Searching for Blind Geothermal Systems Utilizing Play Fairway Analysis, Western Nevada

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Background

Geothermal *play fairway analysis* is a concept adopted from the oil industry aimed at improving the efficiency and success rate of geothermal exploration and drilling. It involves integration of multiple geologic and geophysical parameters indicative of geothermal activity as a means of identifying the most promising areas for new geothermal development[1]. This includes the evaluation of the relative favorability of known, undeveloped geothermal systems, as well as assessing the probability of a particular area for hosting a relatively robust blind system (>~130°C). Blind systems lack surface hot springs and steam vents and are thought to comprise the majority of geothermal systems in the Great Basin region[2]. Compared to the oil industry, play fairway methodologies for geothermal systems are in their relative infancy and have generally not been fully tested. Also, geothermal play fairway methodologies can vary widely between regions depending on the tectonic setting, structural and stratigraphic framework, quality of exposure, and effectiveness of various geophysical techniques under local geologic conditions.

We have applied the play fairway methodology across a broad swath (96,000 km^2) of the Great Basin region of Nevada, a well-exposed extensional to transtensional (from east to west, respectively), active tectonic setting within the Basin and Range province of western North America (Figure 1). The Great Basin region of Nevada and adjacent parts of neighboring states currently host ~25 geothermal power plants with over ~700 MW of capacity. However, studies indicate a vast untapped potential for conventional geothermal energy in this region[3].

Here, we describe a successful application of the play fairway analysis that resulted in the discovery of a heretofore unrecognized, blind geothermal system in southern Gabbs Valley in western Nevada. No previous geothermal exploration had occurred in this area (Figure 2). Initial regional-scale play fairway analysis indicated a high prospectivity. This prompted more detailed geologic and geophysical studies[4,5], which coupled with finer-scale play fairway analyses, yielded favorable targets for geothermal drilling. The project culminated with successful temperature-gradient drilling in June 2018, whereby temperatures of 122ºC were attained at depths of 152 m[6].

This play fairway analysis also identified other sites where preliminary exploration work suggests that undiscovered blind geothermal systems are present[1]. It is expected that when these sites are fully vetted, additional geothermal discoveries will be made.

