating the exploration and development risks associated with them (Ayling et al., 2022). A key contribution to this objective is through quantifying resource potential, uncertainty, and degree of exploration at several new hidden geothermal prospects in the Great Basin. Jersey Summit is one such potential hidden system, which was chosen for detailed analysis in the INGENIOUS project based on its high ranking in the initial play fairway analysis project across the central part of Nevada (Figure 1).

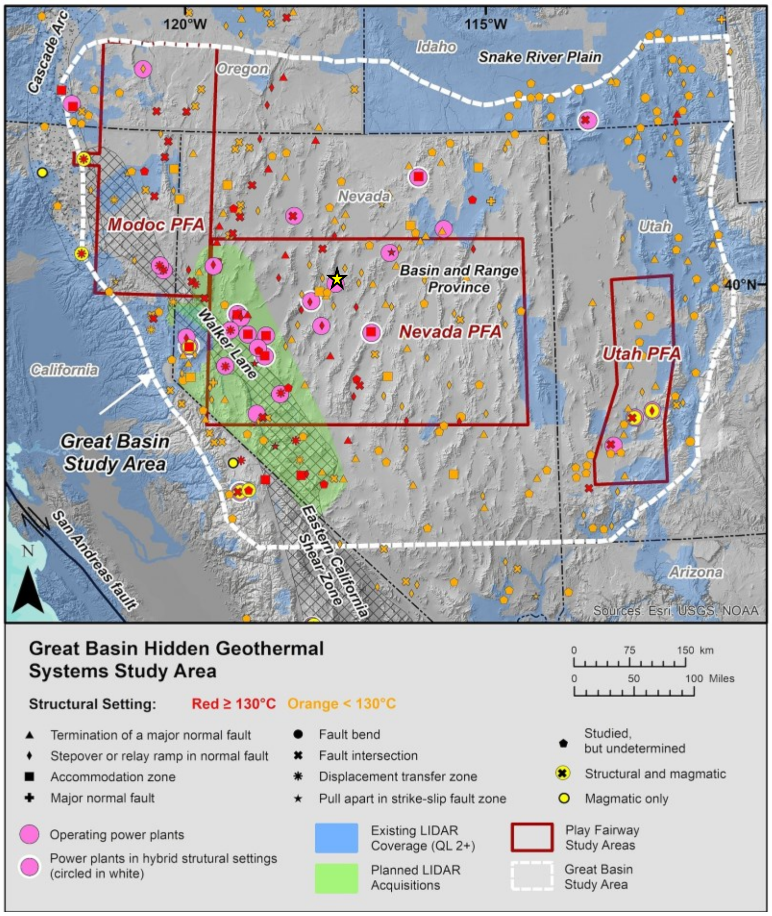

Figure 1: Map illustrating the Great Basin region of the western United States that will be evaluated during the INGENIOUS project. The white dashed line indicates the regional study area for the project; red boxes show the location of the previously completed play fairway projects in the region, and the yellow star marks the location of Jersey Summit (modified from Ayling et al., 2022).

2. GEOLOGIC FRAMEWORK

The Jersey Summit area is located ~50 km southwest of Battle Mountain in north-central Nevada. The Jersey Summit study area is bounded by the Tobin Range to the west and Fish Creek Mountains to the east, encompassing ~111 km^2 between the Buffalo and Jersey basins. Characterized by Basin and Range normal faults, the primary area of interest occupies two major intermeshing, oppositely dipping Quaternary normal fault zones within a major Quaternary accommodation zone. Accommodation zone settings hosting known high-temperature geothermal systems include two of the largest producing systems in Nevada - McGinness Hills at 144 MW and Steamboat Springs at 80 MW (Faulds et al., 2021). Previously, preliminary geothermal exploration (i.e., gravity data collection and 2 slim holes) had been conducted in the central portion of Buffalo Valley near a group of hot springs, but a commercially viable geothermal system was not discovered in that area. The structural setting of the central part of Buffalo Valley does not seem conducive for geothermal activity, as available geological and geophysical data are not indicative of a favorable structural setting. Within the Jersey Summit study area, there are no surface expressions (e.g., springs or fumaroles) of a geothermal system. To our knowledge, there has been no previous geothermal exploration in southern Buffalo Valley or within the Jersey Summit study area.

