Multidisciplinary Assessment of a Potential Hidden Geothermal System: Insights from Northeastern Reese River Valley, North-Central Nevada

Nada Mareechi Jacinto[1], James E. Faulds[1], Tait Earney[2], Jonathan Glen[2], Nicole Hart-Wagoner[1], Cary Lindsey[1], and Jared Peacock[2]

[1]Great Basin Center for Geothermal Energy, Nevada Bureau of Mines and Geology, University of Nevada, Reno, NV 89557

[2]U.S. Geological Survey, Moffett Field, CA 94035

nadamareechij@unr.edu

Keywords: INGENIOUS, geothermal exploration, play fairway analysis, favorable structural settings, Nevada, Great Basin

ABSTRACT

The Great Basin region of the western United States hosts numerous geothermal resources, yet a substantial portion are "hidden" systems lacking surface manifestations. The Argenta Rise study area, within the northeastern Reese River basin of Nevada, was identified as a high-priority blind prospect through regional play fairway analysis (PFA) due to its favorable structural setting, including a major pull-apart between the Argenta Rim and northern Shoshone Range faults. This study, part of the broader INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) project, applies detailed geological and geophysical investigations to characterize the hidden geothermal potential at Argenta Rise. Our integrated approach combined geological mapping and structural analysis, geophysical surveys (gravity, magnetics, magnetotellurics, and seismic reflection), a shallow (2-m) temperature survey, and temperature-gradient (TG) drilling. Results confirm the presence of complex, interacting fault systems conducive to fluid flow and identify geophysical anomalies, including low-resistivity zones at ~1.5 km depth, aligned with some of these structures. However, no clear thermal anomalies were detected in the shallow subsurface by the 2-m survey or in ten TG wells drilled to ~244 m depth. This discrepancy highlights the challenge of exploring truly blind systems, where favorable structural and geophysical indicators are decoupled from shallow thermal signatures. We conclude that the geothermal potential at Argenta Rise remains prospective but unresolved; if present, a potential resource may be localized outside the drilled array, masked by cool groundwater from aquifers, or confined to a deeper reservoir.

1. INTRODUCTION

The Great Basin region of the Basin and Range province in the western United States hosts numerous geothermal power plants due to its favorable geologic framework Since the onset of extensional tectonics in the middle Cenozoic, the crustal thickness of the Great Basin region has greatly reduced (e.g., Colgan and Henry, 2009; Basler et al., 2026), leading to elevated geothermal gradients that range up to >70 °C/km (Coolbaugh et al., 2005; Blackwell et al., 2011). The interplay of active faulting and elevated geothermal gradients produce favorable conditions for geothermal systems, giving the Great Basin region substantial geothermal potential (Curewitz and Karson, 1997; Blackwell et al., 1999; Faulds et al., 2004; Faulds and Hinz, 2015). Estimates suggest ~10 GWe of undiscovered conventional geothermal resource potential within the region (Williams et al., 2008).
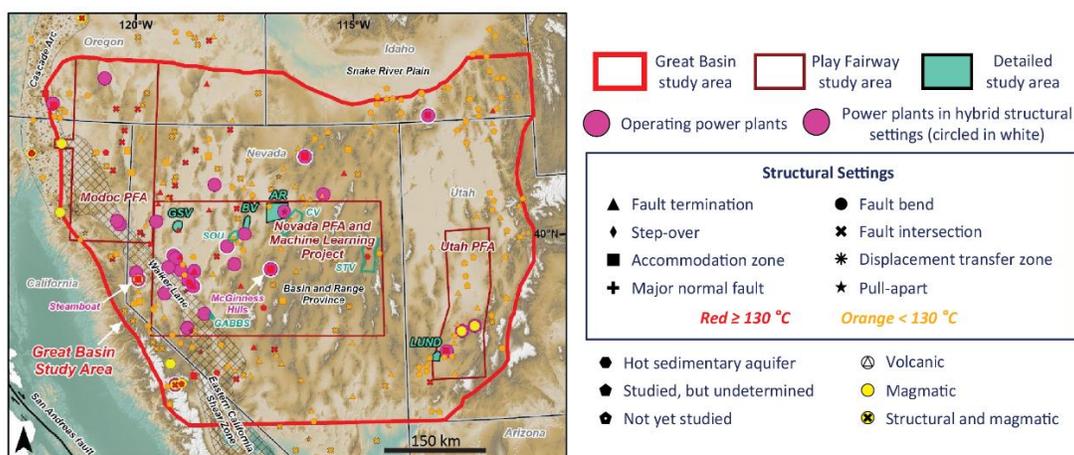

Figure 1: Regional study area of the Great Basin region for the INGENIOUS project with current detailed study areas (GSV = Granite Springs Valley, AR = Argenta Rise (northeastern Reese River Valley), BV = Buffalo Valley, LUND = Lund North). Thin dark red rectangles and polygons indicate locations of previous play fairway analysis (PFA) projects (Modoc, Nevada, and Utah; Siler et al., 2017; Faulds et al., 2016, 2021b; Wannamaker et al., 2017). Modified from Faulds and Richards (2023).

The most promising geothermal resources are invariably linked to favorable structural settings characterized by increased structural complexity. Faulds and Hinz (2015) inventoried 426 known geothermal systems (>37°C) across the Great Basin region to identify eight favorable structural settings based on the dominant faulting pattern (Figures 1 and 2), which was then analyzed in greater detail for the state of Nevada (Faulds et al., 2021a). These inventories revealed eight favorable structural settings based on the dominant fault pattern: 1) step-overs or relay ramps in normal fault zones (~32%); 2) normal fault terminations (25%); 3) fault intersections between two normal faults or between normal faults and transverse oblique-slip faults (22%); 4) accommodation zones (9%); 5) displacement transfer zones associated with the partitioning of strain from strike-slip fault systems into normal fault arrays (5%); 6) pull-aparts in strike-slip faults (3%); 7) bends in normal faults (2%); and 8) major range-front normal faults (1%) (Faulds et al., 2012 and 2013; Faulds and Hinz, 2015; Figure 2).
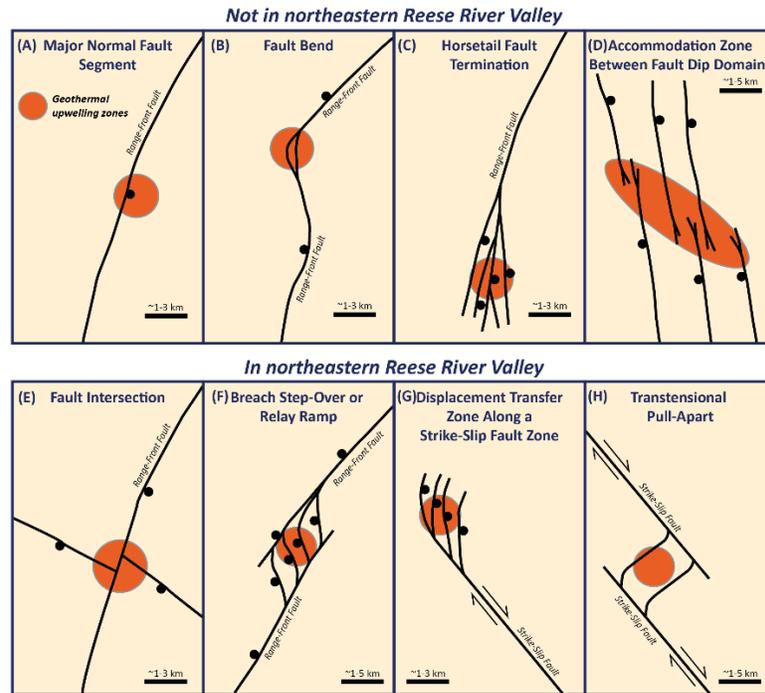
Figure 2: Characteristic favorable structural settings for geothermal systems, modified from Faulds and Hinz (2015). (A) Favorable structural settings not observed in northern Reese River Valley. (B) Favorable structural settings present in the northern Reese River Valley study area.

Despite the abundance of Quaternary normal faults in the Great Basin region, it is estimated that as much as 75% of all geothermal systems are 'blind' or 'hidden' (Coolbaugh et al., 2007), where a geothermal system has no surface manifestations of geothermal activity (e.g., geysers, hot springs). The cryptic nature of hidden systems complicates exploration and discovery, prompting the development of a multidisciplinary approach that integrates geologic, geophysical, and geochemical datasets to detect these systems, referred to as geothermal play fairway analysis (PFA) (e.g., Faulds et al., 2015, 2016, 2020).