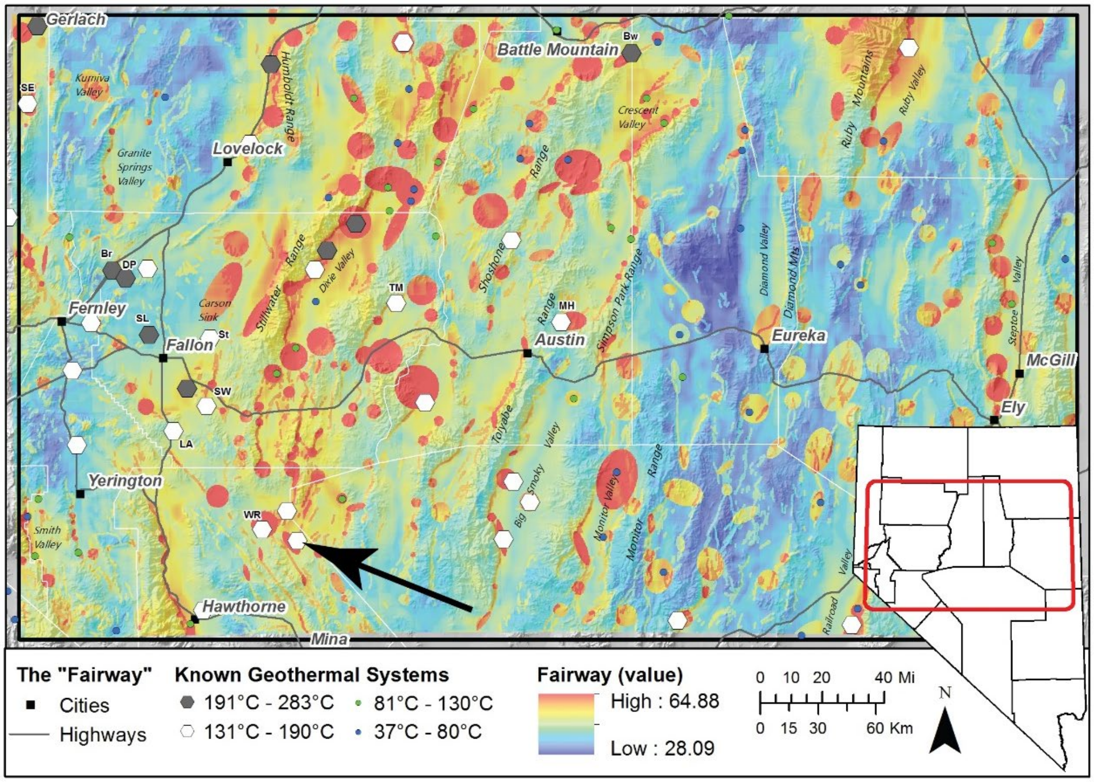

Figure 1: Geothermal play fairway map of west-central to eastern Nevada. Warmer colors indicate areas of higher potential; cool colors show areas of relatively low potential. Fairway values are not normalized and are based on parameters and relative weighting shown in Figure 3. Black arrow points to the southern Gabbs Valley area. Abbreviations for known geothermal systems in the region: Br, Bradys; Bw, Beowawe; DP, Desert Peak; LA, Lee-Allen; MH, McGinness Hills; SE, San Emidio; SL, Soda Lake; St, Stillwater; SW, Salt Wells; TM, Tungsten Mountain; WR, Wild Rose-Don Campbell.

Figure 2. Panoramic view of southern and eastern Gabbs Valley looking toward the northeast.

Play Fairway Methodology – Nevada Style

In Phase I of this project, we developed a comprehensive, statistically based geothermal potential map for 96,000 km^2 across the Great Basin of Nevada (Figure 1). This project focused on fault-controlled geothermal play fairways due to the affiliation of most geothermal systems in the region with Quaternary faults. Nine parameters were incorporated into the regional geothermal potential maps, including: 1) structural settings, 2) age of recent faulting, 3) slip rates on recent faults, 4) regional-scale geodetic strain rates, 5) slip and dilation tendency on Quaternary faults, 6) earthquake density, 7) gravity gradients, 8) temperature at 3 km depth, and 9) geochemistry from springs and wells.

These parameters were grouped into key subsets to define regional permeability, intermediate-scale permeability, local permeability, and regional heat, which were combined to define the fairway (Figures 1 and 3). A major challenge was determining the appropriate weighting of individual data types to best predict permeability and overall geothermal potential. Rigorous statistical methods, utilizing 34 benchmarks of known relatively high-temperature (>130°C) geothermal systems within the region, were employed to constrain the hierarchal weights of each parameter[7]. Analyses of these parameters were also coupled with a thorough review of the degree of previous exploration, thus permitting identification of under-explored regions that are potentially ripe for development. To facilitate economic assessments for exploration and development, the final favorability map also included layers showing land use status and critical infrastructure, such as electrical transmission and transportation corridors.