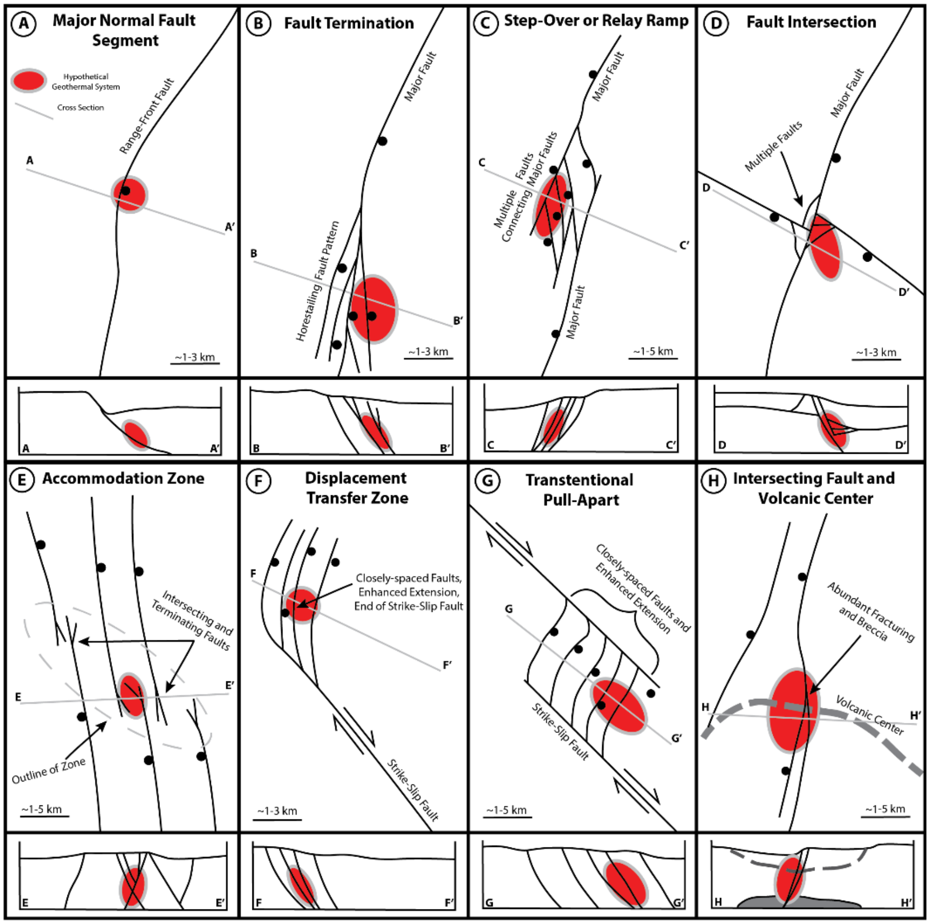

Figure 2: Schematic representations of favorable structural settings. Red shaded areas mark approximate locations of hypothetical geothermal upwellings in map view; black lines represent faults; and gray lines represent cross-section transect; modified from Faulds et al. (2021).

The predominant faults within the study area strike north to north-northeast, consistent with the modern Basin and Range extensional stress regime. This area scored high in the Nevada play fairway analysis (Faulds et al., 2015) due primarily to two major intermeshing, oppositely dipping Quaternary normal fault zones within a major Quaternary accommodation zone. The west-dipping Jersey Valley fault zone terminates northward in this accommodation zone, whereas the east-dipping Buffalo Valley fault zone dies out southward. An inter-basinal high occupies much of the accommodation zone in the Jersey Summit area, as the east-tilted half-graben that comprises the Jersey basin and west-tilted half-graben making up the Buffalo basin terminate to the north and south, respectively, concomitant with the terminating controlling fault zones (Figure 3).

