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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

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ABSTRACT

We have completed a comprehensive inventory of the structural settings of known geothermal systems (>200 total; ≥37°C) and late Miocene (~8 Ma) to Quaternary epithermal mineral deposits in the extensional to transtensional region of Nevada. The structural settings are important to characterize, because many geothermal systems and epithermal mineral deposits are hidden beneath the surface, and thus these settings can be used as an exploration tool to find new systems or deposits. Of the known geothermal systems in Nevada, for example, ~37% are blind or hidden (no surface hot springs or fumaroles).

We catalogued geothermal systems into eight major groups, based on the dominant pattern of faulting. Of the ~214 known systems in Nevada, we found that step-overs or relay ramps in normal fault zones are the most common setting, hosting ~39% of the systems. Step-overs are characterized by multiple, commonly overlapping fault strands, increased fracture density, and thus enhanced permeability. Other common settings include a) normal fault terminations (~23%), where horsetailing generates a myriad of closely spaced faults and thus increased fracture permeability; and b) fault intersections between normal faults or between normal faults and transverse oblique-slip faults (~21%), where multiple minor faults typically connect major structures, and fluids can flow readily through highly fractured, dilational quadrants. Less common settings include: a) accommodation zones (~5%); b) displacement transfer zones (~4%) at the ends of strike-slip faults; c) pull-aparts in strike-slip faults (~4%); d) bends in normal faults (~1%); and e) major range-front normal faults (~1%). Pull-aparts and displacement transfer zones are more abundant in the transtensional western part of the region within and near the dextral shear zone of the Walker Lane. Quaternary faults typically lie within or near most of the geothermal systems. Controlling faults in the systems most commonly strike north-northeast (~54% of systems) approximately orthogonal to the regional extension direction. Northerly striking faults (~N10°W to N10°E) are also relatively common and serve as the primary controlling structure in ~32% of the systems.

Most late Miocene to recent epithermal mineral deposits in Nevada occupy similar structural settings. Step-overs are the most common type of setting, followed by fault terminations, accommodation zones, and displacement transfer zones. Similar to active geothermal systems, the formation of epithermal deposits is favored by complex structural settings. These data can be used to guide exploration strategies, because economic concentrations of precious metals typically occupy only a small percentage of their respective districts.

The favorable structural settings for geothermal systems and epithermal mineral deposits (e.g., step-overs, fault terminations, and accommodation zone) correspond to long-term, critically stressed areas, where fluid pathways more likely remain open in networks of closely spaced, breccia-dominated fractures. Hydrothermal systems are rare along the main segments of normal faults due to reduced permeability in zones of clay gouge and periodic release of stress in major earthquakes. Accommodation zones, displacement transfer zones, and pull-aparts are disproportionately associated with higher temperature and/or power-producing geothermal systems. These settings appear to be especially favorable for enabling fluids to circulate to and from relatively great depths (up to 5+ km). Notably, many higher temperature systems are hybrids containing more than one type of favorable setting.

INTRODUCTION

Better characterization of known geothermal systems and epithermal mineral deposits is critical for discovering new systems, expansion of known systems, and reducing the risks in development. This is especially important in the Great Basin region of the Basin and Range province (fig. 1), where the bulk of the geothermal systems (~75%) may have little or no surface manifestation (i.e., blind or hidden; Coolbaugh et al., 2006a), and thus techniques are needed to indicate the most favorable locations for targeting subsurface resources. Similarly, many young epithermal systems are exposed at shallow levels above their respective precious metal horizons (e.g., Coolbaugh et al., 2020), and future discoveries will increasingly rely on the ability to vector toward hidden resources (Reid et al., 2020). Knowledge of structural settings and their geological significance provides one means of accomplishing this. To provide a foundation for interpreting structural settings in geothermal and epithermal environments, it is useful to characterize and catalogue known systems on the basis of the prominent

fault pattern or structural setting (e.g., Curewitz and Karson, 1997; Faulds et al., 2011, 2012; Faulds and Hinz, 2015). Syntheses in the Great Basin region have been bolstered by detailed studies of individual representative systems across the region (e.g., Faulds and Melosh, 2008; Faulds et al., 2010, 2017; Hinz et al., 2008, 2010, 2011; Rhodes et al., 2010; Dering and Faulds, 2012; Edwards and Faulds, 2012; Anderson and Faulds, 2013; Siler et al., 2016, 2018). In this report, we summarize results of cataloguing favorable structural settings for >200 known geothermal systems and 26 epithermal mineral deposits in Nevada.

REGIONAL SETTING

Western North America contains a diffuse plate boundary (fig. 1A), characterized by dextral motion between the Pacific and North American plates (e.g., Atwater and Stock, 1998) and west- to northwest-directed extension within the Basin and Range province (e.g., Wernicke, 1992). Much of the dextral plate motion is taken up by the San Andreas fault system, including a system of pull-aparts within the Gulf of California and Salton Trough of southern California. However, the San Andreas fault system accommodates ~80% of the plate motion (~4 cm/yr). The other ~20% (~1 cm/yr) is distributed across the western Basin and Range province in a belt of dextral shear known as the Walker Lane in the north and eastern California shear zone in the south (e.g., Stewart, 1988; Faulds and Henry, 2008; Kreemer et al., 2009). In concert with the San Andreas fault terminating northward at the Mendocino triple junction, the Walker Lane dies out northwestward in northwest Nevada-northeast California.

As the Walker Lane terminates to the northwest, dextral shear appears to diffuse into west-northwest-directed extension across much of central to northern Nevada (Faulds et al., 2004; fig. 1B). Enhanced extension and

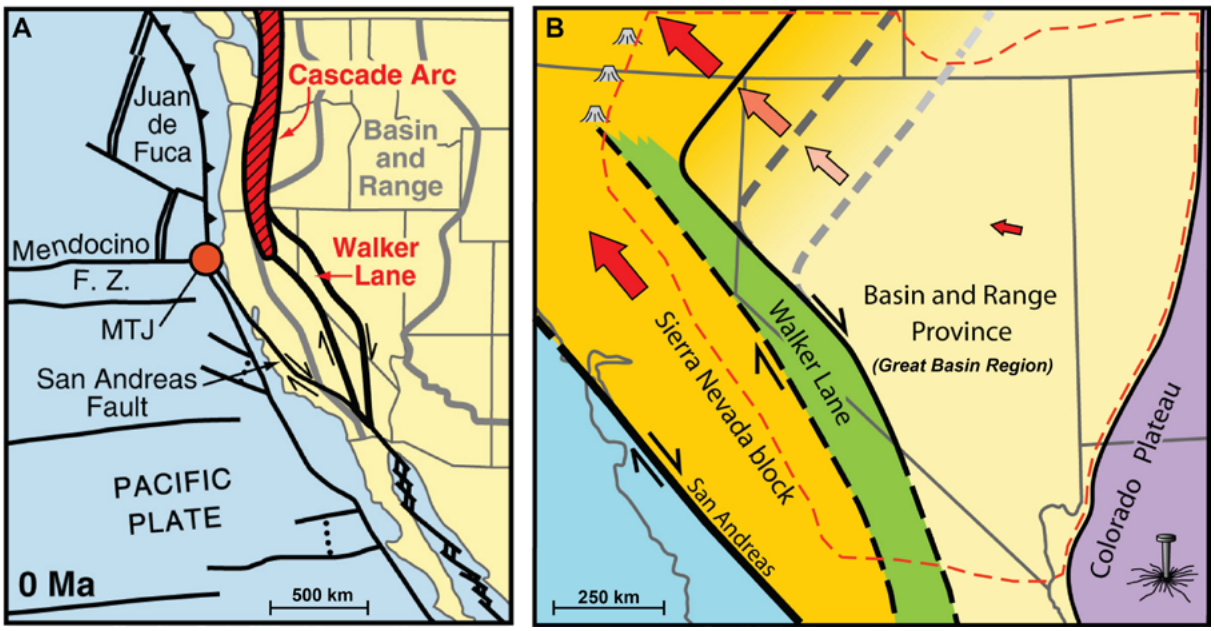

Figure 1. A. Cenozoic tectonic setting, western North America (after Atwater and Stock, 1998). The San Andreas fault system accommodates about 80% (~4 cm/yr) of the relative motion between the Pacific and North American plates and terminates northward at the Mendocino triple junction (MTJ). The Walker Lane accommodates ~20% (1 cm/yr) of the plate motion and terminates in northeastern California directly inland of the MTJ. F.Z.—fracture zone. **B.** Generalized map showing the relations between dextral shear in the Walker Lane and extension in the Great Basin region of the Basin and Range province (from Faulds and Henry, 2008). Red dashed line shows the approximate boundary of the Great Basin region. Arrows show generalized relative motions with respect to the Colorado Plateau, which is held stationary in this schematic model as implied by the nail. As the Walker Lane terminates in northwestern Nevada and northeastern California, ~1 cm/yr of dextral shear is diffused into extension across the northwestern part of the Great Basin, which includes central to northern Nevada. Enhanced extension in this area is conducive to geothermal activity.

dilation in this region generates a favorable environment for geothermal activity. High-temperature systems in particular cluster within the zones of highest strain directly northeast of the Walker Lane (Faulds et al., 2013). Notably, as the Walker Lane has propagated northwestward since the late Miocene, the Cascade magmatic arc has retreated to the northwest (Faulds and Henry, 2008). Accordingly, magmatism has generally ceased since the late Miocene. Thus, most of the geothermal systems in Nevada are not related to obvious upper crustal magmatic heat sources, but are instead fault controlled. Systematic assessment of the characteristic fault patterns or structural settings of geothermal systems can therefore yield important insights into identifying blind geothermal systems throughout the region. Because regional extension generally accompanied magmatism in the ancestral Cascade arc, this analysis is also relevant to late Miocene volcanic-related epithermal mineral deposits in the region, which are generally at least partially fault controlled.

PREVIOUS WORK

Substantial previous work on the structural controls of geothermal systems in the Great Basin and elsewhere has enabled this research. It has long been known that individual fields are commonly controlled by moderately to steeply dipping normal fault zones, as exemplified at the Dixie Valley (Blackwell et al., 1999; Johnson and Hulen, 2002; Wannamaker, 2003), Star Peak (previously referred to as Rye Patch; Waibel et al., 2003), Bradys, and Desert Peak fields (Benoit et al., 1982; Faulds et al., 2010). Our initial regional assessment of structural controls in the Great Basin showed that north- to northeast-striking faults (N0°E–N60°E) are the primary controlling structure for ~75% of the fields, and this control is strongest for higher temperature systems (Coolbaugh et al., 2002; Faulds et al., 2004). In the northwestern Great Basin, the north-northeast-striking controlling faults are oriented approximately orthogonal to the regional extension direction.