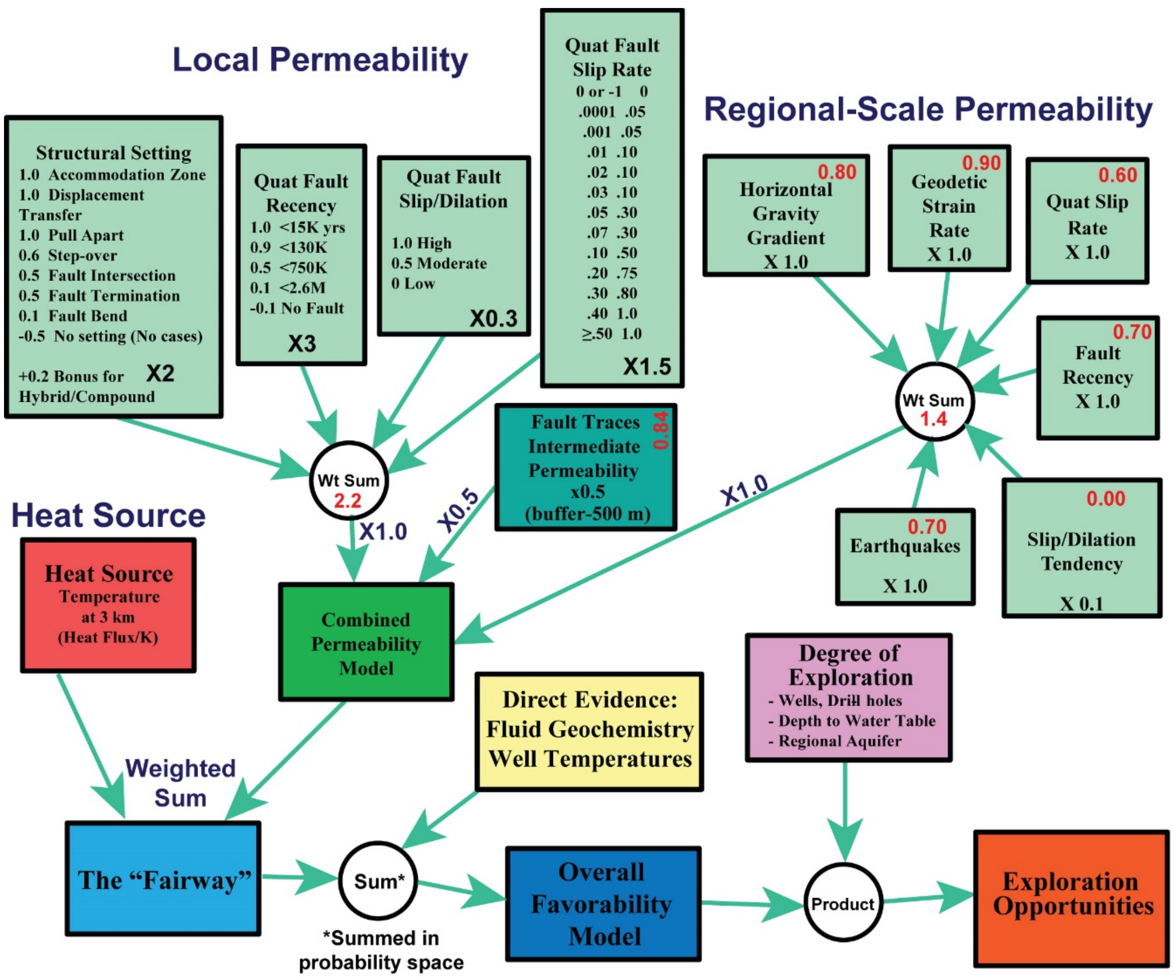

Figure 3: Nevada play fairway modeling workflow. Red numbers indicate relative weights determined from weights of evidence. Black numbers indicate expert driven weights used in the analysis. In all cases, the expert driven weights took into account the statistical analyses. We have generally focused on the fairway model (light blue box in lower left).

Owing to the active extensional to transtensional tectonism and high heat flow, many sites in the broad study area (96,000 km^2) yielded relatively high play fairway values. In Phase II of the project, we chose 24 of the most promising sites for reconnaissance on the basis of the play fairway values, land status, and proximity to an established electrical transmission corridor. We then down-selected five sites for detailed studies through a semi-quantitative analysis involving consideration of a) available geological, geochemical, and geophysical data, b) new shallow temperature and geochemical data collected in this study, c) land status, d) distance from an electrical transmission corridor, and e) degree of previous exploration (Figure 4).