2. INGENIOUS PROJECT

The INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) project is funded by the U.S. Department of Energy and designed to accelerate the discovery of economically viable hidden geothermal resources while simultaneously reducing the exploration and development risks in the Great Basin region (Ayling et al., 2022; Faulds and Richards, 2023). These objectives are pursued through: 1) continued development of geothermal PFA; 2) quantification of resource potential, uncertainty, and degree of exploration at identified hidden geothermal prospects across the region; 3) public release of new geoscience datasets for both industry and research applications; 4) development of software tools that enable external stakeholders to apply the geostatistical workflows developed through the project; and 5) creation of a geothermal "playbook" that synthesizes current conceptual models and best practices for geothermal exploration in the region.

As part of the INGENIOUS project, four prospective sites were chosen for detailed studies (Figure 1). Granite Springs Valley in western Nevada, the first detailed study site of the project, was initially identified through the Nevada PFA project, where detailed investigations documented a potential hidden geothermal system (Faulds et al., 2019, 2021b). Based on insights from regional and local analyses from both the Nevada play fairway and INGENIOUS projects, three additional detailed study sites were selected: northeastern Reese River Valley and Buffalo Valley/Jersey Summit area in Nevada, and Lund North in southwestern Utah.

3. ARGENTA RISE

The northeastern Reese River basin is bounded by the northern Shoshone Range to the south and east, the Battle Mountain Range to the west, and the Sheep Creek Range to the north. The ~1,150 km^2 study area also encompasses the western portion of Whirlwind Valley, which hosts the Beowawe geothermal system and power plant (Figure 3). This part of the Reese River basin was identified during Phase I of the Nevada play fairway project as one of 24 favorable sites across 1/3 of Nevada but was not selected for detailed study in Phase II of that project (Faulds et al., 2016, 2017). The site ranked highly in the PFA largely due to the presence of favorable structural settings, such as fault intersections and a broad pull-apart (Faulds et al., 2024) along with relatively high slip rates on Holocene faults (e.g., Wesnousky et al., 2005). This site also has high favorability rankings from more recent regional-scale geothermal fairway models (Hart-Wagoner et al., 2024, Figure 4). For the purposes of this project, the site is informally referred to as "Argenta Rise," reflecting its location adjacent to the Argenta Rim and relatively elevated topography compared to lower parts of the Reese River Valley to the west and south.
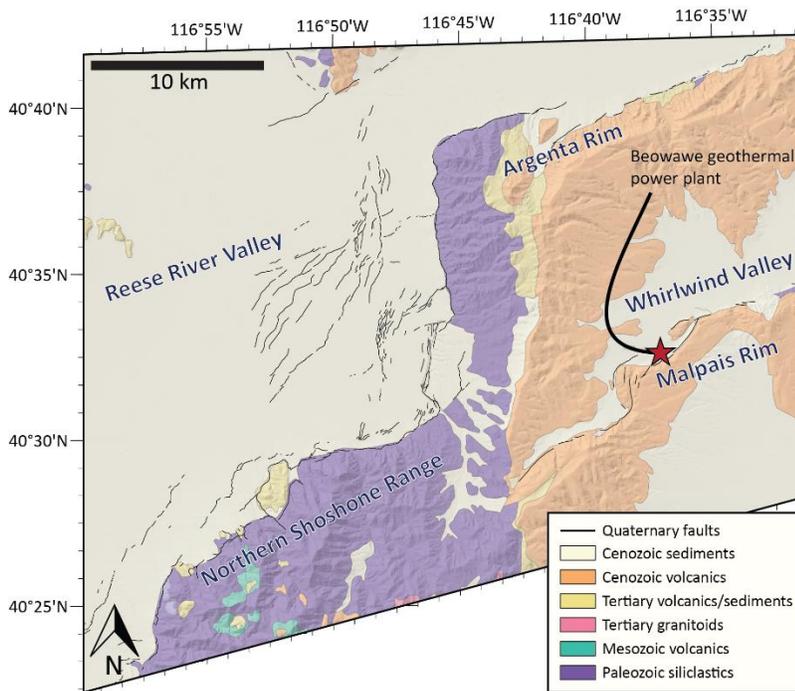

Figure 3: Study area boundary of Argenta Rise. Digital elevation model (DEM) hillshade (U.S. Geological Survey, 2024) topography overlain by simplified geologic map (modified from Crafford, 2007) and labels of notable geographic features. Quaternary faults (thin black lines) are a compilation of existing (U.S. Geological Survey, 2022), and newly identified faults mapped by the University of Nevada, Reno (UNR) using lidar (U.S. Geological Survey, 2021). Red star indicates location of Beowawe geothermal power plant.
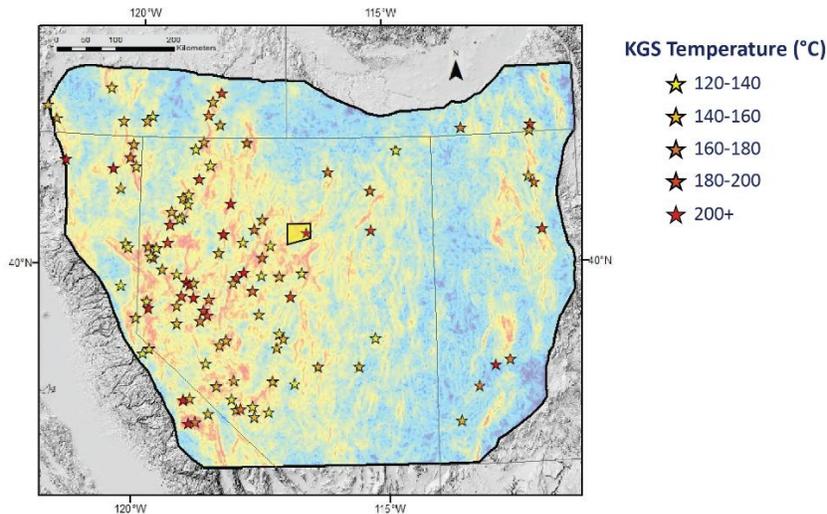

Figure 4: Preliminary regional geothermal fairway model. KGS = known geothermal systems as denoted by stars. Yellow polygon outlines the location of the Argenta Rise study area (Figure 3). Modified from Hart-Wagoner et al. (2024).

The Beowawe geothermal system in Whirlwind Valley is characterized by extensive sinter terraces, hot springs, and numerous hot wells (Hoang et al., 1987; Zoback, 1979; White, 1992). The opaline sinter terraces formed as a result of sustained hot spring and geyser activity and cover approximately 2 km² with an estimated thickness of ~60 m (Zoback, 1979; Struhsacker, 1980). Springs along the Malpais Rim exhibit temperatures ranging from 10°C to 98°C (Figure 5a), whereas wells in the area record temperatures between 10°C and 216°C (Figure 5b).

In contrast to the active Beowawe geothermal system, Argenta Rise lacks surface manifestations of geothermal activity such as hot springs, steam vents, or sinter deposits. Despite the absence of surface expressions, the region is characterized by elevated heat flow, estimated at approximately 100 mW m⁻² (Blackwell, 1983; Blackwell et al., 2011). Argenta Rise also contains structural settings comparable to those in Whirlwind Valley (e.g., Gilluly and Gates, 1965; Struhsacker, 1980; John and Wrucke, 2003), indicating that Whirlwind Valley may provide an analog for a geothermal system in the area (Faulds et al., 2024). The purpose of this study is to analyze the Argenta Rise area in detail to support development of a local-scale play fairway model to better assess geothermal potential.
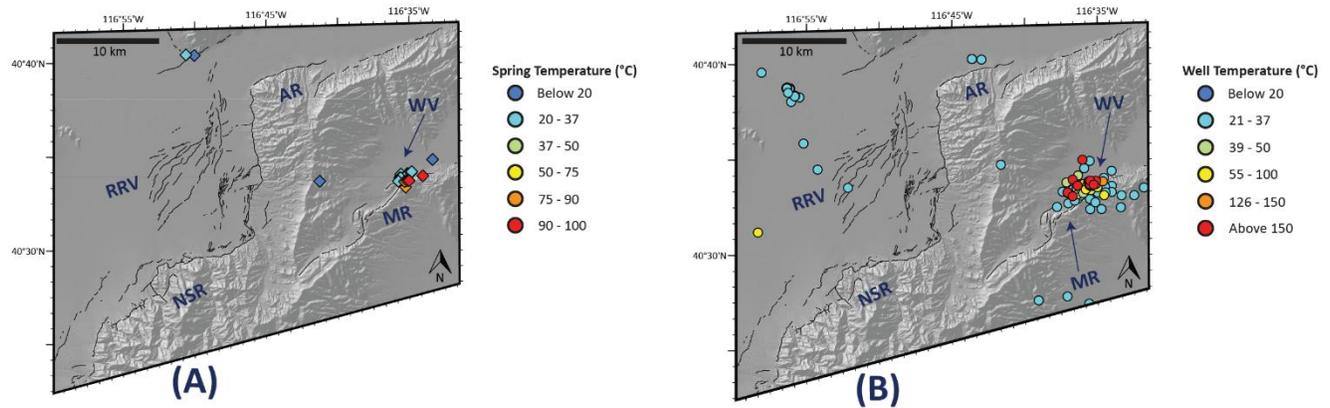