However, north-northeast-striking normal faults abound in the Great Basin, and many show no signs of geothermal activity. Thus, it is important to determine which faults or which segments of individual faults are most likely to host geothermal activity. In an effort to better characterize structural controls on geothermal activity in extended terranes, we have therefore analyzed numerous geothermal fields in the region through integrated geologic and geophysical investigations (Faulds et al., 2004, 2005, 2006, 2010, 2011, 2017; Coolbaugh et al., 2005b, 2006a, b, 2007; Vice et al., 2007; Faulds and Melosh, 2008; Hinz et al., 2008, 2010; Rhodes et al., 2010; Faulds and Hinz, 2015; Siler et al., 2016, 2018, 2019). Methods have included detailed geologic mapping, structural analysis, gravity surveys, studies of surficial geothermal features (e.g., sinter, travertine, springs, and fumaroles), shallow temperature surveys, 3D modeling, and stress modeling.

Our findings have shown that many fields occupy 1) terminations of normal faults; 2) discrete steps in normal fault zones or relay ramps, 3) intersections between normal faults and transversely oriented oblique-slip faults, 4) overlapping oppositely dipping normal fault zones or accommodation zones, 5) displacement transfer zones whereby strike-slip fault zones end in arrays of normal faults, or 6) transtensional pull-apart zones (fig. 2). All of these settings are typically associated with moderately to steeply dipping normal faults, most commonly involving subvertical conduits of highly fractured rock along or near Quaternary fault zones oriented approximately perpendicular to the least principal stress (i.e., regional extension direction). General topographic features indicative of these settings include: a) lateral terminations of mountain ranges, b) major steps in range fronts, c) interbasinal highs, and d) mountain ranges consisting of relatively low, discontinuous ridges. Surficial features, such as sinter deposits, tufa towers, and travertine spring mounds are also associated with many systems. These structural, topographic, and surficial features may indicate hidden or blind geothermal fields, which have no surface thermal waters or steam (i.e., hot springs, fumaroles, or geysers).

Our findings are consistent with the conclusions of other studies. For example, in a global survey, Curewitz and Karson (1997) found that hot springs are generally concentrated near the ends of faults or at fault intersections. Micklethwaite and Cox (2004) found that zones of high permeability in fault systems correspond to paleo-rupture arrest areas at the ends of fault segments. The rupture-arrest regions mark areas of aftershocks and multiple interconnecting fault splays, where fluid flow is favored. In normal fault systems, these rupture arrest regions commonly correspond to discrete step-overs in fault zones or reversals in the dominant dip direction

of systems of faults (Roberts and Jackson, 1991; Faulds and Varga, 1998). Such rupture arrest regions may also account for high-permeability flow paths occurring in spatially discrete but negligible overall fractions of individual faults, as documented in the Borax Lake geothermal field in southern Oregon (Fairley and Hinds, 2004).

Although many structural settings have been documented for geothermal systems in extensional terranes, and conceptual models developed for some of these settings, published syntheses have been rare and generally lacking in accompanying detailed datasets (e.g., Curewitz and Karson, 1997; Rowland and Simmons, 2012; Faulds and Hinz, 2015). The lack of such datasets makes it more difficult to determine the likelihood of finding a geothermal system in a particular structural setting or determine the risk of drilling in a particular location even within a known geothermal field, as that field might contain more than one type of structural feature. The results described herein for 214 geothermal systems across the entire state of Nevada represent one of the first published, comprehensive catalogues of the structural settings of such systems for a large contiguous region.

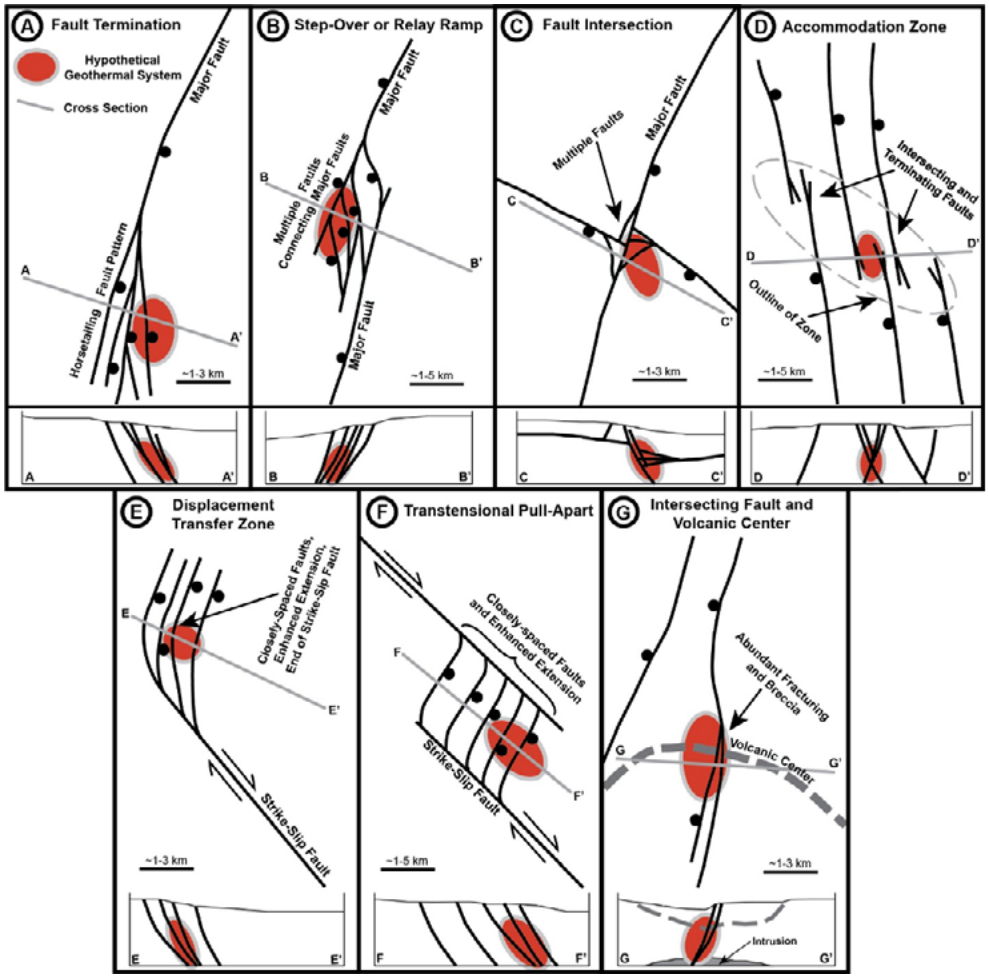

Figure 2. Schematic representations of favorable structural settings with accompanying cross sections. Red shaded areas mark approximate locations of hypothetical geothermal upwellings in map view and cross sections. **A.** Fault tip or termination showing horsetailing pattern of closely spaced faults at the termination of a major normal fault. **B.** Step-over or breached relay ramp showing abundant minor faults connecting overlapping strands of a major normal fault zone. **C.** Fault intersection with abundant minor faults proximal to the intersection. **D.** Accommodation zone (marked by gray ellipse) encompassing a belt of terminating, overlapping, and intersecting normal faults. **E.** Displacement transfer zone whereby a major strike-slip fault terminates in an array of normal faults. **F.** Transtensional pull-apart incorporating multiple closely spaced normal faults connecting a releasing step in a major strike-slip fault. **G.** Intersecting normal fault and margin of volcanic center (thick dashed gray line).

DATABASE

An initial database from Coolbaugh (2003) of geothermal systems in the Great Basin region of the Basin and Range province was used to evaluate relationships between geothermal activity and geospatial data, such as Quaternary fault orientations, and crustal strain rates and to generate predictive maps of geothermal potential for Nevada (Coolbaugh et al., 2002; Coolbaugh, 2003) and the Great Basin region (Coolbaugh et al., 2005b). Coverage of the initial database was limited to the confines of the Great Basin region, as defined by Fenneman (1928), with a 70-km-wide buffer added. The buffer made possible the evaluation of geothermal activity in the geologically complex margins of the Great Basin, which host a number of magmatic-heated geothermal systems (e.g., Coso, Mammoth, Mount Lassen, and Mount Shasta in California; Newberry Crater in Oregon; Roosevelt Hot Springs in Utah; and possibly Steamboat Springs in Nevada (Arehart et al., 2003; Kennedy and van Soest, 2007)).

For the purposes of the database, a geothermal system was defined as the occurrence of hot water either in springs or shallow wells at temperatures of at least 37°C. Multiple, relatively closely spaced hot springs and/or hot wells were grouped into individual "geothermal systems", and a central point was chosen to represent the loci of springs and wells. A minimum 10-km-distance between geothermal systems was required; otherwise the data points were considered part of the same geothermal system, unless geothermal production well data and/or structural data suggested that thermal wells and springs were not in communication with each other.

A key characteristic of geothermal systems is reservoir temperature. In a few cases where deep wells are present, the reservoir temperature can be directly measured, but in most cases, especially where no wells are present, it must be estimated using fluid geothermometry. Fluid geothermometry provides a tool for assessing the thermal history of the fluids, as they have circulated through bedrock prior to sampling from a well or spring. In many cases, where limited data are available, it is not known if the samples reflect reservoir conditions. Nonetheless, the use of geothermometry is considered essential for two reasons: 1) to minimize temperature bias between wells and springs, because well temperatures commonly exceed the surface temperatures, and 2) to make it possible to assess relationships between structural environments and geothermal system temperatures, with the expectation that the range of possible reservoir temperatures of an individual geothermal system is influenced by the depth of penetration of meteoric fluids into the crust. Some oil and gas wells have relatively high temperatures by virtue of their great depths, but where these temperatures do not exceed the regional background temperature gradient (averaging near 45°C/km across much of Nevada), they do not indicate by themselves the presence of geothermal activity. For this reason, data from oil and gas wells were excluded if depths exceeded 500 m.

In the current database, the temperature assigned to a geothermal system was the maximum of either 1) the measured temperature or 2) the average of the Mg-corrected Na-K-Ca geothermometer (Fournier and Potter, 1979) and a silica geothermometer. The choice of silica geothermometer was determined based on the methodology of Mariner et al. (1983), in which the chalcedony geothermometer (Fournier, 1981) was used in place of the quartz geothermometer if the Mg-corrected Na-K-Ca geothermometer was less than 100°C. For approximately 20 relatively high temperature geothermal systems documented by Mariner et al. (1983), where isotopic data were available for estimating the SO_4-H_2O geothermometer and again following the methodology of Mariner et al. (1983), the estimated temperature was the average of the silica geothermometer (as chosen above), the Mg-corrected Na-K-Ca geothermometer, and the SO_4-H_2O geothermometer of McKenzie and Truesdell (1977). It is recognized that each geothermometer responds uniquely to geological and geochemical conditions in the subsurface, and that an average of such geothermometers does not represent a "correct" or necessarily more accurate estimate of subsurface temperatures. Nonetheless, the average of such temperatures was used herein in order to enable a systematic overall assessment of the relationship between structural settings and the temperatures of subsurface geothermal reservoirs. It was observed that the difference between the SiO_2 and Na-K-Ca-Mg temperature estimates, using the methodology described above, in the Nevada Bureau of Mines and Geology (NBMG) database averaged 14%. Data sources include the Geo-Heat Center State Geothermal Database (2002), Blackwell (2002), Garside (1994), Mariner et al. (1983), the NBMG geochemical laboratory, the Desert Research Institute geochemical laboratory, and commercial laboratories.