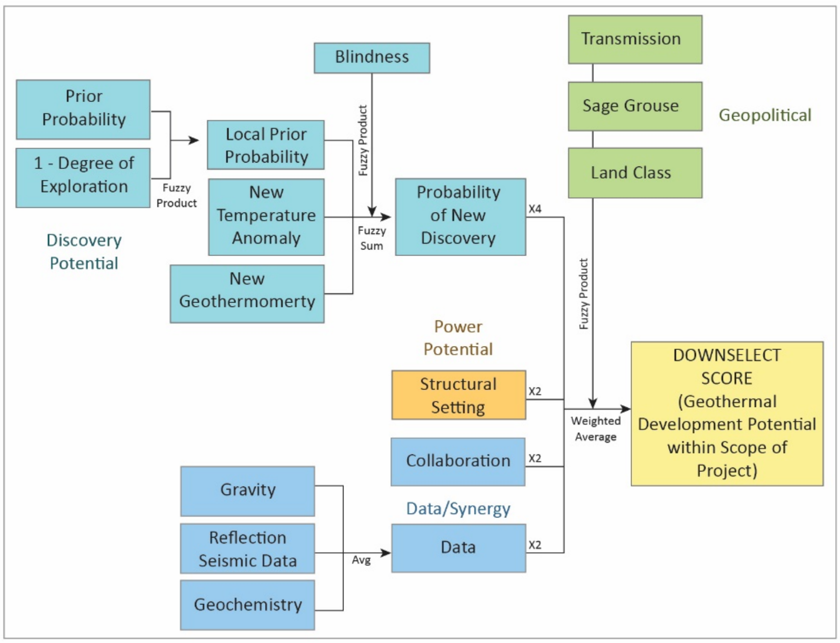

Figure 4: Flow chart showing down-selection process for selecting Phase II detailed study areas from prospective areas identified in Phase I. "Collaboration" refers to potential for industry collaboration.

Southern Gabbs Valley – Evidence Leads to Hot Water

Southern Gabbs Valley in west-central Nevada was one of the areas chosen for detailed study. It is a complex, tectonically active structural basin at the transition between the Walker Lane and Basin and Range province (Figures 1 and 5). The Walker Lane is a belt of primarily right-lateral strike-slip faults that collectively accommodate ~20% of the dextral motion between the Pacific and North American plates. As individual dextral faults in the Walker Lane terminate, they commonly splay into arrays of normal faults in what we refer to as *displacement transfer zones*, generating an area of focused extension favorable for geothermal activity. Southern Gabbs Valley contains a displacement transfer zone near the end of the recently active (<15 ka) Petrified Springs dextral fault (slip rate=1.4 mm/yr), which splays into numerous north- to north-northeast-striking normal faults within the basin, effectively transferring dextral shear from the Walker Lane to WNW-directed extension in the Basin and Range. This favorable structural setting combined with relatively high regional strain rates and Quaternary faults with relatively high slip rates resulted in a high play fairway score for southeastern Gabbs Valley in the regional analysis completed in Phase 1 (Figure 1). Although some geothermal exploration has occurred

~15 km north of the study area, no previous exploration had taken place in southeastern Gabbs Valley.

Our initial reconnaissance of southeastern Gabbs Valley found no surface evidence (e.g. sinter or travertine) of a geothermal system, but anomalously warm wells (32ºC) were identified in the area (Figures 5, 6, and 7), which prompted more detailed reconnaissance, including a shallow (2-m depth) temperature survey (Figure 5A and 8). This survey showed a shallow temperature anomaly (up to 5ºC above background) up hydrologic gradient from the warm wells. Based on these favorable attributes, southern Gabbs Valley was down-selected as one of the five areas for detailed analyses in Phase II.

Detailed analyses in Phase II included detailed geologic mapping (180 km^2), Quaternary fault analysis, a gravity survey (274 stations), 2-m temperature survey (124 stations), geochemical analyses of water samples, and slip and dilation tendency analysis of Quaternary faults. This work defined a 7 km^2 shallow temperature anomaly in southeastern Gabbs Valley near the intersection of gravity gradients indicating a major subsurface fault intersection within the broader displacement transfer zone. Further, geothermometry on water samples suggested subsurface temperatures of 130-140ºC.

All of these favorable factors prompted more detailed geophysical analyses in Phase III to facilitate selection of sites for temperature-gradient holes (TGH). The more detailed geophysical analyses included additional gravity (480 stations) and new magnetic (300 line km) and magnetotelluric (MT, 24 stations) surveys. The additional gravity work better defined the probable location of intersections between subsurface faults. This showed that the shallow temperature anomaly was not only collocated with sharp intersecting gravity gradients but was also collocated with a conspicuous magnetic low and a resistivity low, suggesting hydrothermally altered rocks at depth.