Local stratigraphy of the Jersey Summit area consists of highly deformed and thrust-faulted Paleozoic siliciclastic and carbonate rocks overlain by altered Mesozoic volcanic rocks (Figure 3). Thick sections of Tertiary volcanic rocks, including andesite breccias, rhyolite tuff, volcanic rock avalanche deposits, and Miocene lacustrine sedimentary rocks overlie these units to the south. A Quaternary basaltic volcanic field punctuates the eastern part of Buffalo Valley (Cousens et al., 2013). Quaternary alluvium overlies all older rock types in the area. Potential host rocks for a geothermal reservoir in this area include highly fractured Paleozoic siliciclastic and carbonate rocks and Tertiary ash-flow tuffs along and proximal to Quaternary faults.

3. METHODOLOGY

The primary objective of this detailed study is to integrate multiple geological, geophysical, and geochemical datasets to identify and characterize a potential hidden geothermal system in the Jersey Summit area. Methods employed to achieve these objectives include: 1) detailed geologic mapping; 2) petrographic analysis; 3) structural analysis; 4) 2-m temperature survey; 5) geophysical investigations including gravity, magnetics, and magnetotelluric (MT) surveys; 6) interpretation of one available seismic reflection profile; 7) geochemical investigations; and 8) 2D conceptual modeling. All datasets will be integrated to identify potential hidden geothermal resources and estimate the most favorable locations for drilling. This paper focuses on results gleaned from the detailed geologic mapping, structural analysis, and 2-m temperature survey.

Detailed geologic mapping at 1:24,000 scale within the identified accommodation zone in the Jersey Summit area began in spring 2023 and was completed in fall 2023. The map area includes a portion of the southeast Tobin Range, southern Buffalo Valley, northern Jersey Valley, Jersey Summit, and the western fringe of the Fish Creek Mountains (Figure 3). Recently completed high-resolution lidar imagery from the GeoDAWN project has facilitated both mapping of Quaternary faults and distinguishing between such faults and paleo-shorelines of Pleistocene lakes. New mapping efforts were merged with existing geologic maps of the area (e.g., Ferguson et al., 1951; Muller et al., 1951; Stewart and Carlson, 1976; Gonsior, 2006). The geologic mapping has revealed discrete areas of structural complexity within or proximal to the accommodation zone, which are discussed below.