As part of a major study funded by the Department of Energy from 2009 to 2013 (herein referred to as the initial structural inventory study), the structural settings of more than 450 known geothermal systems in the Great Basin region were reviewed (Faulds et al., 2011, 2012, 2013; Faulds and Hinz, 2015). In this study, we examined the site locations for all geothermal systems, which involved confirming and/or relocating spring and geothermal sites based on imagery, maps, and other information. Since the initial establishment of the database by Coolbaugh (2003), Google imagery had become available for the entire region and greatly facilitated careful checking and relocating of some of the site locations. Additional well and spring data were also available. Furthermore, some systems that included several separate springs spread over large areas but within the original 10 km minimum distance defined by Coolbaugh (2003) were divided into two or more distinct systems if structural and/or geochemical data suggested such systems were independent. Further, all hot wells were assigned names based on their location to facilitate subsequent analyses. The structural settings of ~245 geothermal systems throughout the Great Basin region of Nevada and neighboring states were defined in this study based on 1) published literature, 2) analysis of air photos, imagery, and/or geologic maps, and/or 3) field visits. Many of the "known" systems consisted of individual wells within basins and were therefore difficult to evaluate. Although faults are the major controlling feature of fluid flow within geothermal systems in the region, the literature on the structural settings of individual systems is relatively scant. Thus, we made the first interpretations of the structural settings for many geothermal fields. In general, it was possible to make such determinations if the systems were situated within or near bedrock exposures, but further analysis utilizing geophysical data and/or detailed geologic mapping was needed to determine the settings for many systems, especially those in the central parts of larger basins. Thus, we were not able to classify many of the systems during the initial structural inventory study.

For this report, we carefully reviewed and in many cases refined the structural settings of 214 known geothermal systems in Nevada (plate 1). We incorporated additional studies of these systems conducted since 2013 (e.g., Sadowski and Faulds, 2015; Craig et al., 2017; McConville et al., 2017; Craig, 2018; McLachlan, 2018; Faulds et al., 2019, 2020; Hinz et al., 2020; significant unpublished work by the authors), as well as more thorough analysis of available geologic maps and imagery. In essence, detailed quality assurance and quality control (QA/QC) were carried out for all known geothermal systems in Nevada. The structural setting and location of each system in Nevada was carefully scrutinized, and the uncertainty of the determination was qualitatively rated on a scale of 1 to 10 (with 10 being the highest certainty; tables 1 and 2). For hybrid systems (i.e., systems with more than one structural setting), both the primary and secondary structural settings were defined in the database.

In addition, 26 late Miocene to Quaternary epithermal mineral deposits were included in our analysis of structural settings (tables 3 and 4; plates 2 and 3), because they represent fossil hydrothermal systems that developed in a similar tectonic setting, characterized by regional extension and transtension. Several of these systems are actually situated in the uplifted footwalls of normal fault systems that currently host an active geothermal system, generally residing in the adjacent hanging walls (e.g., Humboldt House, Wind Mountain). The detailed results of the analysis of both geothermal systems and epithermal mineral deposits are presented below.

Geothermal Systems

The accompanying maps show the results of the analysis of geothermal systems, including information on whether the geothermal systems are blind or magmatic heated (plates 1 and 3). Details of each system (e.g., both primary and secondary structural settings, certainty of structural setting, age of faulting, and installed capacity for systems hosting power plants) are shown in table 1. Table 2 summarizes the results.

We were able to identify the structural settings of 194 of the 214 known geothermal systems in Nevada (~91%). Step-overs or relay ramps in normal faults, fault intersections, and normal-fault terminations host most of the geothermal systems in Nevada (table 2 and figure 2A–C). Step-overs or relay ramps in normal fault zones serve as the most favorable structural setting, hosting ~39% of the systems. Such areas are characterized by multiple, commonly overlapping and intersecting fault strands, increased fracture density, and thus enhanced permeability. Step-overs host ~47% of the operating power plants in Nevada, including Desert Peak, Bradys, Jersey Valley, and Tungsten Mountain. Normal fault

terminations, which are marked by horse-tailing splays of multiple closely spaced normal faults, host ~23% of the known systems and ~16% of the operating power plants, with Salt Wells and Stillwater representing two such power-producing systems. Intersections between individual normal faults and either transversely oriented strike-slip or oblique-slip faults accounted for ~21% of the systems but no producing power plants, at least not with respect to the primary structural setting. Examples of geothermal systems marked by fault intersections include Trego, Leach, and Spencer hot springs. Within such intersections, multiple minor faults typically connect major structures, and fluids can flow readily through highly fractured areas, especially in dilational quadrants. Quaternary faults typically lie within or near most of the geothermal systems in Nevada, as previously noted by Bell and Ramelli (2007).

Accommodation zones and displacement transfer zones are more complex types of fault intersections that are less common but host nearly one third of the operating power plants and a disproportionate amount of the higher temperature (>130°C) systems (table 2). Accommodation zones are belts of intermeshing, oppositely dipping normal faults (e.g., Faulds and Varga, 1998; fig. 2D) and therefore include multiple fault intersections. These zones host ~5% of the systems but include nearly 16% of the power plants, including the two largest systems in Nevada (McGinness Hills and Steamboat). Accommodation zones mark a particularly complex type of structural setting, and thus it is not surprising that they host a large proportion of operating power plants compared to their overall abundance. Displacement transfer zones (fig. 2E) accommodate a transfer of strain between strike-slip and normal faults and are particularly common within and along the margins of the Walker Lane. Such zones host ~4% of the known geothermal systems, with fluid flow typically focused along the normal faults proximal to their dilational intersections with strike-slip faults. Although not common, displacement transfer zones host a disproportionate amount of operating power plants (~16%), which is testament to the structural complexity of such zones and possibly also to enhanced slip rates on normal faults near major strike-slip faults of the Walker Lane. Examples with operating power plants include Don Campbell, Wabuska, and Blue Mountain. Pull-aparts or releasing bends in strike-slip fault zones also represent complex structural settings, commonly with multiple fault intersections. Pull-aparts (fig. 2F) host ~4% of the known geothermal systems and one operating power plant at Beowawe. Pull-aparts, similar to displacement transfer zones, are more common within and adjacent to the Walker Lane.

Other observed but much less common settings for geothermal systems include major range-front faults and bends in major normal faults, with each accounting for ~1% of the known geothermal systems in Nevada. Deep circulation on major normal faults is probably hindered by abundant clay gouge, and thus such faults commonly serve as barriers to permeability and deep fluid circulation. Notably, these settings do not host any known systems with temperatures greater than 90°C in Nevada (table 2).

Many of the higher-temperature systems are characterized by more than one type of favorable setting at a single locality (table 1). For example, the Salt Wells geothermal system in west-central Nevada occurs at the south end of a major east-dipping normal fault zone but within a broader accommodation zone between east- and west-dipping normal faults. The Bradys system lies within a discrete left step in a northwest-dipping normal fault zone but also within a broader accommodation zone. Steamboat appears to occupy a broad accommodation zone between overlapping east- and west-dipping normal fault zones while also containing discrete fault intersections that control fluid flow within the developed part of the field. McGinness Hills, the largest producing system in Nevada, occupies a discrete step-over within a prominent accommodation zone between two relatively active, oppositely dipping Quaternary normal fault systems.

Table 1 also shows the primary orientation of faults inferred to control hydrothermal fluid flow in the geothermal systems. North-northeast-striking normal faults (i.e., ~N10°E to N35°E) are most common and control ~54% of the 194 catalogued systems. This is compatible with the regional west-northwest-trending extension direction, as faults orthogonal to the regional extension direction generally have the highest dilation tendency (e.g., Ferrill et al., 1999) and thus will most readily accommodate fluid flow (e.g., Sibson, 1994). Northerly striking faults (~N10°W to N10°E) are also relatively common and serve as the primary controlling structure in ~32% of the systems. Northeast- to east-