Figure 5: (A) DEM hillshade (U.S. Geological Survey, 2024) overlain by spring locations (colored diamonds) and Quaternary faults (black outline). (B) Study area boundary of Argenta Rise overlain by well locations (colored circles) and Quaternary faults (thin black lines). WV = Whirlwind Valley; MR = Malpais Rim; RRV = Reese River Valley; NSR = northern Shoshone Range; AR = Argenta Rim.

3.1 Regional Tectonic Setting

The structural framework of north-central Nevada records a complex tectonic history of repeated contraction and extension. In the Paleozoic, the region lay along the continental margin of Laurentia (Grauch et al., 2003), formed by Neoproterozoic rifting of Rodinia (Dalziel, 1997; Karlstrom et al., 1999), which produced deep-water sediments to the west and shallow continental shelf deposits to the east. From the late-middle Mississippian through the middle Pennsylvanian, sinistral-oblique convergence drove juxtaposition of deep-water siliceous rocks over shallow-water carbonates along the Roberts Mountains thrust (Cashman and Sturmer, 2021). Deformation continued into the Late Permian and Early Triassic with uplift and thrusting along the Golconda thrust during the Sonoma orogeny. In the Mesozoic, eastward subduction beneath the continental margin initiated the Cordilleran magmatic arc, with Triassic magmatism along the margin, opening of the Triassic Auld Lang Syne back-arc basin (Schwartz et al., 2024), and diffusive Jurassic plutonism throughout the central and eastern Nevada (Elison, 1995; Miller and Hoisch, 1995). Southeast-directed shortening in the Jurassic led to the closure of the deep-marine back-arc basin and formed the Luning-Fencemaker fold-and-thrust belt (Wyld, 2002; Dickinson, 2006). Contractile deformation migrated eastward, culminating in the Late Cretaceous-early Cenozoic Sevier and Laramide orogeny (DeCelles, 2004, DeCelles and Coogan, 2006, Yonkee and Weil, 2015). The Great Basin region of the Basin and Range province mostly contains north-northeast- to north-striking range-bounding normal faults that cover most of Nevada and the western part of Utah, reflecting west-northwest to east-west directed regional extension (Zoback, 1989). Modern topography began to develop during a widespread episode of extension between approximately 19 and 14 Ma. The northern Nevada rift (NNR) in north-central Nevada is defined by a linear positive magnetic anomaly and by north-northwest striking basaltic dikes and associated lava flows emplaced between 17 and 14 Ma (Zoback, 1989; Zoback et al., 1994; Watt et al., 2007). These basaltic dikes intrude the northern Shoshone Range and Argenta Rim in the eastern portion of the Argenta Rise study area.

3.2 Stratigraphic Framework

The bedrock stratigraphy of the Argenta Rise study area has been extensively studied and mapped (Gilluly and Gates, 1965; John and Wrucke, 2003; Ramelli et al., 2001; Richardson and Seedorff, 2023). Broadly, the region is characterized by late Paleozoic rocks associated with the Roberts Mountains thrust, overlain by Tertiary volcanic units. The upper-plate formations of the Roberts Mountains thrust include the Ordovician Valmy Formation, the Silurian Elder Sandstone, and the Devonian Slaven Chert, whereas lower-plate formations consist of the Shwin Formation and the Roberts Mountains Limestone. The Paleozoic rocks are unconformably overlain by a package of Cenozoic sedimentary and volcanic units. The oldest Cenozoic unit, the Oligocene Caetano Tuff, is rhyolitic and 33.8 Ma (John et al., 2008; Colgan et al., 2014), but exposures within the Argenta Rise study area are limited. Overlying the Caetano Tuff and Paleozoic rocks is a ~100 m thick package of middle Miocene volcanic rocks approximately 15 Ma, ranging from basalt to dacite, which form extensive caps on Argenta Rim and Malpais Rim (Figure 3). In the central part of the study area, north-northwest striking basaltic

dikes associated with the northern Nevada rift intrude the Paleozoic basement and may have served as feeders for the overlying basalt flows. Together, this stratigraphic framework, shaped by older thrusting and more recent extension and magmatism, provides the structural and lithologic context critical for assessing geothermal potential at Argenta Rise.

The Quaternary geology of the northeastern Reese River basin has been extensively mapped by Ramelli et al. (2001, 2017) and House et al. (2000), with units ranging from the Pleistocene to Holocene. Depositional environments include alluvial fan, alluvial flat, stream, and eolian deposits. Alluvial fans are moderately to poorly sorted pebble-, gravel-, and sand-sized sediments; alluvial flats are medium- to fine-grained and low-gradient; stream deposits, associated with the Reese and Humboldt Rivers, include meander-belt and floodplain deposits; and eolian deposits are fine-grained and locally form dunes. Quaternary units have been further subdivided by relative age.

3.3 Structural Framework

The structural framework of the Argenta Rise study area is characterized by gently tilted Cenozoic fault blocks typical of the Basin and Range province (Faulds et al., 2024). The northern Shoshone Range forms a north-northeast trending, east-tilted fault block, whereas Argenta Rim is a southeast tilted block. The northeastern Reese River basin lies within a broad left-step between the east-northeast striking, north-dipping Argenta Rim fault (ARF) and the east-northeast striking, north-dipping northern Shoshone Range fault (NSRF) at the northern end of the Shoshone Range (Figure 1 and 6). These faults are linked by a north-northwest striking, west-dipping fault zone along the western flank of Argenta Rim, referred to as the west Argenta Rim fault, with major fault intersections at its northern and southern terminations. The Bateman Spring fault (BSF) is a major north-northeast-striking, west-dipping intrabasinal fault in the northeastern Reese River basin. To the east, Whirlwind Valley developed between southeast-tilted fault blocks controlled by east–northeast striking faults and is bounded by Argenta Rim to the north and Malpais Rim to the south (Figure 3). This combination of fault orientations and step-over geometry generates a structural configuration favorable for geothermal activity (Faulds et al., 2024), as recognized in the Nevada play fairway project.

Quaternary fault scarps are widespread in the northeastern Reese River basin and Whirlwind Valley and cut Holocene alluvial fan deposits. Paleoseismic studies along the northern Shoshone Range indicate multiple deformational events, with at least two occurring in the past 10,000 years; the most recent, ~3,317 years B.P., produced 0.4 m of offset, corresponding to a slip rate of 0.1 mm/yr (Wesnousky et al., 2005). In Whirlwind Valley, scarps along similar faults show a recurrence interval of ~10,000 years, with the most recent event ~7,450 years B.P. producing 0.7 m of vertical offset and a slip rate of 0.09 mm/yr (Wesnousky et al., 2005).

4. METHODOLOGY AND RESULTS

The ultimate objective of this study is to apply the play fairway methodology to characterize a potential blind geothermal system at the Argenta Rise site in the northeastern Reese River basin and to subsequently achieve the goal of the INGENIOUS project to reduce exploration and development risks. This paper provides a synopsis of key features and datasets that can be employed in that analysis to produce a local-scale PFA model for Argenta Rise. Methods include detailed geological mapping, structural and petrographic analyses, geophysical surveys, a 2-m temperature survey, geochemical investigations, and temperature-gradient (TG) drilling.