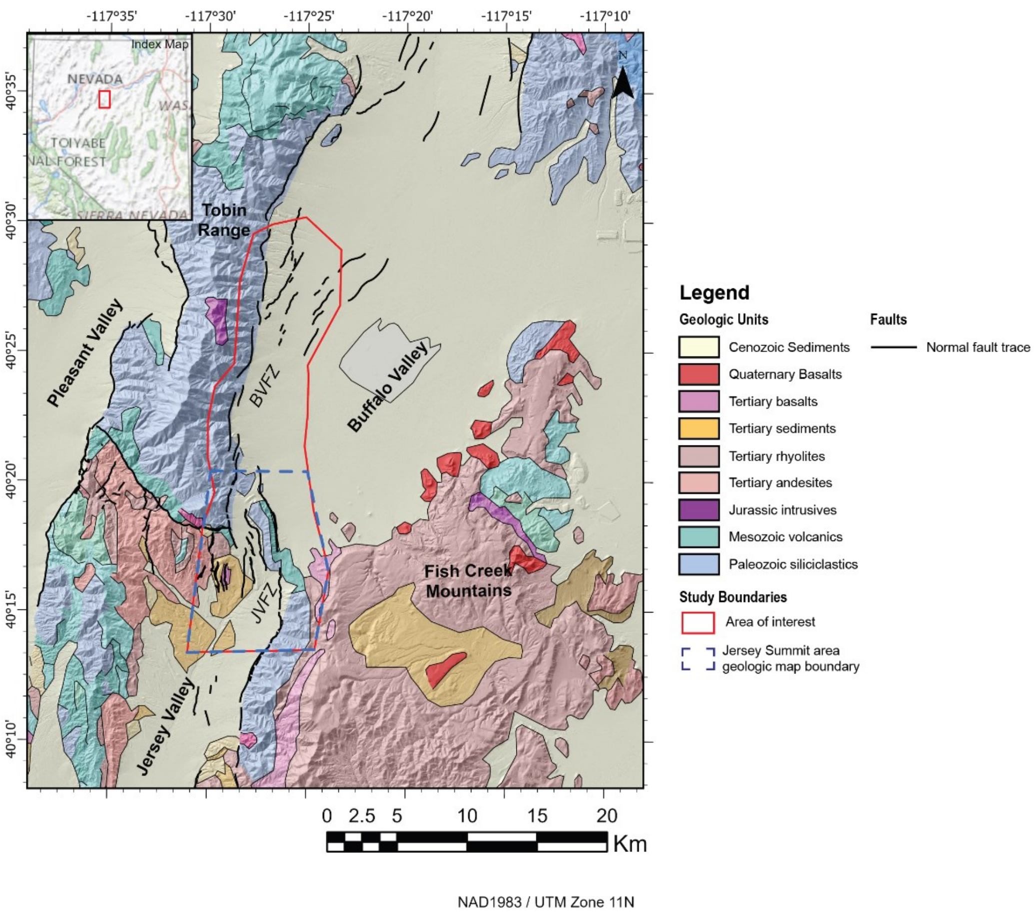

Figure 3: Generalized geologic map of the Jersey Summit-Buffalo Valley detailed study site (red polygon) and Jersey Summit area geologic map boundary (dashed blue polygon). Normal fault traces are in black.

Shallow 2-m temperature surveys are a versatile, cost-effective method for temperature data acquisition that can be used to discover hidden thermal anomalies by helping locate temperatures in the subsurface that may be related to an area of upwelling or outflow (Coolbaugh et al., 2007; Kratt et al., 2010). Thermal anomalies are determined based on the difference between the average background temperature of the subsurface and the temperature measured at 2 m resulting in a degree above or below background (DAB) value. Two surveys have been completed within the study area (June and October 2023) resulting in the collection of 43 measurements from three areas (Figure 4). The survey grid spacing was 300 – 800 m, and measurements were collected along the range front and into the Buffalo basin, including targeted areas of high structural complexity, such as terminations and step-overs in the competing, oppositely dipping fault zones. A third 2-m temperature survey is slated for early 2024 to further investigate the identified thermal anomalies.