TABLE 1. STRUCTURAL INVENTORY

ID	System Name	State	County	Latitude (nad83)	Longitude (nad83)	Max Temp Measured (°C)	Geothermometry Temp (°C)	Maximum Temp (°C)	Blind System	Primary Structural Setting	Secondary Structural Setting	Certainty of Setting (1 to 10)	Primary Fault Orientation	Magmatic Heated	Recency of Faulting	Installed Power Capacity 2020 (MWe)	Direct Use
	Washoe County																
WA1	Hill's Warm Spring	NV	Washoe	41.73113348	-119.78487697	28	76.0	76.0	No	Fault Termination		9	NNW	No	Quaternary/ Holocene?	0.0	
WA2	Surprise Valley Hot Spring	NV	Washoe	41.16592281	-119.97875218	47	67.0	67.0	No	Accommodation Zone		9	NNW	No	Holocene	0.0	
WA3	Fly Ranch	NV	Washoe	40.85999741	-119.33103407	104	141.0	141.0	Yes	Fault Termination		5	NNE	No	Holocene	0.0	
WA4	Gerlach	NV	Washoe	40.66295655	-119.36720261	131	192.0	192.0	No	Fault Termination		10	NNE	No	Holocene	0.0	
WA5	San Emidio	NV	Washoe	40.38640034	-119.40846406	148	190.0	190.0	No	Step-Over		10	NNE	No	Holocene	11.8	Yes
WA6	Bonham Ranch	NV	Washoe	40.31595662	-119.79700349	49	154.0	154.0	No	Step-Over	Fault Intersection	10	N	No	Holocene	0.0	
WA7	Emerson Pass	NV	Washoe	40.30099722	-119.63217780	120	0.0	120.0	Yes	Fault Termination	Step-Over	10	NNW	No	Holocene	0.0	
WA8	Astor Pass	NV	Washoe	40.17684000	-119.74443500	95	132.0	132.0	Yes	Fault Intersection		10	NNW and WNW	No	late Pleistocene	0.0	
WA9	Needle Rock Hot Springs	NV	Washoe	40.14416314	-119.68173196	116	179.0	179.0	No	Pull-Apart	Displacement Transfer Zone	6	NNW	No	late Pleistocene	0.0	
WA10	Pyramid Rock	NV	Washoe	39.98035685	-119.50176581	97	153.0	153.0	No	Fault Intersection	Displacement Transfer Zone	10	N and NNE	No	Holocene	0.0	
WA11	Black Warrior	NV	Washoe	39.88841467	-119.23007910	128	-1.0	128.0	Yes	Step-Over	Fault Termination	10	NNE	No	late Quaternary	0.0	
WA12	Lawton Hot Springs	NV	Washoe	39.51160800	-119.90875300	46	71.0	71.0	No	Fault Intersection		8	NNW and WNW	No	late Pleistocene	0.0	Yes
WA13	Moana	NV	Washoe	39.49064020	-119.79942451	98	131.0	131.0	No	Step-Over		8	N	No	late Pleistocene; Holocene	0.0	Yes
WA14	Steamboat	NV	Washoe	39.38817284	-119.75414931	236	207.0	236.0	No	Accommodation Zone	Fault Intersection	10	N and ENE	Yes	Holocene	134.5	Yes
WA15	Bowers Mansion	NV	Washoe	39.28544558	-119.84140742	53	42.0	53.0	No	Major Normal Fault		7	N	No	Holocene	0.0	Yes
	Storey County																
ST1	Yellow Jacket Shaft	NV	Storey	39.29223484	-119.65811327	77	0.0	77.0	Yes	Major Normal Fault		8	NNE	No	None mapped	0.0	
	Carson City																
CC1	Carson Hot Spring	NV	Carson City	39.19244949	-119.75397360	50	84.0	84.0	No	Fault Termination		7	NNE	No	Holocene	0.0	
	Douglas County																
DO1	Hobo Hot Spring	NV	Douglas	39.05741300	-119.81767100	46	70.0	70.0	No	Step-Over	Fault Intersection	9	N and ENE	No	Holocene	0.0	
DO2	Walleys Hot Springs	NV	Douglas	38.98065898	-119.83203490	83	82.0	83.0	No	Fault Bend		8	N	No	Holocene	0.0	Yes
DO3	Hastie Well	NV	Douglas	39.01916758	-119.71306542	21	83.0	83.0	Yes	Accommodation Zone		4	N	No	late Quaternary, probable Holocene	0.0	
	Humboldt County																
HU1	Roadsite rest area	NV	Humboldt	41.87587331	-119.04662615	18	86.0	86.0	Yes	Fault Intersection		2	NW and NE	No	late Quaternary?	0.0	
HU2	Virgin Valley Ranch Warm Spring	NV	Humboldt	41.79030969	-119.10788200	21	83.0	83.0	No	Fault Intersection		3	NW and NE	No	None mapped	0.0	
HU3	McGee	NV	Humboldt	41.80616600	-118.86482100	120	0.0	120.0	Yes	Fault Intersection	Step-Over	8	NNE and NW	No	Possible late Quaternary	0.0	
HU4	Bog Hot Spring	NV	Humboldt	41.92427600	-118.80581200	56	114.9	114.9	No	Step-Over	Fault Intersection	4	NNW and NNE	No	Quaternary	0.0	
HU5	Baltazor Hot Spring	NV	Humboldt	41.92136690	-118.71006977	128	156.0	156.0	No	Step-Over	Fault Intersection	9	NNE	No	Holocene	0.0	
HU6	Howard Hot Spring	NV	Humboldt	41.72098794	-118.50595024	73	95.0	95.0	No	Step-Over		2	NNW	No	late Quaternary?	0.0	
HU7	Dyke Hot Springs	NV	Humboldt	41.56685765	-118.56636739	70	133.0	133.0	No	Fault Intersection		6	NNE and NW	No	late Pleistocene	0.0	
HU8	Five Mile Spring	NV	Humboldt	41.76309469	-118.28020363	27	76.0	76.0	No	Undetermined				No	late Quaternary	0.0	
HU9	USGS Test Well-Bilk Creek Mts	NV	Humboldt	41.47178328	-118.28538011	24	74.0	74.0	Yes	Accommodation Zone	Fault Termination	3	N	No	None mapped	0.0	
HU10	Cordero Mine area	NV	Humboldt	41.91900900	-117.80974500	60	175.0	175.0	Yes	Fault Intersection	Fault Termination	8	NNW and NNE	No	Holocene	0.0	
HU11	The Hot Springs	NV	Humboldt	41.42223933	-117.38750948	58	66.0	66.0	No	Fault Intersection		6	NE and N	No	late Quaternary	0.0	
HU12	Soldier Meadows	NV	Humboldt	41.35777203	-119.21894296	54	74.0	74.0	No	Accommodation Zone		9	NNE	No	late Quaternary	0.0	
HU13	Pinto Hot Spring	NV	Humboldt	41.36162815	-118.78849395	94	181.0	181.0	No	Fault Intersection		6	NNE and E	No	Holocene	0.0	
HU14	Cane Spring	NV	Humboldt	41.02071875	-119.27522915	23	43.0	43.0	No	Fault Termination		4	NNW	No	late Quaternary	0.0	
HU15	WW3922T1	NV	Humboldt	41.07433273	-119.11046126	24	142.0	142.0	Yes	Step-Over		2	N	No	Possible Holocene	0.0	
HU16	Hardin City North Hot Spring	NV	Humboldt	41.14666444	-119.02070269	67	0.0	67.0	No	Step-Over		3	NW	No	Holocene	0.0	
HU17	TH SP Hardin City SE QD	NV	Humboldt	41.11570259	-119.00169471	51	122.0	122.0	No	Fault Intersection	Step-Over	6	NNE and NNW	No	Holocene	0.0	
HU18	Double Hot Springs	NV	Humboldt	41.05092766	-119.02647718	37	0.0	37.1	No	Fault Intersection		8	NNE and NNW	No	Holocene		
HU19	Black Rock Hot Spring	NV	Humboldt	40.97375950	-119.00816204	96	133.0	133.0	No	Fault Intersection	Step-Over	7	NNE and N	No	Holocene	0.0	
HU20	MacFarlane Hot Spring	NV	Humboldt	41.05107495	-118.71937525	77	85.0	85.0	No	Step-Over		10	NNE	No	Holocene	0.0	
HU21	Jackson Well	NV	Humboldt	41.26626558	-118.08699515	20	82.0	82.0	Yes	Fault Intersection		4	N and NE	No	Holocene	0.0	
HU22	Blue Mountain	NV	Humboldt	40.99742777	-118.12716857	207	214.0	214.0	Yes	Displacement Transfer Zone	Fault Intersection	8	N, NNE, WNW	No	Possible late Pleistocene?	49.5	
HU23	Calif. Public Utilities	NV	Humboldt	40.96036734	-117.74396676	34	65.0	65.0	Yes	Undetermined				No	Holocene	0.0	
HU24	Paradise Valley	NV	Humboldt	41.10609509	-117.57162673	75	81.0	81.0	Yes	Fault Intersection		7	N and E	No	Holocene	0.0	
HU25	Golconda	NV	Humboldt	40.95419589	-117.49083573	81	89.0	89.0	No	Fault Termination		5	N	No	None mapped	0.0	
HU26	Unnamed Spring - Lone Butte	NV	Humboldt	41.02809890	-117.31977310	21	72.0	72.0	No	Fault Termination	Step-Over	8	NNE	No	late Quaternary	0.0	
HU27	Hot Pot Spring	NV	Humboldt	40.92238824	-117.11061966	58	119.0	119.0	No	Step-Over	Fault Intersection	7	NNE and NNW	No	Holocene	0.0	
HU28	Tipton	NV	Humboldt	40.76099100	-117.49320100	104	156.0	156.0	No	Step-Over		7	NNE	No	late Pleistocene	0.0	
HU29	Pumpernickel Valley	NV	Humboldt	40.86506361	-117.34918347	70	0.0	70.0	No	Step-Over		9	NNE	No	Holocene	0.0	
HU30	Brooks Hot Spring	NV	Humboldt	40.83098722	-117.30400795	34	66.0	66.0	No	Undetermined				No	Holocene/late Quaternary	0.0	
	Pershing County																
PE1	Frog Pond	NV	Pershing	40.74563300	-119.17193600	52	125.0	125.0	No	Fault Intersection		7	NNE and ENE	No	late Quaternary	0.0	
PE2	Trego	NV	Pershing	40.77171760	-119.11683114	140	134.0	140.0	No	Fault Intersection		6	NNE and ENE	No	Holocene	0.0	
PE3	Bach Well	NV	Pershing	40.40940012	-118.76807758	21	78.0	78.0	Yes	Step-Over	Fault Termination	4	NNE	No	Quaternary	0.0	
PE4	Adobe Flat-Granite Springs Valley	NV	Pershing	40.24383300	-118.91448000	96	130.0	130.0	Yes	Fault Termination		9	NNE	No	late Quaternary	0.0	
PE5	Humboldt House	NV	Pershing	40.58083480	-118.25201376	205	220.0	220.0	No	Fault Termination		9	NNE	No	Holocene	0.1*	
PE6	Star Peak	NV	Pershing	40.52726334	-118.27184593	205	224.0	224.0	Yes	Step-Over		10	NNE	No	Holocene	0.0+	
PE7	Colado	NV	Pershing	40.24452698	-118.36970300	155	149.0	155.0	Yes	Step-Over	Fault Termination	9	NNE	No	Holocene	0.0	
PE8	Kyle Hot Springs	NV	Pershing	40.40656492	-117.88520414	96	124.0	124.0	No	Step-Over	Fault Termination	5	NNW and NNE	No	Holocene	0.0	
PE9	New York Canyon	NV	Pershing	40.05003789	-118.00406466	75	0.0	75.0	Yes	Step-Over		6	NE	No	late Quaternary	0.0	
PE10	Leach Hot Springs	NV	Pershing	40.60363341	-117.64976736	132	169.0	169.0	No	Fault Intersection		9	NE and NNW	No	Holocene; historic 1915	0.0	
PE11	Coyote Spring - Pleasant Valley	NV	Pershing	40.43858324	-117.62683193	22	64.0	64.0	No	Fault Intersection		3	NNE and E	No	Holocene; historic 1915	0.0	
PE12	Paris Well	NV	Pershing	40.24447000	-117.67586000	22	63.0	63.0	Yes	Step-Over		6	NNE	No	Historic 1915	0.0	
PE13	Sou Hot Springs	NV	Pershing	40.08753465	-117.72575099	85	85.0	85.0	No	Accommodation Zone		10	NNE	No	Holocene/ historic 1915	0.0	
PE14	Hyder Hot Spring	NV	Pershing	40.00287534	-117.71853385	79	84.0	84.0	No	Step-Over		3	NNE	No	Holocene	0.0	
PE15	McCoy Hot Springs	NV	Pershing	40.07933530	-117.60482452	49	0.0	49.0	No	Step-Over		4	NNE	No	Holocene	0.0	
PE16	Western Augusta Mtn Hot Springs	NV	Pershing	40.03774420	-117.61931489	40	0.0	40.0	No	Fault Termination		5	NNE	No	Holocene	0.0	
PE17	Jersey Valley Hot Springs	NV	Pershing	40.17796815	-117.49094297	91	130.0	130.0	No	Step-Over		10	NNE	No	late Pleistocene/ likely Holocene	23.5	

TABLE 1. (CONTINUED)