4. 1 Geological Investigations

Geological investigations of the study area involve the compilation of existing geological maps, the interpretation of high-resolution lidar data to assess surface morphology and Quaternary fault location and geometry, kinematic analysis of fault surfaces to determine slip sense, fault movement history, deformation patterns, and petrographic analysis to characterize the lithologies within the Argenta Rise study area.

4.1.1 Geological Mapping

Previous geological maps of parts of the Argenta Rim (John and Wrucke, 2003), northern Reese River basin (Ramelli et al., 2017), and northern Shoshone Range (Gilluly et al., 1965; Richardson and Seedorff, 2023) have been compiled to aid geothermal investigations and develop detailed models for the study site. A new geological map will be made along a strip that straddles the east-northeast-striking Malpais Rim and northern Shoshone Range faults (Figure 6). The two faults have similar orientations and may be structurally linked across Argenta Rim. Understanding the relationship between these faults is relevant, as the Malpais Rim fault governs permeability at the Beowawe geothermal system, which may serve as an analog for a potential system at Argenta Rise. This mapping will build on the aforementioned compiled geological maps. If these faults are connected, it may indicate a larger, regional extensive deep-seated shear zone that may play a role in controlling geothermal activity.
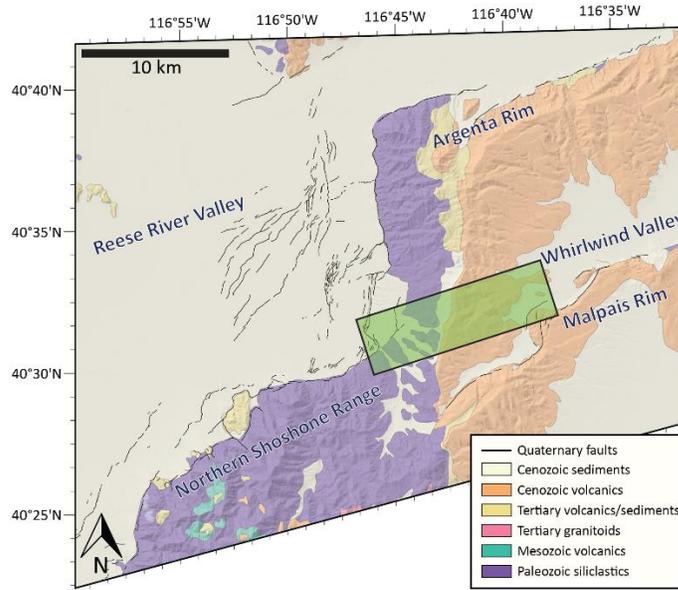
Figure 6: DEM hillshade (U.S. Geological Survey, 2024) topography of the Argenta Rise study area overlain by Quaternary faults (thin black lines). Green box outlines approximate boundary of planned detailed geological mapping.

4.1.2 Structural and Petrographic Analysis

Ongoing structural analysis at Argenta Rise is focused on defining fault geometries and kinematics using field observations and geophysical data, estimating principal stress orientations through kinematic inversion of fault surfaces and slickenlines, and calculating slip and dilation tendencies based on the resulting stress tensors. This analysis is critical for geothermal exploration, because Quaternary faults commonly act as permeable conduits for geothermal fluids (Curewitz and Karson, 1997), making an understanding of fault geometry and kinematics essential.

Kinematic analyses of fault surfaces indicate that east-northeast striking faults accommodate sinistral-normal slip, whereas north- to north-northeast striking faults are dominated by normal slip. Preliminary interpretations of lidar imagery and field observations reveal that Quaternary faulting in the study area is characterized by multiple zones of fault interaction, including prominent fault intersections where the west Argenta Rim fault meets the northern Shoshone Range and Argenta Rim faults, and a well-developed step-over at the southern end of the west Argenta Rim fault (Faulds et al., 2024).

Based on lidar analysis, field reconnaissance, and kinematic data, four favorable structural settings for geothermal activity have been identified in the Argenta Rise study area (Figure 7a), most of which fall within the broader favorable structural area recognized in the Nevada play fairway project (Figure 7b). Structural setting A is a right-stepping step-over of the north-northeast striking Shoshone Range normal fault. Structural setting B is a hybrid of a fault intersection and displacement transfer zone between the Shoshone Range, northern Shoshone Range, and Bateman Spring faults. Structural setting C is a hybrid of several favorable settings, including a left step in the northerly striking west Argenta Rim fault and fault intersections between north-northeast-, east-northeast-, and north-striking faults. Structural setting D is a fault intersection between the northerly striking west Argenta Rim normal fault and east-northeast striking Argenta Rim fault. Recognition of these finer scale favorable structural settings within the broader Argenta Rise area represents the natural progression from regional- to local-scale exploration, as demonstrated in other detailed studies in the region (Craig et al., 2021; Burgess and Faulds, 2024).
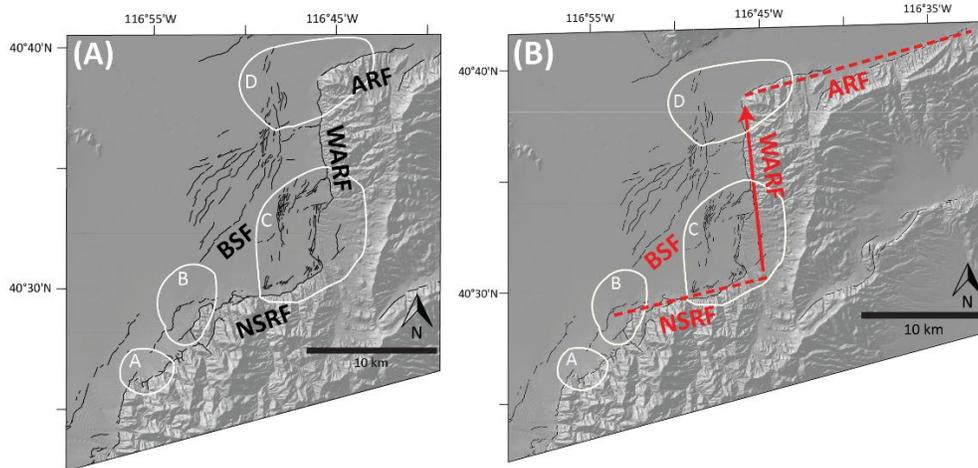
Figure 7: DEM hillshade (U.S. Geological Survey, 2024) topography of the Argenta Rise study area. Thin black lines represent Quaternary faults. White outlines indicate favorable structural settings. ARF = Argenta Rim fault; WARF = west Argenta Rim fault; BSF = Bateman Spring fault; NSRF = northern Shoshone Range fault. (B) Red dashed lines indicate major normal and oblique-slip faults, including northern Shoshone Range Fault and Argenta Rim Fault. Red arrow indicates pull-apart between NSRF and ARF.

Ongoing petrographic analysis can enhance characterization of lithologies within the study area. It not only characterizes the composition and texture of key rock units but can also reveal the extent and intensity of hydrothermal alteration caused by geothermal fluids.