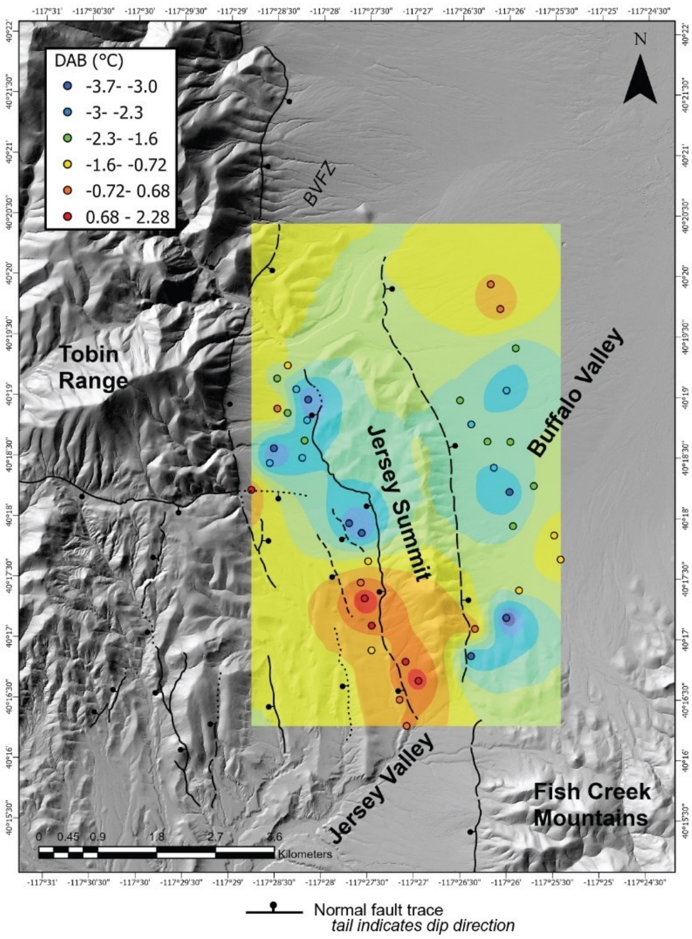

Figure 4: 2-m temperature survey executed in June and October 2023, totaling 43 sites. Dots represent 2-m probe locations and recorded degrees above or below background (DAB). An Empirical Bayesian Kriging (EBK) regression is overlain to contour the measured temperatures.

4. PRELIMINARY RESULTS AND DISCUSSION

Geologic mapping of the Jersey Summit area has resulted in several important findings. It revealed that both the Buffalo Valley and Jersey Valley fault zones are marked by Holocene fault scarps and contain several discrete step-overs that represent more localized geothermal prospects within the area. Additionally, the central part of the accommodation zone consists of complex systems of intermeshing, overlapping, oppositely dipping normal faults, including several apparent left steps in the northern end of the west-dipping Jersey Valley fault zone (Figure 5). A major east-striking transverse fault cutting through the Tobin Range appears to intersect the southernmost end of the main strand of the east-dipping Buffalo Valley fault zone and continues eastward to intersect a left-stepping northern splay of the west-dipping Jersey Valley fault zone. This group of multiple intersecting faults appears to mark the area of greatest structural complexity within the accommodation zone and thus may be characterized by enhanced fracture permeability. Accordingly, this area corresponds to a more highly prospective zone for hidden geothermal activity. Interestingly, results from the 2-m temperature survey show a nearly linear trend of minor thermal anomalies ranging in DAB from ~+1°C- +2.3°C directly south and down gradient from this area, which could potentially represent outflow from this structural nexus. Another area of greater potential for hidden geothermal activity is in the northern extent of the map area, where the Buffalo Valley fault zone steps eastward toward the eastern flank of Jersey Summit, as it begins to lose displacement to the south toward the accommodation zone. This left-step is notably larger than the more discrete left steps in the northern part of the Jersey Valley fault zone. Continuing north along the Tobin Range, this pattern of left-step faulting is consistent through the entirety of the range front. Notably, a minor 2-m temperature anomaly was observed directly east and down gradient of this broad left step-over and could potentially represent another zone of outflow.

Future work will include detailed cross-sections that will accompany the completed geologic map to better conceptualize the structural framework of the Jersey Summit area and contribute to future 3D conceptual modeling of potential hidden geothermal resources. Slip and dilation tendency analyses will be conducted to indicate which identified faults are more favorably oriented to transmit hydrothermal fluids within the present stress field. Gravity, magnetic, and magnetotelluric surveys recently conducted by the U.S. Geological Survey will also be integrated with the geologic and 2-m temperature investigations to aid in characterizing basin architecture, identifying concealed faults, and detecting features (e.g., possible clay caps and altered rocks) associated with geothermal activity (e.g., Glen et al., 2018; Craig et al., 2021). Additionally, fluid geochemistry and geothermometers will be used to assess temperatures of potential geothermal reservoirs at depth.