ID	System Name	State	County	Latitude (nad83)	Longitude (nad83)	Max Temp Measured (°C)	Geothermometry Temp (°C)	Maximum Temp (°C)	Blind System	Primary Structural Setting	Secondary Structural Setting	Certainty of Setting (1 to 10)	Primary Fault Orientation	Magmatic Heated	Recency of Faulting	Installed Power Capacity 2020 (MWe)	Direct Use
	Churchill County																
CH1	Bradys	NV	Churchill	39.79037054	-119.01293894	212	193.0	212.0	No	Step-Over	Accommodation Zone	10	NNE	No	Holocene	26.1	Yes
CH2	Desert Peak	NV	Churchill	39.75746229	-118.94903578	213	219.0	219.0	Yes	Step-Over		10	NNE	No	Holocene	23.0	
CH3	Desert Queen	NV	Churchill	39.78089067	-118.86489293	104	155.0	155.0	Yes	Fault Termination	Step-Over	9	NNE	No	Holocene	0.0	
CH4	Upsal Hogback	NV	Churchill	39.65604979	-118.80393753	36	0.0	36.0	Yes	Undetermined			NNE	No	late Pleistocene to Holocene	0.0	
CH5	Soda Lake	NV	Churchill	39.56024947	-118.85044172	216	213.0	216.0	Yes	Step-Over	Fault Intersection	9	NNE	No	Holocene?	26.1	
CH6	TCID 1 Well	NV	Churchill	39.77931100	-118.57986400	70	0.0	70.0	Yes	Hot Sedimentary Aquifer				No	Historic 1954	0.0	
CH7	Stillwater	NV	Churchill	39.54515455	-118.55693227	178	169.0	178.0	Yes	Fault Termination		9	NNE	No	Historic 1954	47.2	
CH8	Indian Health Service Well-City of Fallon	NV	Churchill	39.48570726	-118.76113895	21	67.0	67.0	Yes	Undetermined				No	Holocene	0.0	
CH9	Carson Lake	NV	Churchill	39.36320033	-118.66328950	191	0.0	191.0	Yes	Undetermined			NNE	No	Holocene	0.0	
CH10	Lee-Allen Hot Springs	NV	Churchill	39.20962931	-118.72603543	95	171.0	171.0	No	Pull-Apart	Fault Intersection	10	NW and NNE	No	Holocene	0.0	
CH11	Salt Wells	NV	Churchill	39.29977925	-118.57084823	177	188.0	188.0	No	Fault Termination	Accommodation Zone	10	NNE	No	Holocene	23.6	
CH12	Dixie Valley	NV	Churchill	39.95748911	-117.85647179	250	235.0	250.0	No	Step-Over		9	NNE	No	Holocene	70.9	
CH13	Dixie Comstock	NV	Churchill	39.86205203	-118.01086983	196	139.0	196.0	No	Step-Over		10	NNE	No	Holocene	0.0	
CH14	Dixie Meadows	NV	Churchill	39.79353708	-118.07152544	94	145.0	145.0	No	Fault Intersection	Step-Over	8	NNE	No	Historic 1954	0.0	
CH15	Hatton Well No. 1	NV	Churchill	39.67716277	-118.06297063	22	70.0	70.0	Yes	Step-Over		4	NNE	No	Historic 1954	0.0	
CH16	Pirouette Mountain (Dixie Valley)	NV	Churchill	39.51002637	-118.15576281	87	0.0	87.0	Yes	Fault Termination	Accommodation Zone	8	NNE	No	Historic 1954/late Quaternary	0.0	
CH17	Eleven Mile Canyon	NV	Churchill	39.41724400	-118.24599794	82	0.0	82.0	Yes	Step-Over		10	NNE	No	Holocene/ Historic 1954	0.0	
CH18	McCoy	NV	Churchill	39.91170496	-117.50161286	102	122.0	122.0	Yes	Undetermined			NNE	No	Holocene	0.0	
CH19	Tungsten Mountain	NV	Churchill	39.67255200	-117.68407000	97	176.0	176.0	Yes	Step-Over		10	NNE	No	Holocene	37.0	
	Lyon County																
LY1	Patua Hot Springs	NV	Lyon	39.58359916	-119.09344207	135	182.0	182.0	No	Step-Over	Fault Termination	8	NNE	No	Holocene	48.0	
LY2	Silver Springs	NV	Lyon	39.42960700	-119.19938700	60	149.0	149.0	Yes	Fault Intersection		5	ENE and NW	No	Possible Holocene	0.0	
LY3	Sutro Tunnel	NV	Lyon	39.28075648	-119.58307488	27	38.0	38.0	yes	Step-Over		6	NNE	No	Quaternary	0.0	
LY4	Wabuska	NV	Lyon	39.15988414	-119.18007138	108	146.0	146.0	No	Displacement Transfer Zone	Step-Over	5	ENE and N	No	Holocene	5.6	
LY5	Ambassador Well	NV	Lyon	38.96175718	-119.36204192	28	110.0	110.0	Yes	Fault Termination		5	N	No	late Quaternary	0.0	
LY6	Hind's-Nevada Hot Springs	NV	Lyon	38.89871821	-119.41094838	66	80.0	80.0	No	Fault Bend		4	N	No	Holocene	0.0	
LY7	Wellington Well	NV	Lyon	38.75384171	-119.37782884	47	83.0	83.0	Yes	Step-Over		5	NW and N	No	Holocene	0.0	
LY8	Wilson Hot Spring	NV	Lyon	38.76739781	-119.17485259	94	0.0	94.0	No	Fault Termination	Step-Over	10	N	No	late Quaternary	0.0	
LY9	Grant View Hot Springs	NV	Lyon	38.48145958	-118.99588099	53	53.0	53.0	No	Undetermined				No	Mid- late Quaternary	0.0	
	Lander County																
LA1	Izzenhood Ranch Spring	NV	Lander	40.92852098	-116.89588959	31	66.0	66.0	No	Fault Intersection		7	ENE and NNW	No	late Quaternary?	0.0	
LA2	Battle Mountain City Well	NV	Lander	40.64884637	-116.93634827	23	89.0	89.0	Yes	Fault Intersection		4		No	late Quaternary?	0.0	
LA3	Buffalo Valley Hot Spring	NV	Lander	40.36781001	-117.32717816	79	128.0	128.0	No	Step-Over		4	NE	No	late Pleistocene; likely Holocene	0.0	
LA4	Mound Spring	NV	Lander	40.31458190	-117.06325709	32	54.0	54.0	No	Step-Over	Fault Intersection	10	N and ENE	No	Holocene	0.0	
LA5	Valley of the Moon	NV	Lander	40.19080598	-117.10630495	53	56.0	56.0	No	Step-Over	Fault Termination	8	NNE	No	Holocene	0.0	
LA6	Unnamed Hot Pool-Carico Valley	NV	Lander	40.18684033	-116.88390912	50	45.0	50.0	No	Fault Termination		4	NNE	No	Holocene	0.0	
LA7	Reese River	NV	Lander	39.89789393	-117.14612034	150	63.0	150.0	Yes	Step-Over	Accommodation Zone	10	NNE	No	late Pleistocene	0.0	
LA8	Hot Springs Point-Lander County	NV	Lander	39.94116455	-116.68170556	64	128.0	128.0	No	Fault Termination		9	NNE	No	Holocene	0.0	
LA9	McGinness Hills	NV	Lander	39.59006774	-116.90704554	88	192.0	192.0	Yes	Accommodation Zone	Step-Over	10	NNE	No	late Pleistocene	144.0	
LA10	Peterson	NV	Lander	39.31265959	-117.55018132	92	150.0	150.0	No	Fault Termination	Step-Over	9	NE	No	late Pleistocene; possible Holocene?	0.0	
LA11	Spencer Hot Springs	NV	Lander	39.32741919	-116.85576024	73	95.0	95.0	No	Fault Intersection		7	NNE and NNW	No	late Pleistocene; possible Holocene	0.0	
	Eureka County																
EU1	BW2 Well	NV	Eureka	40.98346697	-116.37476628	52	69.0	69.0	Yes	Fault Termination		6	NNE	No	late Quaternary	0.0	
EU2	Brahma Spring	NV	Eureka	40.88710741	-116.28009991	19	45.0	45.0	No	Step-Over	Accommodation Zone	3	NNE	No	late Quaternary	0.0	
EU3	Newmont Well MC2	NV	Eureka	40.79871696	-116.20211539	32	57.0	57.0	Yes	Fault Termination		6	N	No	Quaternary	0.0	
EU4	Mack Creek Farm Well	NV	Eureka	40.74925148	-116.42101174	26	75.0	75.0	Yes	Displacement Transfer Zone		5	NNE	No	Holocene	0.0	
EU5	Horseshoe Ranch Spr	NV	Eureka	40.60582822	-116.46343616	58	77.0	77.0	No	Displacement Transfer Zone	Fault Intersection	6	ENE	No	Holocene	0.0	
EU6	Beowawe	NV	Eureka	40.56004930	-116.60280498	216	227.0	227.0	No	Pull-Apart	Fault Intersection	10	ENE	No	Holocene	18.5	
EU7	Hot Springs Point	NV	Eureka	40.40628252	-116.51683277	74	87.0	87.0	No	Fault Intersection		8	NNE	No	Holocene	0.0	
EU8	Hand-Me-Down Spring	NV	Eureka	40.31624855	-116.43483722	86	0.0	86.0	No	Step-Over		10	NNE	No	Holocene	0.0	
EU9	Carlotti Ranch Springs	NV	Eureka	40.29215628	-116.05627823	39	0.0	39.0	No	Step-Over		8	N	No	Mid-late Quaternary	0.0	
EU10	Bruffey's Hot Springs	NV	Eureka	40.21919085	-116.06910012	66	72.0	72.0	No	Step-Over	Fault Intersection	7	N	No	late Quaternary	0.0	
EU11	Walti Hot Springs	NV	Eureka	39.90191208	-116.58925413	72	83.0	83.0	No	Step-Over		6	N	No	Holocene	0.0	
EU12	Shipley Hot Springs	NV	Eureka	39.94350000	-116.07316600	39	55.0	55.0	No	Step-Over		5	N	No	None mapped	0.0	
EU13	Bartine Hot Springs	NV	Eureka	39.55838010	-116.36038844	47	62.0	62.0	No	Fault Termination	Accommodation Zone	7	N	No	late Quaternary	0.0	
EU14	Klobe Hot Spring	NV	Eureka	39.40485284	-116.34736158	70	86.0	86.0	No	Step-Over		7	N	No	Mid-Quaternary	0.0	
EU15	Fish Creek Springs	NV	Eureka	39.27786296	-116.03572579	19	45.0	45.0	No	Step-Over		6	NNE	No	late Quaternary, possible late Pleistocene	0.0	
	Elko County																
EL1	Midas	NV	Elko	41.24155900	-116.77657000	85	126.0	126.0	Yes	Fault Intersection		7	NNW and ENE	No	Quaternary	0.0	
EL2	Hot Lake	NV	Elko	41.14786397	-116.73554693	22	73.0	73.0	No	Pull-Apart	Fault Intersection	7	ENE	No	Quaternary?	0.0	
EL3	Rock Creek, unnamed	NV	Elko	41.27905306	-116.62119140	35	53.0	53.0	No	Fault Termination	Fault Intersection	5	ENE	No	late Quaternary, possible Holocene	0.0	
EL4	spring near Deep Creek Res	NV	Elko	41.61377810	-116.30014910	52	98.0	98.0	No	Fault Termination		9	NNE	No	Quaternary	0.0	
EL5	Tuscarora	NV	Elko	41.47688212	-116.14674167	117	176.0	176.0	No	Accommodation Zone	Step-Over	10	NNE	No	late Pleistocene	32.0	
EL6	Rizzi Ranch Hot Spring	NV	Elko	41.77364452	-115.92227661	41	71.0	71.0	No	Undetermined			NE	No	None mapped	0.0	
EL7	Wild Horse Hot Spring	NV	Elko	41.64748417	-115.77633542	54	67.0	67.0	No	Fault Termination		5	NNE	No	Quaternary	0.0	