4.2 Geophysical Surveys

Geophysical surveys for the INGENIOUS project at Argenta Rise were conducted by the U.S. Geological Survey (Earney et al., 2022, 2023, 2024) and include 1,207 gravity stations, approximately 70 line-km of magnetic profiles, and 43 magnetotelluric (MT) stations, along with extensive rock property measurements to constrain potential-field models. Details of these datasets and resulting interpretations are reported in a paper by Earney et al. (2024). These datasets are complemented by interpretation of several proprietary 2D seismic reflection profiles with permission to interpret the profiles acquired by UNR from a seismic data broker.
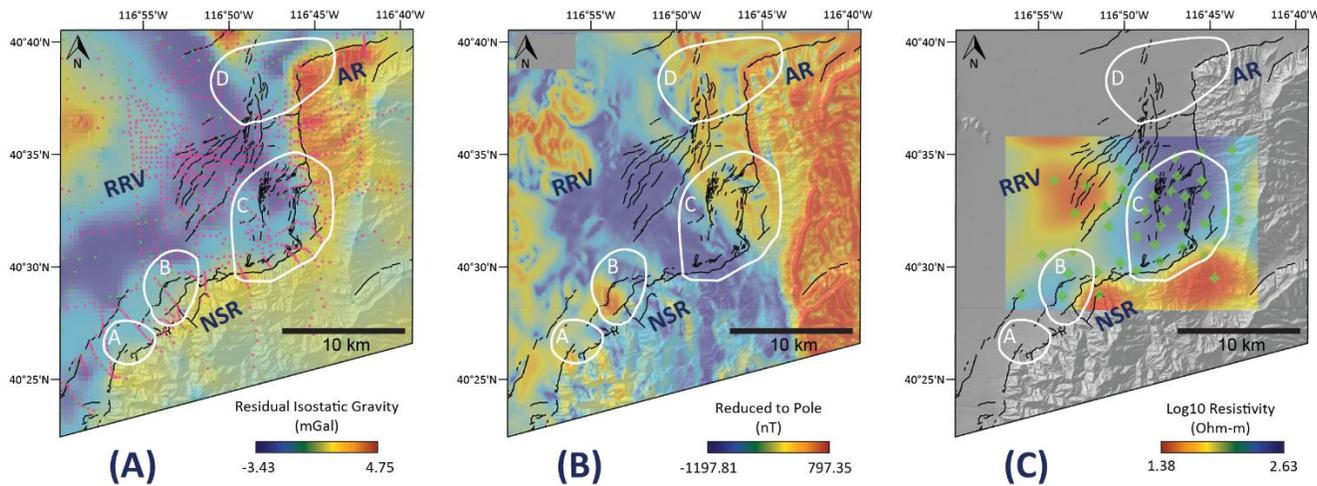

Figure 8: DEM hillshade topography (U.S. Geological Survey, 2024) of the Argenta Rise area of interest overlain by geophysical data. Thin black lines represent Quaternary faults. White outlines indicate favorable structural settings. RRV = Reese River Valley; NSR = northern Shoshone Range; AR = Argenta Rim. (A) Isostatic residual gravity data, including existing (green dots) and new (pink dots) gravity stations; (B) Magnetic data. (C) Magnetotelluric (MT) data at 1.5 km depth, including MT stations (green diamonds).

Preliminary residual isostatic gravity data (Figure 8a) provide an initial interpretation of the subsurface structure at the Argenta Rise study site. In addition to residual isostatic gravity maps, horizontal gravity gradient maps are being used to characterize subsurface geometry. The results highlight pronounced positive gravity gradients associated with basement rocks beneath the northern Shoshone Range and Argenta Rim, in contrast to negative gravity gradients within the Reese River Valley. Gravity gradient maxima are spatially coincident with the northern Shoshone Range fault and Argenta Rim fault. Additionally, a distinct inflection in the gravity gradient at structural setting C corresponds to the broad step-over between the northern Shoshone Range fault and Argenta Rim fault.

Jacinto et al.

Magnetic variations can result from juxtaposed rock types across faults, change in polarity of magnetic remanence in volcanic rocks, the intrusion of igneous bodies, or hydrothermal alteration (Kana et al., 2015). Flight lines were flown along an azimuth of 90 degrees and spaced 400 m apart, while tie lines were flown along an azimuth of 180 degrees and spaced 4,000 m apart (Earney et al., 2024). Structural settings A and D are generally characterized by high magnetic responses, whereas magnetic low anomalies are observed at favorable structural settings B and C (Figure 8b), potentially reflecting alteration of mineral assemblages. These low anomalies exhibit a consistent northwest–southeast orientation, marked by sharp breaks and steep gradients in the magnetic data. Magnetic lows are predominantly concentrated on the western side of the Argenta Rise study area.

In geothermal settings a low-resistivity (high conductivity) anomaly can be indicative of geothermal fluids or high clay content potentially due to hydrothermal alteration. The MT slice at approximately 1.5 km depth reveals low-resistivity anomalies concentrated in structurally favorable settings (specifically the southern margins of favorable structural settings B and C), which include fault intersections and pull-apart zones along the northern Shoshone Range fault (Figure 8c).
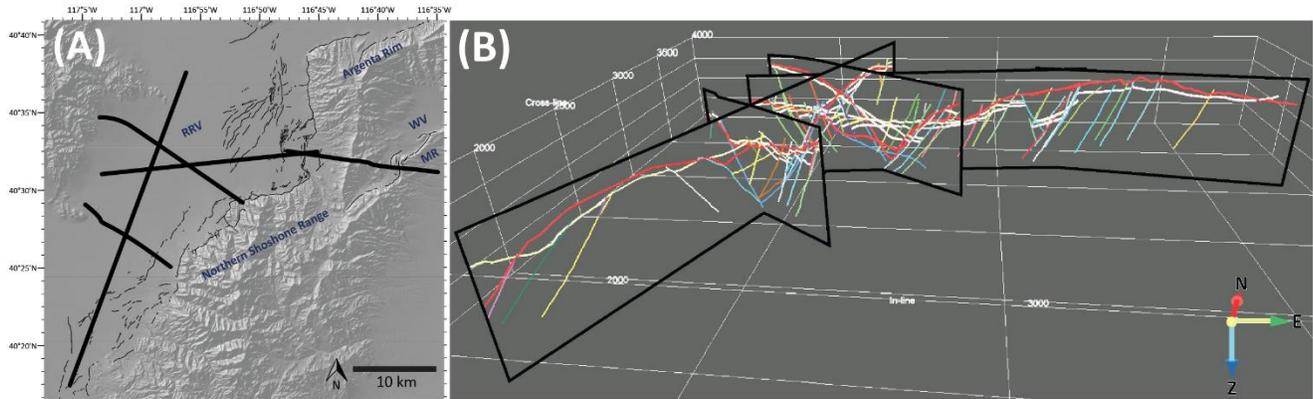

Figure 9. (A) DEM hillshade (U.S. Geological Survey, 2024) topography of northern Reese River Valley highlighting the locations of seismic reflection profiles. WV = Whirlwind Valley; MR = Malpais Rim; RRV = Reese River Valley. (B) Interpreted seismic reflection profiles shown in 3D. Colored lines indicate interpreted stratigraphic horizons, depth to basement, and faults. Image taken from OpendTect software by Nada Mareechi Jacinto.

Five 2D seismic reflection profiles initially acquired in the 1980s were reprocessed for this study. Permission to interpret these profiles was acquired from a seismic data broker. The dataset comprises profiles oriented approximately orthogonal and one parallel to the structural grain as defined by north-northeast striking normal faults (Figure 9a and 9b). Preliminary interpretations include thin volcanic units situated between overlying basin-fill sediments and the underlying basement rocks. Depth-to-basement estimates support the subsurface interpretations and correlate well with existing geological maps, showing increasing depth toward the range front, suggesting half-graben structures.

4.3 Shallow (2-m) Temperature Survey

Two-m temperature surveys provide a cost-effective method for detecting thermal anomalies associated with blind geothermal systems (Kratt et al., 2010). The method involves driving a 2-m hollow steel rod into the ground and lowering a thermal sensor to record temperatures at 1, 1.5, and 2 m depths after at least 45 minutes for equilibration. Base station measurements are also inferred to account for seasonal, radiative, and weather-related temperature variations during multi-phase surveys.
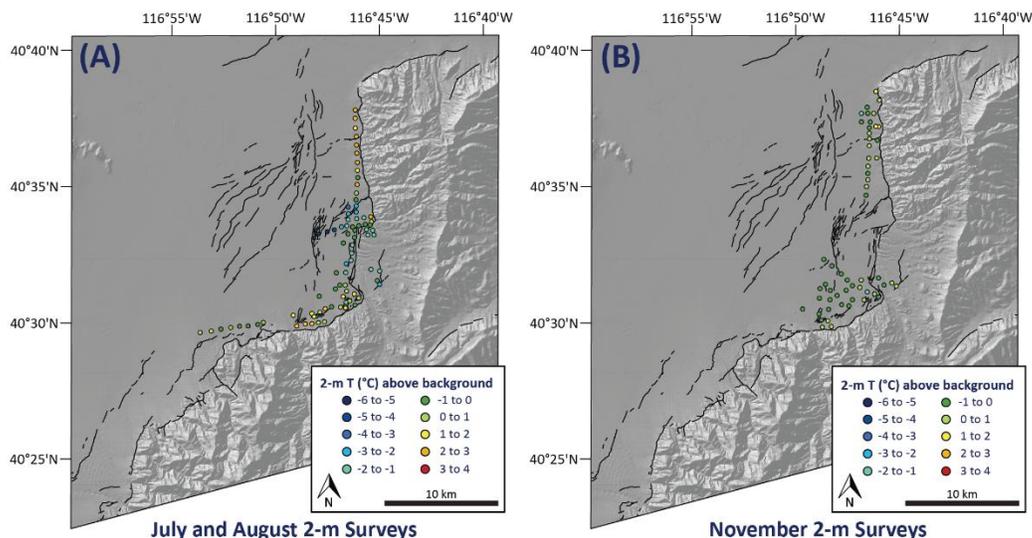
Figure 10. DEM hillshade (U.S. Geological Survey, 2024) topography of the Argenta Rise study area overlain by Quaternary faults and shallow (2-m) temperature survey locations, showing degrees above background measure at each station. (A) Survey from July and August 2021; (B) Survey from November 2021.