TGH targets were therefore selected to span and straddle the collocated 2-m temperature anomaly, intersecting gravity gradients, magnetic low, and resistivity low. We commenced drilling of TGHs in late May 2018 and completed six holes in a month (Figure 9). Bottom-hole temperatures from two wells in the central part of the collocated anomalies were 112°C and 122.5°C at 152 m (500 ft) depth (Figures 5D and 10). Bottom-hole temperatures fall off rapidly to the north and more gradually to the south. At ~150 m depth, the thermal anomaly is at least ~2 km long in a north-south extent and probably at least 1 km wide from east to west. Potential host rocks for a geothermal reservoir include highly fractured Mesozoic basement rocks (granitoids and metasediments) and Miocene ash-flow tuffs along and proximal to faults. NNE-striking normal faults have the highest slip and dilation tendency (Figure 5B). Thus, many faults are well oriented for potential geothermal fluid flow.

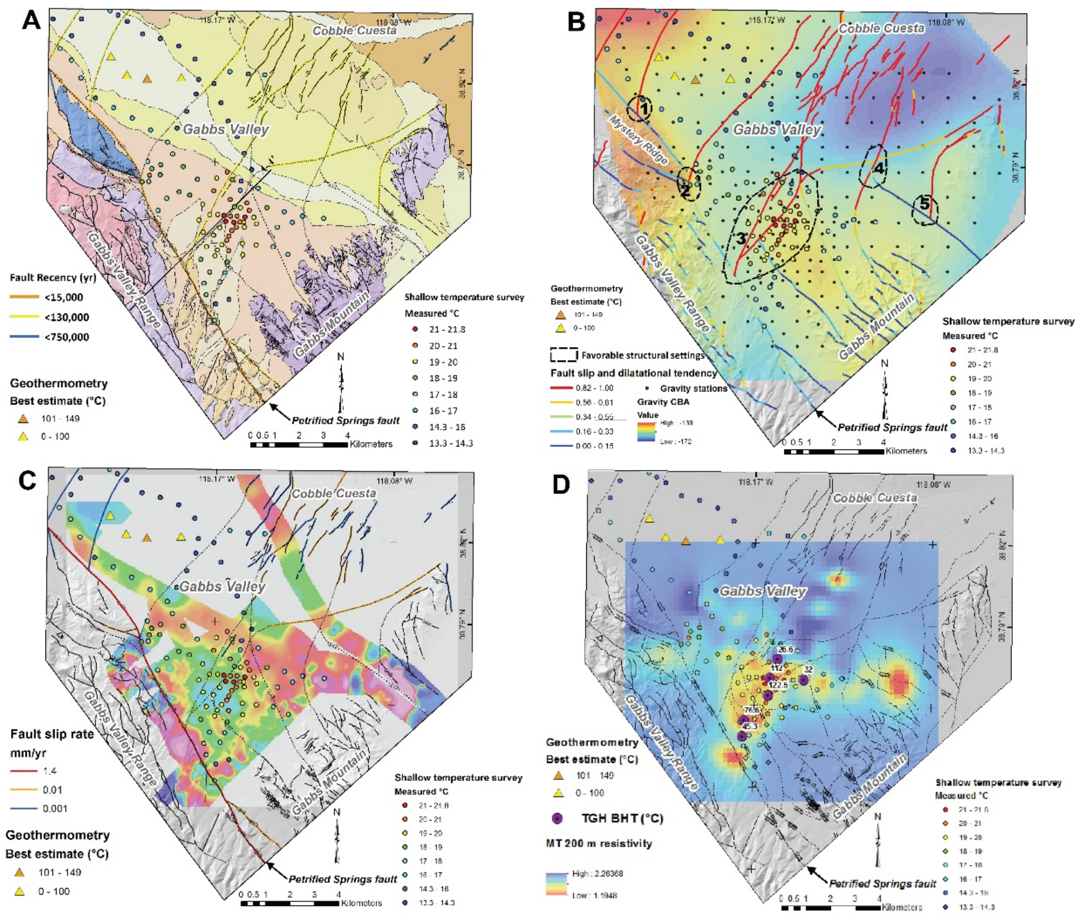

Figure 5: Southeastern Gabbs Valley. A. Geologic map showing Quaternary faults, geothermometry, and 2-m temperature data. Quaternary sediments are in yellow, white, and light orange; Tertiary