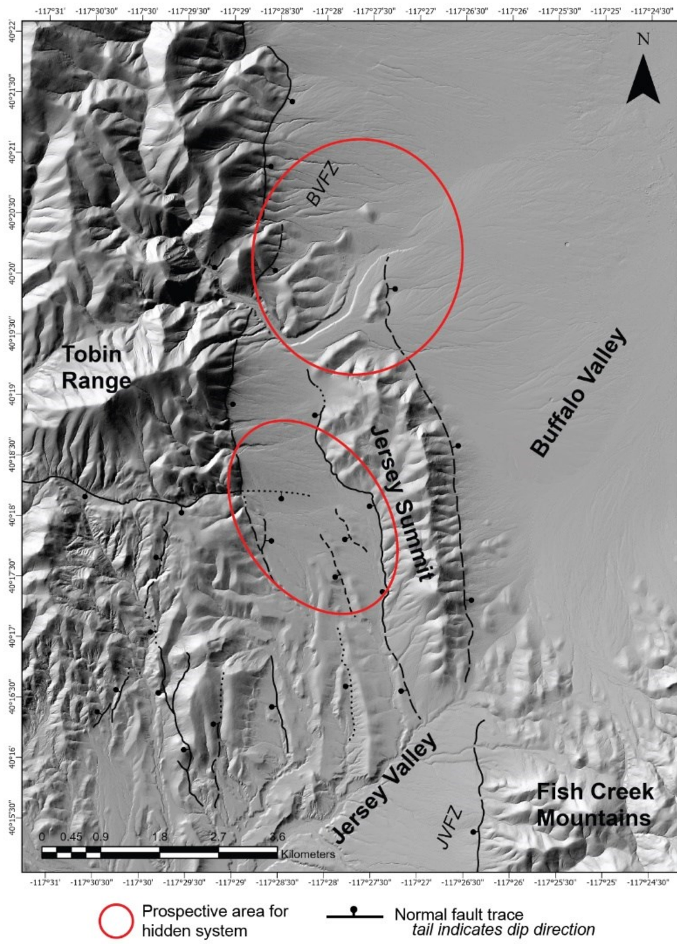

Figure 5: Lidar imagery of the Jersey Summit area. Black lines show traces of major normal faults, with bar and ball on downthrown side. Red circles outline areas most prospective areas for hidden geothermal resource based on higher levels of structural complexity.

5. CONCLUSIONS

The GBR of the western U.S. is one of the largest geothermal provinces on Earth, but the vast potential of this region cannot be tapped until systematic workflows and methodologies are developed to identify hidden geothermal systems with minimal risk. Geothermal play fairway analysis is one approach that holds significant promise of facilitating exploration and development. Regional play fairway analysis initially indicated that the Jersey Summit area was a promising site for hosting a hidden geothermal system due primarily to the presence of a major Quaternary accommodation zone. The detailed geologic mapping and 2-m surveys presented here indicate several individual, favorable structural settings for geothermal activity within the broader major accommodation zone, whereby the mutually terminating, overlapping, oppositely dipping normal fault systems include several discrete step-overs and fault intersections. The area of tightly spaced terminations and fault intersections in the northwest part of the Jersey Summit area is a particularly promising structural setting. A subtle 2-m temperature anomaly directly down gradient to the south may represent outflow from a possible hidden geothermal upwelling in this area. However, a broad left step in the southern part of the Buffalo Valley fault zone marks a second, highly prospective site in the northern part of the study area and is also marked by a subtle, down gradient 2-m thermal anomaly.

Comparatively, the McGinness Hills geothermal system located ~145 km south of Jersey Summit (Norquist and Delwiche, 2013), serves as a relevant benchmark for the importance of understanding favorable structural settings. Characterized as a hybrid setting, McGinness Hills is an accommodation zone, consisting of overlapping, opposite dipping normal fault systems with multiple fault intersections and fault step-overs, as well as minor faults connecting the overlapping fault segments (Faulds et al., 2013). The highest permeability within the system appears to be related to the intersection of north-northeast-striking faults with steeply dipping northwest-striking faults within a left step-over (Faulds et al., 2013). Jersey Summit shares similarities with McGinness Hills as exemplified by the identified structural nexus of terminating, overlapping, and left-stepping fault systems. Notably, McGinness Hills is a hidden system, only marked by paleo-geothermal deposits but with no active surface manifestations, emphasizing the need for integrated geological and geophysical techniques to identify the most prospective locations for hidden geothermal activity. The success of McGinness Hills suggests that the more structurally complex parts of the Jersey Summit accommodation zone hold substantial promise for hidden geothermal activity. The systematic integration of play fairway analysis offers a viable framework for advancing exploration and untapping the vast geothermal potential for commercial-grade hidden geothermal systems in the GBR.

6. ACKNOWLEDGMENTS

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