At Argenta Rise, a 2-m temperature survey was carried out in the summer and fall of 2021 with 139 stations measured (Figure 10). The data detected only two subtle anomalies. These were either isolated to single stations or exceeded the locally defined background temperature by only a small magnitude (generally ≤ 2 - 3 °C above background). Nonetheless, these data do not negate the possible presence of a potential geothermal resource, because it may be masked by a shallow cool aquifer or located at a greater depth than systems producing definitive shallow anomalies (e.g., Coolbaugh et al., 2007b). There is a possibility that additional 2-m temperature surveys will be conducted due to the lack of data in the southwestern part of the Argenta Rise study area.

4.4 Temperature Gradient (TG) Wells

Based on preliminary geological and geophysical investigations, 10 locations were chosen for TG drilling (Figure 11a). Temperature gradient holes (TGH) were drilled down to ~244 m (800 ft) in the spring of 2025 and equilibrated for a month before temperatures were measured. The geothermal gradients of the wells range from 33.1 °C/km (well 34-41 "I") to 71 °C/km (well 1-88 "E") and have a mean of 46.2 °C/km, which is lower than the regional geothermal gradient of ~56 °C/km (Aljubran and Horne, 2024; Lee et al., 2025; Statewide California Earthquake Center, 2025). Despite the lack of thermal anomalies, the temperatures of the wells at ~244 m depth have a mean of 24.35 °C, which is consistent with the regional temperature of 25.7 °C at 250-m depth (Aljubran and Horne, 2024).
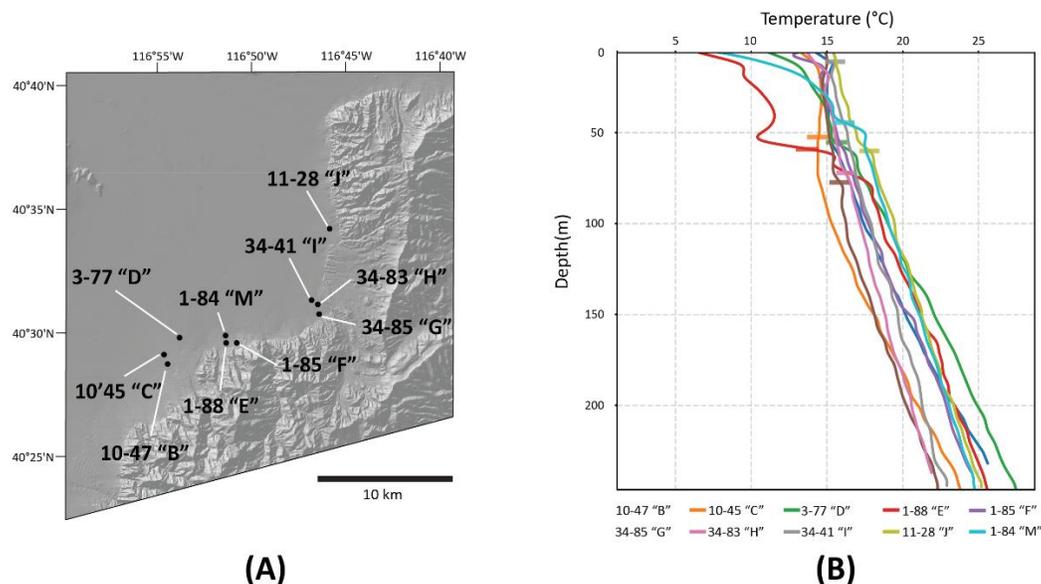

Figure 11: (A) DEM hillshade (U.S. Geological Survey, 2024) topography of the Argenta Rise study area excluding Whirlwind Valley overlain by temperature gradient (TG) well locations (indicated by black dots). (B) Temperature versus depth graph of each TG well. Short horizontal lines indicate the measured water level of each well below land surface.

Jacinto et al.

5. DISCUSSION

The combined geological, structural, geophysical, and thermal datasets provide a refined view of the Argenta Rise area and its potential for hosting a blind geothermal system. Geological mapping, lidar, and structural analysis identified four structurally favorable settings characterized by fault intersections, step-overs, and displacement transfer zones. Structural and kinematic analyses indicate that east-northeast striking faults accommodate sinistral-normal slip, whereas north- to north-northeast striking faults are dominated by normal slip, highlighting the variability in fault behavior and the potential influence of fault kinematics on fluid flow (Faulds et al., 2024). Geophysical surveys complement these observations: gravity gradients align with major faults (e.g., northern Shoshone Range and Argenta Rim faults), magnetic lows correspond to possible hydrothermal alteration zones, and MT data at ~1.5 km depth show low-resistivity anomalies concentrated at structural settings B and C (Figure 7). Overall, the geological and geophysical datasets largely converge, identifying zones where fault geometry and subsurface properties could support a geothermal system, though each method provides slightly different spatial constraints on these apparently favorable zones.

Despite the promising geological and geophysical attributes, shallow thermal measurements do not currently support the presence of a geothermal resource at the investigated locations. The 2-m temperature survey detected only subtle anomalies (Figure 10). Moreover, the 10 TG wells drilled to ~244 m did not record any thermal anomalies (Figure 11). These results may reflect limitations in the current survey design, including the large size of the study area (~1,150 km²), which may have led to under-sampling of thermally anomalous zones. Another possibility is that shallow cool aquifers associated with drainage from the nearby mountain ranges (e.g., favorable setting C - Figure 7) mask a deeper geothermal system. These negative results underscore the challenges of geothermal exploration for blind systems, where surface and shallow subsurface proxies may not directly reflect deeper heat sources.

The absence of shallow thermal anomalies does not preclude the presence of a geothermal system at Argenta Rise but instead suggests alternative system geometries and processes that may not be captured by the current exploration depth or spatial sampling. Given the large areal extent of the study area, which is much larger than the adjacent Beowawe geothermal system, it is plausible that the geothermal reservoir is localized outside the current TG well array or concentrated within a narrower structural corridor that was not directly tested. Alternatively, in such a broad and structurally complex domain, fluid flow may be diffused rather than focused, limiting the development of discrete upflow zones detectable by shallow temperature surveys and also reducing the likelihood of a commercially viable system. It is also possible that Argenta Rise may represent a downwelling or recharge-dominated area, where meteoric fluids circulate downward along permeable fault zones, effectively suppressing shallow thermal expressions despite favorable structural indicators. These hypotheses highlight the importance of considering scale, hydrologic regime, and depth of circulation in evaluating blind geothermal systems.

6. CONCLUSIONS

Based on the multidisciplinary analysis conducted at Argenta Rise, we conclude that the site exhibits relatively compelling geological and geophysical indicators consistent with a favorable geothermal setting, yet the absence of shallow thermal anomalies presents an exploration paradox. Geological mapping and structural analysis have identified several favorable structural settings, including fault intersections and step-overs, which are known to host permeability conducive to geothermal systems. Geophysical surveys further support this potential, revealing gravity and magnetic signatures aligned with major faults and low-resistivity anomalies suggestive of fluid or alteration zones at depth. However, data from shallow temperature surveys and a network of ten temperature-gradient wells to ~244 m depth did not detect thermal anomalies, indicating that any potential geothermal system is not expressed in the shallow subsurface within the sampled areas. This discrepancy underscores the "blind" nature of the target and suggests that the geothermal resource, if present, may be localized in a narrower structural zone, masked by shallow cool aquifers, situated at a greater depth than currently probed, or is simply absent. Consequently, although Argenta Rise remains a prospective area, definitively characterizing its resource will likely require refined targeting, potentially through deeper drilling focused on the most promising structural and geophysical anomalies identified through planned local-scale play fairway analysis.