TABLE 1. (CONTINUED)

ID	System Name	State	County	Latitude (nad83)	Longitude (nad83)	Max Temp Measured (°C)	Geothermometry Temp (°C)	Maximum Temp (°C)	Blind System	Primary Structural Setting	Secondary Structural Setting	Certainty of Setting (1 to 10)	Primary Fault Orientation	Magmatic Heated	Recency of Faulting	Installed Power Capacity 2020 (MWe)	Direct Use
	Elko County Continued																
EL8	Rowland Hot Springs	NV	Elko	41.87744313	-115.62837326	77	99.0	99.0	No	Undetermined				No	None mapped	0.0	
EL9	Hot Creek Springs	NV	Elko	41.57625534	-115.18177615	66	99.0	99.0	No	Accommodation Zone		5	NNW	No	late Quaternary, possible Holocene	0.0	
EL10	Mineral (Contact) Hot Springs	NV	Elko	41.79151649	-114.74070917	60	129.0	129.0	No	Step-Over		6	NNE	No	Quaternary	0.0	
EL11	San Jacinto Ranch	NV	Elko	41.87402191	-114.69265720	64	36.0	64.0	No	Fault Termination		6	NNE	No	Late Quaternary	0.0	
EL12	Wheeler Ranch	NV	Elko	41.97055144	-114.57503729	44	47.0	47.0	Yes	Fault Termination		7	N	No	Quaternary	0.0	
EL13	Trout Creek Ranch Well	NV	Elko	41.88436200	-114.11798700	43	69.0	69.0	Yes	Fault Termination		4	NNE	No	Quaternary?	0.0	
EL14	Marys River Hot Springs	NV	Elko	41.18797959	-115.28734672	36	178.0	178.0	No	Fault Termination		3	N	No	None mapped	0.0	
EL15	Humboldt Wells	NV	Elko	41.16093126	-114.98702239	113	117.0	117.0	No	Fault Intersection		8	N and WNW	No	Quaternary; possible Holocene	0.0	Yes
EL16	Cobre	NV	Elko	41.11343000	-114.11343000	77	0.0	77.0	Yes	Step-Over		4	NNE	No	Quaternary?	0.0	
EL17	Carlin	NV	Elko	40.69982900	-116.12939700	93	83.0	93.0	No	Fault Termination		7	NNE	No	late Quaternary?	0.0	
EL18	Dry Susie Creek	NV	Elko	40.76381904	-116.04110667	64	73.0	73.0	No	Fault Termination	Step-Over	4	NNW	No	None mapped	0.0	
EL19	Elko Hot Springs	NV	Elko	40.81848844	-115.77730925	96	108.0	108.0	No	Fault Termination		7	NNE	No	late Quaternary?	0.0	Yes
EL20	Sulphur Hot Springs	NV	Elko	40.58655324	-115.28637835	136	182.0	182.0	No	Step-Over		6	NNE	No	late Pleistocene, possible Holocene	0.0	
EL21	Smith Ranch	NV	Elko	40.25227939	-115.40809361	65	72.0	72.0	No	Fault Termination	Step-Over	10	NNE	No	late Quaternary	0.0	
	White Pine County																
WP1	Warm Springs Ranch-Newark Valley	NV	White Pine	39.81130000	-115.60704000	23	42.0	42.0	No	Step-Over		9	N	No	None mapped	0.0	
WP2	Alligator Ridge well	NV	White Pine	39.73737438	-115.51432176	34	44.0	44.0	Yes	Fault Intersection	Fault Termination	8	N	No	late Quaternary	0.0	
WP3	Steptoe Valley north	NV	White Pine	39.94101199	-114.77258343	151	0.0	151.0	Yes	Hot Sedimentary Aquifer		9	N	No	late Quaternary	0.0	
WP4	Steptoe Valley south	NV	White Pine	39.77449511	-114.81868323	198	0.0	198.0	Yes	Hot Sedimentary Aquifer		9	NNE	No	late Quaternary	0.0	
WP5	Cherry Creek Hot Springs	NV	White Pine	39.88769400	-114.89899900	65	102.0	102.0	No	Step-Over		10	NNE	No	late Quaternary?	0.0	
WP6	Monte Neva Hot Springs	NV	White Pine	39.66791563	-114.80740570	89	111.0	111.0	No	Step-Over		9	NNE	No	late Quaternary; possible Holocene	0.0	
WP7	Spring Valley Well	NV	White Pine	39.83037046	-114.55606929	28	79.0	79.0	Yes	Undetermined				No	late Quaternary	0.0	
WP8	Williams Hot Springs	NV	White Pine	38.95100887	-115.23379041	52	123.0	123.0	No	Fault Intersection		2	N	No	Quaternary	0.0	
	Mineral County																
MI1	Rawhide-Wedell Hot Spring	NV	Mineral	38.91899278	-118.19625675	62	151.0	151.0	No	Step-Over		2	NNE	No	likely Holocene	0.0	
MI2	Don Campbell	NV	Mineral	38.83986084	-118.32309234	151	0.0	151.0	Yes	Displacement Transfer Zone		9	NNE	No	Holocene	47.5	
MI3	Gabbs Valley-Southeast	NV	Mineral	38.76393800	-118.16760000	125	130.0	130.0	Yes	Displacement Transfer Zone	Fault Intersection	10	NNE	No	Holocene	0.0	
MI4	Hawthorne 1	NV	Mineral	38.50634100	-118.64876727	115	120.0	120.0	Yes	Step-Over	Fault Intersection	10	NNW	No	Holocene	0.0	
MI5	Hawthorne 3	NV	Mineral	38.55620761	-118.58824227		137.0	137.0	Yes	Pull-Apart		1		No	Holocene	0.0	
MI6	Hawthorne 2	NV	Mineral	38.55068310	-118.51130791	99	79.0	99.0	Yes	Fault Intersection		1	ENE, NW	No	Holocene	0.0	
MI7	Aurora	NV	Mineral	38.35134166	-118.81831596	109	0.0	109.0	Yes	Undetermined				No	Quaternary	0.0	
MI8	Whiskey Flat - BLM well	NV	Mineral	38.28127412	-118.56808831	43	57.0	57.0	Yes	Undetermined				No	Holocene	0.0	
MI9	Teels Marsh	NV	Mineral	38.21024322	-118.38467500	65	155.0	155.0	Yes	Pull-Apart	Step-Over	10	ENE and NNE	No	Holocene	0.0	
MI10	Rhodes Marsh	NV	Mineral	38.27941945	-118.07184070	35	159.0	159.0	Yes	Displacement Transfer Zone	Step-Over	8	NNW and ENE	No	Holocene	0.0	
MI11	Mustang Springs - well	NV	Mineral	38.33245500	-117.95855500	40	54.0	54.0	Yes	Undetermined			NE	No	Holocene/ historic	0.0	
	Esmeralda County																
ES1	Columbus Marsh	NV	Esmeralda	38.04354968	-118.00866714	14	126.0	126.0	Yes	Displacement Transfer Zone		9	ENE	No	Holocene	0.0	
ES2	Fish Lake Valley	NV	Esmeralda	37.85960300	-118.04312100	157	0.0	157.0	Yes	Undetermined			NNE	No	Holocene	0.0	
ES3	Emigrant Pass	NV	Esmeralda	37.87704601	-117.89747689	164	143.0	164.0	Yes	Step-Over		9	N	No	Holocene	0.0	
ES4	Emigrant Well	NV	Esmeralda	37.97271701	-117.80787811	25	61.0	61.0	Yes	Undetermined				No	None mapped	0.0	
ES5	Alum	NV	Esmeralda	37.90861165	-117.66442797	125	0.0	125.0	Yes	Fault Termination	Fault Intersection	7	NNE	No	late Pleistocene/ Holocene?	0.0	
ES6	Silver Peak Hot Springs	NV	Esmeralda	37.75499800	-117.63308400	75	141.0	141.0	No	Fault Intersection		5	N and ENE	No	Holocene	0.0	
ES7	Pearl Hot Spring	NV	Esmeralda	37.82205694	-117.48112972	60	0.0	60.0	No	Fault Intersection		2	NNE	No	late Quaternary	0.0	
ES8	Alkali Hot Springs	NV	Esmeralda	37.82559940	-117.33820724	51	124.0	124.0	No	Fault Termination		7	NNE	No	Quaternary	0.0	
	Nye County																
NY1	Gene Sawyer well	NV	Nye	38.96232128	-117.93916540	54	84.0	84.0	Yes	Step-Over		2	NNW	No	late Quaternary?	0.0	
NY2	Gabbs	NV	Nye	38.86010586	-117.92166512	68	0.0	68.0	Yes	Step-Over		8	NNE	No	late Quaternary; possible Holocene	0.0	
NY3	McLeod Hot Spring	NV	Nye	39.02710011	-117.13730616	88	134.0	134.0	No	Step-Over		7	NNE	No	late Pleistocene/ likely Holocene	0.0	
NY4	Big Blue	NV	Nye	38.95107775	-117.05909164	32	155.0	155.0	No	Undetermined				No	probable Holocene	0.0	
NY5	Darroughs Hot Springs	NV	Nye	38.81728371	-117.18149950	129	145.0	145.0	No	Step-Over		9	NNE	No	Holocene	0.0	Yes
NY6	Diana's Punch Bowl-Potts Ranch	NV	Nye	39.06081700	-116.65456300	59	74.0	74.0	No	Accommodation Zone		9	NNE	No	late Quaternary; possible Holocne	0.0	
NY7	Mosquito Ranch Springs	NV	Nye	38.82304833	-116.71822778	32	73.0	73.0	No	Step-Over		6	N and NNE	No	late Quaternary	0.0	
NY8	Spring & Test hole Uce 10	NV	Nye	38.69527998	-116.43706483	40	42.0	42.0	No	Step-Over		7	NNE	No	late Quaternary; possible Holocene	0.0	
NY9	Hot Creek Ranch Hot Spr	NV	Nye	38.52011007	-116.36772924	82	160.0	160.0	No	Step-Over		9	N to NE	No	late Pleistocene/ possible Holocene	0.0	
NY10	Blue Jay Hot Spring, Hot Creek Valley	NV	Nye	38.44753400	-116.29854400	61	0.0	61.0	No	Step-Over		6	N	No	late Quaternary	0.0	
NY11	Duckwater Area	NV	Nye	38.94948514	-115.70121295	34	45.0	45.0	No	Step-Over		5	N	No	late Quaternary; possible latest Pleistocene	0.0	
NY12	Chimney Hot Springs	NV	Nye	38.46330148	-115.79129068	64	68.0	68.0	No	Step-Over		1	NNE	No	None mapped	0.0	
NY13	Abel-Coyote Hole Spring	NV	Nye	38.38832715	-115.86634422	46	56.0	56.0	No	Step-Over		1	NNE	No	Quaternary?	0.0	
NY14	Blue Eagle Springs	NV	Nye	38.56277683	-115.52845363	29	41.0	41.0	No	Fault Intersection	Fault Bend	8	N to NNE	No	late Quaternary	0.0	
NY15	Bacon Flat	NV	Nye	38.45602100	-115.57993000	153	0.0	153.0	Yes	Step-Over		9	N and NNE	No	late Pleistocene	0.0	