volcanic units in lavender and pink; Mesozoic metasedimentary rocks are blue. Cross section A-A' is in Figure 6. B. Slip and dilation tendency, complete Bouguer gravity, and favorable structural settings with geothermometry and 2-m temperature data. C. Ground magnetic data and fault slip data with geothermometry and 2-m temperatures. Note collocated magnetic low and shallow temperature anomaly. D. MT data (200 m depth), TG holes, and bottom-hole temperatures (as of June 2018) of TGHs (~152 m depth). Note collocation of resistivity low with hot TGHs and shallow temperature anomaly.

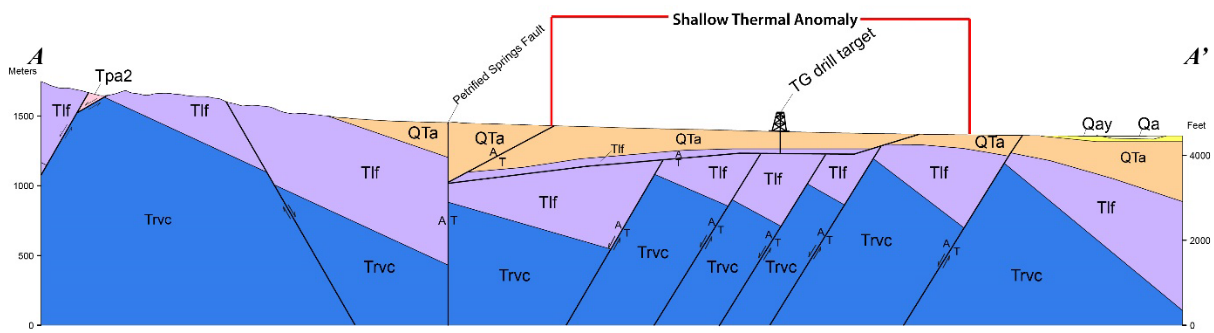

Figure 6: Cross section A-A' in southern Gabbs Valley (location in Figure 3A), showing complex fault intersection collocated with 2-m temperature anomaly and approximate location of hot TG wells marked by drilling derrick. Qay, Qs, QTA – late Miocene-Quaternary sediments; Tlf – Miocene volcanic rocks; Trvc – Triassic metasedimentary rocks.

Figure 7. Measuring temperatures of water wells in southeastern Gabbs Valley.

Figure 8. Shallow (2 m depth) temperature survey in southeastern Gabbs Valley.

Figure 9. Temperature-gradient drilling in southeastern Gabbs Valley.