7. ACKNOWLEDGMENTS

REFERENCES

Aljubran, M., and Horne, R., 2024, Stanford Thermal Earth Model for the Conterminous United States: Stanford University, Geothermal Data Repository, https://doi.org/10.15121/2324793.

Ayling, B., Faulds, J., Morales Rivera, A., Koehler, R., Kreemer, C., Mlawsky, E., Coolbaugh, M., Micander, R., dePolo, C., Kraal, K., Wagoner, N., Siler, D., DeAngelo, J., Glen, J., Peacock, J., Batir, J., Gentry, E., Berti, C., Lifton, Z., Clark, A., Kirby, S., Hardwick, C., and Kleber, E., 2022, INGENIOUS – Great Basin Regional Dataset Compilation: U.S. Department of Energy (DOE) Geothermal Data Repository.

Basler, L.C., Carrapa, B., Kapp, P., and Ducea, M.N., 2026, Crustal thickness and elevation of the North American Cordillera from the Late Cretaceous to the Early Miocene: *Tectonics*, v. 45, e2025TC009110, https://doi.org/10.1029/2025TC009110.

Blackwell, D.D., 1983, Heat flow in the northern Basin and Range Province, *in* The role of heat in the development of energy and mineral resources in the northern Basin and Range Province: Geothermal Resources Council Special Report 13, p. 81–92.

Blackwell, D., Richards, M., Wisian, K., and Steele, J., 1999, System specific geothermal gradient/heat flow data base for the western United States: Geothermal Resources Council Transactions, v. 23, p. 461–466.

Blackwell, D.D., Richards, M., Frone, Z., and Batir, J., 2011, Temperature-at-depth maps for the conterminous U.S. and geothermal resource estimates: Geothermal Resources Council Transactions, v. 35, p. 1545–1550.

Burgess, Q., and Faulds, J.E., 2024, Characterization and Analysis of a Potential Hidden Geothermal Resource in the Jersey Summit Area, North-Central, Nevada: 49th Workshop on Geothermal Reservoir Engineering, Stanford University, 8 p.

Cashman, P.H., and Sturmer, D.M., 2021, Paleogeographic reconstruction of Mississippian to Middle Pennsylvanian basins in Nevada, southwestern Laurentia: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 584, 110697, https://doi.org/10.1016/j.palaeo.2021.110697.

Colgan, J.P., and Henry, C.D., 2009, Rapid middle Miocene collapse of the Mesozoic orogenic plateau in north-central Nevada: *International Geology Review*, v. 51, p. 920–961, https://doi.org/10.1080/00206810902923714.

Colgan, J.P., Henry, C.D., and John, D.A., 2014, Evidence for large-magnitude, post-Eocene extension in the northern Shoshone Range, Nevada, and its implications for the structural setting of Carlin-type gold deposits in the lower plate of the Roberts Mountains allochthon: Economic Geology, v. 109, p. 1843–1862, https://doi.org/10.2113/econgeo.109.7.1843.

Crafford, A.E.J., 2007, Geologic map of Nevada: U.S. Geological Survey Data Series 249, https://pubs.usgs.gov/ds/249.

Craig, J.W., Faulds, J.E., Hinz, N.H., Earney, T.E., Schermerhorn, W.D., Siler, D.L., and Deoreo, S.B., 2021, Discovery and analysis of a blind geothermal system in Southeastern Gabbs valley, Western Nevada, USA: Geothermics, v. 97, 102177, https://doi.org/10.1016/j.geothermics.2021.102177.

Dalziel, I.W.D., 1997, Overview: Neoproterozoic-Paleozoic geography and tectonics: Review, hypothesis, environmental speculations: Geological Society of America Bulletin, v. 109, p. 16–42, https://doi.org/10.1130/0016-7606(1997)109<0016:ONPGAT>2.3.CO;2.

DeCelles, P.G., 2004, Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western USA: American Journal of Science, v. 304, p. 105–168, https://doi.org/10.2475/ajs.304.2.105.

DeCelles, P.G., and Coogan, J.C., 2006, Regional structure and kinematic history of the Sevier fold-and-thrust belt, central Utah: *Geological Society of America Bulletin*, v. 118, p. 841–864, https://doi.org/10.1130/B25759.1.

Dickinson, W.R., 2006, Geotectonic evolution of the Great Basin: Geosphere, v. 2, p. 353–368, https://doi.org/10.1130/GES00054.1.

Earney, T.E., Glen, J., Peacock, J., Faulds, J., Schermerhorn, W., Rea-Downing, G., Anderson, J., Lindsey, C., and Richards, M., 2024, Geophysical modeling of a possible blind geothermal system near Battle Mountain, NV: Geothermal Resources Council Transactions, v. 48, p. 209–229.

Elison, M.W., 1995, Causes and consequences of Jurassic magmatism in the northern Great Basin: Implications for tectonic development [Ph.D. thesis]: Los Angeles, University of California, 300 p.

Faulds, J.E., Coolbaugh, M., Blewitt, G., and Henry, C.D., 2004, Why is Nevada in hot water? Structural controls and tectonic model of geothermal systems in the northwestern Great Basin: Geothermal Resources Council Transactions, v. 28, p. 649–654.

Faulds, J., Hinz, N., Kreemer, C., and Coolbaugh, M., 2012, Regional patterns of geothermal activity in the Great Basin region, western USA: Correlation with strain rates: Geothermal Resources Council Transactions, v. 36, p. 897–902.

Faulds, J., Hinz, N., Dering, G., and Siler, D., 2013, The hybrid model—The most accommodating structural setting for geothermal power generation in the Great Basin, western USA: Geothermal Resources Council Transactions, v. 37, p. 3–10.

Faulds, J.E., and Hinz, N.H., 2015, Favorable tectonic and structural settings of geothermal systems in the Great Basin region, western USA: Proxies for discovering blind geothermal systems, *in* Proceedings, World Geothermal Congress 2015: Melbourne, Australia, 6 p.

Faulds, J.E., Hinz, N., dePolo, C., Hammond, W., Kreemer, C., Shevenell, L., Coolbaugh, M., Queen, J., Siler, D., Visser, C., and Wannamaker, P., 2016, Discovering blind geothermal systems in the Great Basin Region: An integrated geologic and geophysical approach for establishing geothermal play fairways: U.S. Department of Energy Final Report DE-EE0006731, p. 1–106.

Faulds, J.E., Hinz, N.H., Coolbaugh, M.F., Sadowski, A.J., Shevenell, L.A., McConville, E.G., Craig, J.W., Siler, D.L., and Sladek, C., 2017, Progress report on the Nevada play fairway project: Integrated geological, geochemical, and geophysical analyses of possible new geothermal systems in the Great Basin region, *in* Proceedings, 42nd Workshop on Geothermal Reservoir Engineering: Stanford, California, Stanford University, SGP-TR-212, 11 p.

Faulds, J.E., Hinz, N.H., Coolbaugh, M.F., Ramelli, A., Glen, J.M, Ayling, B.A., Wannamaker, P.E., DeOreo, S.B., Siler, D.L., and Craig, J.W., 2019, Vectoring into potential blind geothermal systems in the Granite Springs Valley area, western Nevada: Application of the play fairway analysis at multiple scales: Proceedings 44th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, SGPTR-214, p. 74-84.

Faulds, J.E., Coolbaugh, M.F., and Hinz, N.H., 2021a, Inventory of structural settings for active geothermal systems and late Miocene (~8 Ma) to Quaternary epithermal mineral deposits in the Basin and Range province of Nevada: Nevada Bureau of Mines and Geology Report 58, 27 p., 3 plates, scale 1:2,500,000.

Jacinto et al.

Faulds, J.E., Hinz, N.H., Coolbaugh, M.F., Craig, J.W., Glen, J.M., Ayling, B.F., Sadowski, A.J., Siler, D.L, and DeOreo, S., 2021b, The Nevada geothermal play fairway project: Exploring for blind geothermal systems through integrated geological, geochemical, and geophysical analyses: Proceedings World Geothermal Congress, Reykjavik, Iceland, 12 p.

Faulds, J.E., and Richards, M.C., 2023, INGENIOUS transitions from regional to local scale to find hidden geothermal systems: Geothermal Resources Council Transactions, v. 47, 17 p.