TABLE 1. (CONTINUED)

ID	System Name	State	County	Latitude (nad83)	Longitude (nad83)	Max Temp Measured (°C)	Geothermo-metry Temp (°C)	Maximum Temp (°C)	Blind System	Primary Structural Setting	Secondary Structural Setting	Certainty of Setting (1 to 10)	Primary Fault Orientation	Magmatic Heated	Recency of Faulting	Installed Power Capacity 2020 (MWe)	Direct Use
	Nye County Continued																
NY16	Moorman	NV	Nye	38.59441418	-115.13925073	37	45.0	45.0	No	Step-Over		7	NNE	No	late Quaternary	0.0	
NY17	Moon River	NV	Nye	38.35158466	-115.18112518	33	43.0	43.0	No	Fault Termination	Fault Intersection	8	NNE	No	late Quaternary; likely Holocene	0.0	
NY18	Hall Mine-Liberty Springs	NV	Nye	38.29144938	-117.26893953	28	158.0	158.0	Yes	Fault Termination		8	N	No	Quaternary; late Pleistocene	0.0	
NY19	Well near Belmont Mine	NV	Nye	38.07103061	-117.15155846	37	86.0	86.0	Yes	Fault Termination	Step-Over	9	N	No	late Quaternary?	0.0	
NY20	Salisbury Spring	NV	Nye	38.25385124	-116.83114920	30	130.0	130.0	No	Fault Intersection		5	N and NW	No	None mapped	0.0	
NY21	Mud Spring	NV	Nye	38.16573274	-116.79716457	26	84.0	84.0	No	Fault Termination		5	N	No	late Quaternary	0.0	
NY22	Coyote Hole Spring	NV	Nye	38.02568415	-116.68107257	29	49.0	49.0	No	Fault Termination	Fault Intersection	7	N and NE	No	late Quaternary	0.0	
NY23	Warm Springs-HWY 6	NV	Nye	38.18756683	-116.37400742	63	81.0	81.0	No	Step-Over		10	N	No	late Quaternary	0.0	Yes
NY24	Cedar Spring	NV	Nye	37.75066154	-116.27361321	25	44.0	44.0	No	Fault Termination		9	NNW	No	late Quaternary	0.0	
NY25	Baileys Hot Springs	NV	Nye	36.97050400	-116.72265100	43	89.0	89.0	No	Fault Intersection		7	N	No	None mapped	0.0	Yes
NY26	Climax Seep	NV	Nye	37.22430068	-116.05887677	42	25.0	42.0	Yes	Fault Termination	Fault Intersection	7	N and ENE	No	Holocene	0.0	
NY27	Yucca Flat well	NV	Nye	37.05507948	-116.01423256	42	123.0	123.0	Yes	Undetermined			N	No	late Quaternary	0.0	
NY28	Test Well	NV	Nye	36.76027700	-116.11694000	65	0.0	65.0	Yes	Pull-Apart	Displacement Transfer Zone	3	ENE	No	Holocene	0.0	
NY29	Cooks East Well	NV	Nye	36.57433769	-116.39450673	46	50.0	50.0	Yes	Fault Intersection	Fault Termination	8	N and ENE	No	Holocene	0.0	
NY30	USGS Tracer Well 2-Amargosa Valley east	NV	Nye	36.53622572	-116.22826080	31	52.0	52.0	Yes	Step-Over		6	N	No	Holocene	0.0	
NY31	Scruggs Spring	NV	Nye	36.43150313	-116.30972810	33	57.0	57.0	No	Step-Over		3	N	No	late Quaternary; possible Holocene	0.0	
	Lincoln County																
LI1	Rose Spring	NV	Lincoln	37.87100620	-115.65194901	21	57.0	57.0	No	Step-Over		7	N	No	Quaternary; probable late Quaternary	0.0	
LI2	Hiko Spring	NV	Lincoln	37.59840481	-115.21536633	27	55.0	55.0	No	Step-Over	Fault Intersection	9	N and NE	No	late Quaternary?	0.0	
LI3	Ash Springs	NV	Lincoln	37.46358300	-115.19261400	36	55.0	55.0	No	Fault Termination	Accommodation Zone	10	N	No	None mapped	0.0	Yes
LI4	Caliente Mineral Spring	NV	Lincoln	37.62051015	-114.51029133	67	101.0	101.0	No	Fault Intersection		5	NNE and E-W	No	None mapped	0.0	Yes
LI5	Panaca Warm Spring	NV	Lincoln	37.80677807	-114.38018625	30	70.0	70.0	No	Fault Termination		7	NNW	No	None mapped	0.0	
LI6	Flatnose Spring	NV	Lincoln	37.89647088	-114.22654542	25	70.0	70.0	No	Step-Over		5	NNW	No	Quaternary?	0.0	
	Clark County																
CL1	Indian Spring	NV	Clark	36.56605899	-115.66855299	26	44.0	44.0	No	Fault Intersection		2	ENE	No	None mapped	0.0	
CL2	Apex Well	NV	Clark	36.34101300	-114.92759700	31	47.0	47.0	Yes	Undetermined			NNE	No	None mapped	0.0	
CL3	Dry Lake	NV	Clark	36.45471152	-114.84606688	29	42.0	42.0	No	Step-Over		3	NNE	No	None mapped	0.0	
CL4	Fugro Coyote Well	NV	Clark	36.79602128	-114.89297533	36	51.0	51.0	Yes	Step-Over	Fault Termination	9	N	No	Mid to late Quaternary	0.0	
CL5	Iverson Spring	NV	Clark	36.70964427	-114.71592231	32	52.0	52.0	No	Fault Intersection		3	N	No	None mapped	0.0	
CL6	Rogers Spring	NV	Clark	36.37764578	-114.44370204	30	46.0	46.0	No	Pull-Apart		8	ENE	No	None mapped	0.0	
CL7	Hoover Dam-Black Canyon Hot Springs	NV	Clark	35.98539800	-114.74228400	63	70.0	70.0	No	Fault Intersection		8	N	No	None mapped	0.0	
CL7	Sundance Shores	NV	Clark	35.15340723	-114.57644499	32	50.0	50.0	Yes	Undetermined			N	No	None mapped	0.0	

Table 1. Geothermal systems of Nevada. For each system, information is provided on name, location (latitude, longitude, NAD83), temperature (°C), whether blind or not, type of structural setting, certainty of structural setting, primary fault orientation(s), whether magmatic heated, recency of faulting, installed power capacity, and whether utilized for direct use. IDs shown in first column on left are configured for each county in Nevada and correspond to labels shown on plate 1. "Maximum temperature measured" represents measurements from wells or springs, whereas geothermometry is based on geochemical analyses, as discussed in text. Blind systems have no active surface manifestations, such as hot springs or fumaroles. Structural setting types are shown in figure 2. Certainty of structural setting is qualitative, with 1 the least certain and 10 the most certain. Primary fault orientations are estimates derived from existing maps or imagery, with groupings as follows: 1) N, ~N10°W to N10°E; 2) NNE, ~N10°E to N35°E; 3) NE, ~N35°E to N55°E; 4) ENE, ~N55°E to N80°E; 5) E-W, ~N80°E to N80°W; 6) NNW, ~N10°W to N35°W; 7) NW, ~N35°W to N55°W; and 8) WNW, ~N55°W to N80°W. Magmatic-heated systems are inferred from the geochemistry of fluids and presence of nearby Quaternary intermediate to felsic volcanic rocks. Steamboat, directly south of Reno in Washoe County, is the only system in Nevada with an apparent magmatic signature and is associated with nearby Quaternary rhyolite domes (Arehart et al., 2003). Systems occurring near Quaternary mafic volcanic rocks derived directly from the upper mantle (e.g., Soda Lake near Fallon in Churchill County and Buffalo Valley in Lander County) are inferred to be amagmatic due the probable lack of crustal magma chambers. Recency of faulting represents the inferred age of most recent surface ruptures, which is based on existing literature (e.g., USGS, 2010) and analysis of imagery. Installed capacity (megawatts electricity, MWe) is sourced from Muntean et al. (2019). Direct use includes applications such as district heating, vegetable dehydration, and aquaculture.

*Power plant no longer operational. $^{+}$Power plant currently under construction.

TABLE 2. GEOTHERMAL STATISTICS

Structural Setting Type	Average Abundance (%) of Each Setting for All Geothermal Systems	Relative Abundance (%) of each Structural Setting for each Category of Geothermal Systems				
		Grouped by Maximum Temperature				Power Producing
		36–90°	90–130°	130–160°	≥160°	
Accommodation Zones	5.2	5.8	3.3	0.0	10.7	15.8
Displacement Transfer Zones	4.1	1.9	3.3	12.1	3.6	15.8
Pull-Aparts	4.1	2.9	0.0	6.1	10.7	5.3
Step-Overs	39.2	40.8	33.3	36.4	42.9	47.4
Fault Intersections	20.6	18.4	30.0	27.3	10.7	0.0
Fault Terminations	23.2	25.2	30.0	15.2	17.9	15.8
Fault Bends	1.0	1.9	0.0	0.0	0.0	0.0
Major Normal Faults	1.0	1.9	0.0	0.0	0.0	0.0
Hot Sedimentary Aquifers	1.5	1.0	0.0	3.0	3.6	0.0
% Sum	100.0	100.0	100.0	100.0	100.0	100.0
Number of Systems	194	103	30	33	28	19

Table 2. Summary of structural settings for known geothermal systems in Nevada based on percentage of total number of systems. The structural setting was inferred for 194 of these systems, with 20 systems remaining undetermined. The systems were grouped into eight types of structural settings, with a few systems classified as hot sedimentary aquifers (e.g., Allis et al., 2011). The systems were also grouped by maximum temperature obtained through either direct measurement of wells or springs or by means of geothermometry. Percentage of power producing systems is shown on the right but does not include direct-use applications. Table 1 provides details of each geothermal system, and locations are shown on plates 1 and 3.

northeast-striking faults (~N35°E to N80°E) and north-northwest to northwest-striking faults (~N10°W to N55°W) each influence ~18–19% of the systems, with many of these representing the secondary structure associated with fault intersections. East-west-striking (~N80°E to N80°W) and west-northwest-striking faults (~N55°W to N80°W) are associated with ~1–2% of the systems, and in all cases serve as the secondary structure in fault intersections.