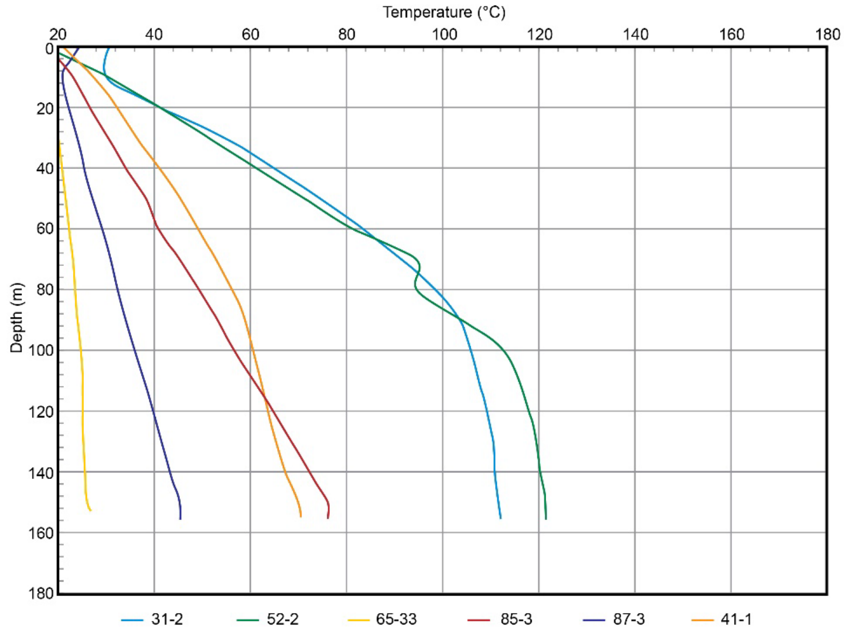

Figure 10: Data from TG holes in southern Gabbs Valley. The two hot wells are collocated with the shallow temperature anomaly, intersecting and terminating gravity gradients, magnetic low, and low-resistivity anomaly.

Discussion – Multi-Scale Adaptability of Play Fairway Analysis

It is important to note that the regional analysis of Phase I recognized relatively broad favorable settings (Figure 1), which were later refined with additional data input in Phase II. As is typical in any regional exploration program for natural resources, it is difficult in the early stages to parse out the detailed characteristics of a particular area to select the most favorable targets for drilling. Upon more detailed analysis in Phase II, it became apparent that southeastern Gabbs Valley contained multiple favorable structural settings (Figures 5B). This presented the immediate challenge of applying our play fairway methodology at a finer scale to effectively model the geothermal potential of each of the favorable settings within a particular study area. The detailed geological, geochemical, and geophysical investigations afforded such an analysis. Ultimately, we utilized play fairway scores to compare individual favorable settings in each of the study areas to one another and rank such areas to select the most promising sites for drilling. Thus, we found that our play fairway methodology was very adaptable to the natural evolution of an exploration program, as it progresses from a regional analysis and subsequently vectors into the most promising prospects that present the lowest risk for development.

We further note that the additional geophysical data from southeastern Gabbs Valley was especially important due to its location in a large, late Cenozoic basin. New geophysical data from the basin afforded discovery of previously unrecognized intrabasinal, favorable structural settings and identifying the most promising area based on the collocation of multiple features. These findings epitomize the importance of the detailed studies in refining exploration targets in such areas. Considering that about half of the Great Basin region is covered by basins, this also demonstrates the broad applicability of such detailed studies as well as the large untapped potential for commercial-grade geothermal systems in many of these basins.

Conclusions

Multiple features, including hot TGHs, geothermometry from nearby wells, intersecting gravity gradients, magnetic low, and low-resistivity, indicate that the south-central part of southeastern Gabbs Valley contains a relatively high temperature (>130ºC) blind geothermal system. Additional work is needed, however, to fully characterize the temperature and geometry of this resource and provide a platform for evaluating commercial viability. These tasks include: 1) collecting and analyzing fluid samples directly associated with the resource to better define the reservoir temperature and provide direct context for the TGH results; 2) integrating the detailed potential field geophysical (gravity and magnetics) and geologic data to build a detailed 3D geologic model; and 3) integrating all data to develop conceptual models of the geothermal resource and constrain its size.

Nonetheless, the discovery in Gabbs Valley is significant, as no previous geothermal exploration had been conducted in this area. These results provide preliminary validation of our methodology and suggest that broader applications of play fairway analysis will likely yield positive results. Not only are there many additional promising sites within the original 96,000 km^2 study area, but other parts of the Great Basin region abound in favorable geologic settings and could greatly benefit from play fairway analysis, especially considering that blind systems probably represent the bulk of the geothermal resources. Play fairway analysis provides a platform from which to conduct geothermal exploration at multiple scales and ultimately minimize the inherent risks in drilling and development. Although the details of play fairway analysis will differ between regions, depending on tectonic setting, available data, and other factors, the general methodology utilized in this project provides a roadmap for unleashing the vast untapped potential of conventional geothermal systems in the Great Basin and other regions.

Acknowledgments

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Reference Footnotes

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