Faulds, J.E., Earney, T.E., Glen, J.M.G., Queen, J.H., Peacock, J., Hart-Wagoner, N., Kraal, K., Lindsey, C., Burgess, Q., and Giddens, M.H., 2024, Structural setting and geothermal potential of northeastern Reese River Valley, north-central Nevada: highly prospective detailed study site for the INGENIOUS project: Geothermal Resources Council Transactions, v. 48, 18 p.

Gilluly, J., Gates, O., Plouff, D., and Ketner, K.B., 1965, Tectonic and igneous geology of the northern Shoshone Range, Nevada: U.S. Geological Survey Professional Paper 465, 153 p.

Grauch, V.J.S., Rodriguez, B.D., Bankey, V., and Wooden, J.L., 2003, Evidence for a Battle Mountain–Eureka crustal fault zone, north-central Nevada, and its relation to Neoproterozoic–Early Paleozoic continental breakup: Journal of Geophysical Research: Solid Earth, v. 108, B3, 2163, https://doi.org/10.1029/2001JB000687.

Hart-Wagoner, N., Coolbaugh, M.F., Faulds, J.E., Mlawsky, E., Lindsey, C., Trainor-Guitton, W., and Brown, S., 2024, Preliminary regional play fairway workflow for the Great Basin Region, USA, *in* Proceedings, 49th Workshop on Geothermal Reservoir Engineering: Stanford, California, Stanford University, 12 p.

Hoang, V.T., James, E.D., and Epperson, I.J., 1987, Development drilling, testing and initial production of the Beowawe Geothermal Field, *in* Proceedings, 12th Workshop on Geothermal Reservoir Engineering: Stanford, California, Stanford University, SGP-TR-109, p. 23–31.

House, P.K., Ramelli, A.R., Wrucke, C.T., and John, D.A., 2000, Geologic map of the Argenta quadrangle, Lander County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 2000-07, scale 1:24,000.

John, D.A., and Wrucke, C.T., 2003, Geologic map of the Mule Canyon quadrangle, Lander County, Nevada: Nevada Bureau of Mines and Geology Map 144, scale 1:24,000.

John, D.A., Henry, C.D., and Colgan, J.P., 2008, Magmatic and tectonic evolution of the Caetano caldera, north-central Nevada: A tilted, mid-Tertiary eruptive center and source of the Caetano Tuff: Geosphere, v. 4, p. 75–106, https://doi.org/10.1130/GES00162.1.

Kana, J.D., Djongyang, N., Raïdandi, D., Nouck, P.N., and Dadjé, A., 2015, A review of geophysical methods for geothermal exploration: Renewable and Sustainable Energy Reviews, v. 44, p. 87–95, https://doi.org/10.1016/j.rser.2014.12.026.

Karlstrom, K.E., Harlan, S.S., Williams, M.L., McLelland, J., Geissman, J.W., and Åhäll, K.I., 1999, Refining Rodinia: Geologic evidence for the Australia–Western U.S. connection in the Proterozoic: GSA Today, v. 9, no. 10, p. 1–6.

Kratt, C., Sladek, C., and Coolbaugh, M., 2010, Boom and bust with the latest 2m temperature surveys: Dead Horse Wells, Hawthorne Army Depot, Terraced Hills, and other areas in Nevada: Geothermal Resources Council Transactions, v. 34, p. 567–574.

Lee, T., Zuza, A.V., Trugman, D.T., Vlaha, D.R., and Cao, W., 2025, Statewide Community Thermal Model of California and Nevada: Model comparisons, implications, and a new explorer platform: 2025 Statewide California Earthquake Center Annual Meeting, https://central.scec.org/meetings/2025/am/poster/319.

Miller, D., Hoisch, T.D., 1995, Jurassic tectonics of northeastern Nevada and northwestern Utah from the perspective of barometric studies, chap. *of* Jurassic magmatism and tectonics of the North American cordillera: Special Papers of the Geological Society of America, v. 299, p. 267-294, https://doi.org/10.1130/SPE299-p267.

Ramelli, A.R., House, P.K., Wrucke, C.T., and John, D.A., 2001, Geologic map of the Stony Point quadrangle, Lander County, Nevada: Nevada Bureau of Mines and Geology Map 131, scale 1:24,000.

Ramelli, A.R., Wrucke, C.T., and House, P.K., 2017, Geologic map of the Bateman Spring quadrangle, Lander County, Nevada: Nevada Bureau of Mines and Geology Map 185, scale 1:24,000.

Richardson, C.A., and Seedorff, E., 2023, Exploring for structurally concealed Carlin-type mineralization: A case study from the northern Shoshone Range, Nevada, USA: Ore Geology Reviews, v. 163, 105738, https://doi.org/10.1016/j.oregeorev.2023.105738.

Schwartz, T.M., Wyld, S.J., Colgan, J.P., and Prihar, D.W., 2024, Late Triassic paleogeography of southern Laurentia and its fringing arcs: Insights from detrital zircon U-Pb geochronology and Hf isotope geochemistry, Auld Lang Syne basin (Nevada, USA): *Geological Society of America Bulletin*, v. 136, p. 4595–4615, https://doi.org/10.1130/B37080.1.

Southern California Earthquake Center, 2025, Community Thermal Model Explorer, http://moho.scec.org/research/ctm-explorer/explorer.php.

Struhsacker, E.M., 1980, The geology of the Beowawe geothermal system, Eureka and Lander Counties, Nevada: Salt Lake City, University of Utah Research Institute, Earth Science Laboratory Report 37, 78 p.

U.S. Geological Survey, 2021, The National Map data delivery, https://www.usgs.gov/the-national-map-data-delivery

U.S. Geological Survey, 2022, Interactive U.S. Fault Map, https://www.usgs.gov/tools/interactive-us-fault-map

U.S. Geological Survey, 2024, 3D Elevation Program 10-meter resolution digital elevation, https://www.usgs.gov/the-national-map-data-delivery.

Watt, J.T., Glen, J.M., John, D.A., and Ponce, D.A., 2007, Three-dimensional geologic model of the northern Nevada rift and the Beowawe geothermal system, north-central Nevada: Geosphere, v. 3, p. 667–682, https://doi.org/10.1130/GES00123.1.

Wesnousky, S.G., Barron, A.D., Briggs, R.W., Caskey, S.J., Kumar, S., and Owen, L.A., 2005, Paleoseismic transect across the northern Great Basin: Journal of Geophysical Research: Solid Earth, v. 110, B05408, https://doi.org/10.1029/2004JB003283.

White, D.E., 1992, The Beowawe Geysers, Nevada, before geothermal development: U.S. Geological Survey Bulletin 1998, 25 p.

Williams, C.F., Reed, M.J., Mariner, R.H., DeAngelo, J., and Galanis, S.P., Jr., 2008, Assessment of moderate- and high-temperature geothermal resources of the United States: U.S. Geological Survey Fact Sheet 2008–3082, 4 p.

Wyld, S.J., 2002, Structural evolution of a Mesozoic backarc fold-and-thrust belt in the U.S. Cordillera: New evidence from northern Nevada: Geological Society of America Bulletin, v. 114, p. 1452–1468, https://doi.org/10.1130/0016-7606(2002)114<1452:SEOAMB>2.0.CO;2.

Yonkee, W.A., and Weil, A.B., 2015, Tectonic evolution of the Sevier and Laramide belts within the North American Cordillera orogenic system: *Earth-Science Reviews*, v. 150, p. 531–593, https://doi.org/10.1016/j.earscirev.2015.08.001.

Zoback, M.L., 1979, A geologic and geophysical investigation of the Beowawe geothermal area, north-central Nevada: Stanford University Publications in the Geological Sciences, v. 16, 79 p.

Zoback, M.L., 1989, State of stress and modern deformation of the northern Basin and Range province: Journal of Geophysical Research: Solid Earth, v. 94, p. 7105–7128, https://doi.org/10.1029/JB094iB06p07105.

Zoback, M.L., McKee, E.H., Blakely, R.J., and Thompson, G.A., 1994, The northern Nevada rift: Regional tectono-magmatic relations and middle Miocene stress direction: Geological Society of America Bulletin, v. 106, p. 371–382, https://doi.org/10.1130/0016-7606(1994)106<0371:TNNRRT>2.3.CO;2.