Epithermal Mineral Deposits

To better understand the structural controls of relatively young gold and silver deposits, some of which are spatially associated with active geothermal systems, the structural settings of late Miocene and younger precious metal deposits in Nevada were compiled and compared with the settings found at active geothermal sites. Improved definitions of structural controls can lead to more efficient exploration targeting of gold and silver mineralization. The benefits could be significant because economic mineralization typically comprises a very small percentage of the individual mining districts.

For this analysis, a database of young gold deposits in Nevada originally compiled by Coolbaugh et al. (2005b, 2011) was augmented and updated. The database includes all epithermal gold and silver deposits with known or estimated ages ≤8 Ma. Production categories include >1.0 Moz (million troy ounces) Au, 0.1–1.0 Moz Au, <0.1 Moz Au, and prospects. Prospects have at least some assays of ≥100 ppb gold. For the silver-rich Silver Peak (Red Mountain) district, silver was converted to equivalent gold production at a ratio of 70:1. Structural settings were assessed at a district scale to identify structural controls responsible for the location of the main deposits within each district. This is distinguished from structural controls within individual mines (ore zone scale) and at more regional (tectonic) scales, which can be different. This is analogous to differences in the populations of open fractures in a geothermal reservoir and the regional structural setting that hosts a geothermal system.

Nevada is richly endowed in epithermal precious metal deposits. Some of these deposits are classified as low- and intermediate-sulfidation precious metal systems, and these types of deposits are inferred to have formed

from paleo-geothermal systems with temperatures and fluid compositions not much different from those of geothermal systems active in Nevada today (Henley, 1985). Examples of these types of deposits in Nevada include those found in the Comstock (e.g., Vikre, 1989), Sleeper (e.g., Nash et al., 1991), Midas (e.g., Marma and Vance, 2011), Tonopah (e.g., John, 2001), and Round Mountain (e.g., Henry et al., 1997) districts.

Most of the low- and intermediate-sulfidation systems in Nevada are mid- to late-Tertiary, but some are likely as young as Quaternary (Coolbaugh et al., 2005b). Some of the youngest deposits, of Pliocene and younger ages, are unusual in that they are not spatially associated with coeval volcanic rocks, but instead are spatially associated with active geothermal systems (Coolbaugh et al., 2005b). This suggests that some active geothermal systems in Nevada could be depositing precious metals at depth without the influence of coeval magmatism. In contrast, almost all epithermal deposits older than approximately 5 Ma in Nevada are associated with coeval volcanic rocks and are generally inferred to have formed from hydrothermal fluids that received heat and some metals from underlying magmas. For the database compilation, epithermal systems associated with coeval volcanic rocks are termed "magmatic systems", to contrast them with "amagmatic systems" that are not associated with coeval volcanic rocks and are assumed to have formed in an amagmatic setting.

With one possible exception, all ≤8 Ma "magmatic" epithermal systems in Nevada are associated with post-subduction, post-ancestral Cascade arc, volcanic rocks. As defined by John and Henry (2020), these volcanic rocks are presumed to have formed in a slab window behind the northward retreating ancestral Cascade magmatic arc. The retreating arc was trailed by the northward advancement of transtensional tectonics that characterizes much of the Walker Lane today. Because of their broadly transtensional tectonic settings, ≤8 Ma magmatic epithermal systems were included in this database, so that their structural settings could be evaluated and compared with the structural settings of active geothermal systems in Nevada that occur in the modern transtensional to extensional environment.

Mineral deposits around the globe are diverse in their metal endowments and geologic settings, and their structural settings are similarly diverse. Examples of this diversity include the presence of: 1) antiformal structures (Mitchell and Carlile, 1994), 2) intersections of detachment faults with higher angle listric and/or cross-cutting younger normal faults (e.g., Eng et al., 1996), 3) the superposition of younger structures upon older zones of structural preparation (e.g., Rhys et al., 2015), 4) radial and ring fractures related to magmatic intrusion (e.g., Carten et al., 1988; Sillitoe, 1993), 5) intersections of favorable structures with conducive lithologies, as defined either by their rheological properties (e.g., Simmons et al., 2005) or reactivities with hydrothermal fluids (e.g., Corbett, 2002; Guilbert and Park, 2007), 6) proximity to magmas/intrusions that can serve as a source of heat, metals, and juvenile fluids (e.g., Guilbert and Park, 2007), and 7) intersections of faults and veins with depth-related pressure horizons, as they influence boiling and/or effervescence (e.g., Simmons et al., 2005).

Notwithstanding this global diversity, it was found that many of the structural settings of 8–0 Ma epithermal deposits in Nevada, at a district scale, are similar to those found in active geothermal systems (tables 3 and 4; fig. 2). This is not surprising, given the relatively young ages of the epithermal systems evaluated, and the mutual occurrence of the mineral deposits and active geothermal systems in the same regional tectonic setting. The accompanying maps (plates 2 and 3) show the results of the analysis, including information on the structural settings and whether the deposits are directly associated with volcanism. Similar to geothermal systems, step-overs in normal fault zones are the most common structural setting for the late Miocene to Quaternary epithermal mineral deposits, hosting ~39% of the known deposits. Other common structural settings include fault terminations (~19%), displacement transfer zones (~15%), fault intersections (~8%), accommodation zones (~8%), pull-aparts (~4%), and fault bends (~4%). Also similar to geothermal systems, the main segments of major normal faults are apparently not conducive to epithermal mineralization, with no known deposits occupying such a setting. The primary orientation of faults controlling mineralization at these deposits is similar to that of the geothermal systems, with ~58% striking north-northeast, ~27% striking northerly, ~19% striking northeast, ~19% striking east-northeast, and less than 8% striking in other directions. Details of each system (e.g., both primary and secondary structural settings, certainty of structural setting, orientation of controlling structures,

TABLE 3. STRUCTURAL INVENTORY OF EPITHERMAL DEPOSITS

ID	Name	State	County	Lat_n83	Long_n83	Primary Structural Setting	Secondary Structural Setting	Certainty	Primary Structure Attitude	Magmatic	Hydrothermal Setting	Form of Mineralization
Washoe County												
WA-M1	Wind Mountain	NV	Washoe	40.427080	-119.391727	Step-over	Fault Termination	10	NNE	No	low-sulfidation epithermal (hot-springs type)	silicification, pyrite, Fe oxides, with steam overprint
WA-M2	Steamboat Springs	NV	Washoe	39.380922	-119.761048	Accommodation Zone	Fault Intersection	10	N and ENE	Yes	low-sulfidation epithermal (hot-springs type)	
Humboldt County												
HU-M1	Blue Mountain	NV	Humboldt	40.991832	-118.126512	Displacement Transfer Zone	Fault Intersection	8	N and NNE	No	low-sulfidation epithermal (hot-springs type)	quartz/silica-pyrite-arsenopyrite veinlets (with steam overprint)
HU-M2	Northern East Range	NV	Humboldt	40.871301	-117.937465	Fault Termination	Fault Intersection	10	NNE and ENE	No	low-sulfidation epithermal (hot-springs type)	siliceous and calcareous spring deposits
Pershing County												
PE-M1	Hycroft	NV	Pershing	40.874566	-118.686398	Fault Termination	Step-over	9	NNE	No	low-sulfidation epithermal (hot-springs type)	silica-adularia stockwork with steam overprint
PE-M2	Scossa	NV	Pershing	40.733930	-118.588740	Step-over	Fault Intersection	4	NNE and N	No	low-sulfidation epithermal (hot-springs type)	quartz veins and silicification
PE-M3	Humboldt House	NV	Pershing	40.594788	-118.265097	Fault Termination		9	NNE	No	low-sulfidation epithermal (hot-springs type)	silicified sediments
PE-M4	Florida Canyon	NV	Pershing	40.577515	-118.238838	Fault Termination		9	NNE	No	low-sulfidation epithermal (hot-springs type)	quartz-adularia stockwork with steam overprint
PE-M5	Colado	NV	Pershing	40.260396	-118.360730	Step-over	Fault Intersection	9	NNE	No	low-sulfidation epithermal (hot-springs type)	silicification, argillization, and silica-clay-pyrite stockworks
PE-M6	Willard	NV	Pershing	40.248500	-118.336840	Fault Intersection		8	N, NW, E	No	low-sulfidation epithermal	silicification and quartz-calcite-adularia veining
PE-M7	Red Edge	NV	Pershing	40.002504	-118.513642	Fault Bend		5	ENE	No	low-sulfidation epithermal (hot-springs type)	argillized and silicified sediments
PE-M8	New York Canyon	NV	Pershing	40.046142	-118.017478	Step-over	Fault Intersection	7	NE	No	low-sulfidation epithermal (hot-springs type)	silicification and steam-heated alteation following Quaternary faults
PE-M9	Jersey Valley	NV	Pershing	40.179590	-117.472738	Step-over		10	NNE	No	low-sulfidation epithermal (hot-springs type)	silicified fault breccia
Churchill County												
CH-M1	Dixie Valley-Senator	NV	Churchill	39.994510	-117.853138	Step-over		9	NNE	No	low-sulfidation epithermal (hot-springs type)	shallow silicification, steam-heated alteration
CH-M2	Dixie Comstock	NV	Churchill	39.865697	-118.017496	Step-over	Fault Intersection	10	NNE	No	low-sulfidation epithermal (hot-springs type)	quartz/silica-pyrite-sulfide breccia matrix, stockworks
Lyon County												
LY-M1	Patua Hot Springs	NV	Lyon	39.594076	-119.112204	Step-over	Fault Termination	8	NNE	No	low-sulfidation epithermal (hot-springs type)	silicified alluvium
LY-M2	Como	NV	Lyon	39.171626	-119.477563	Displacement Transfer Zone	Step-over	6	N60E	Yes	volcanic-hosted low-sulfidation epithermal	quartz-sulfide-K feldspar-calcite veins in andesite
LY-M3	Rockland	NV	Lyon	38.648784	-119.095123	Step-over	Fault Intersection	5	NNW, N, and NE	Yes	volcanic-hosted low-sulfidation epithermal	quartz-chalcedony-sulfide banded veins with silicified platy calcite
Lander County												
LA-M1	McGinniss Hills	NV	Lander	39.599986	-116.904863	Accommodation Zone	Step-over	10	NNE	No	low-sulfidation epithermal (hot-springs type)	banded silica veins beneath sinter cap
Eureka County												
EU-M1	Beowawe-White Canyon	NV	Eureka	40.565565	-116.565015	Fault Intersection		7	NNW	No	low-sulfidation epithermal (hot-springs type)	silicification and quartz-sulfide stockworks
Mineral County												
MI-M1	Alkali Flat (Don Campbell)	NV	Mineral	38.837042	-118.325206	Displacement Transfer Zone	Fault Intersection	9	NNE	No	low-sulfidation epithermal (hot-springs type)	pyrite and quartz/chalcedony in argillized host rocks
MI-M2	Spring Peak	NV	Mineral	38.249444	-118.855804	Step-over	Fault Intersection	6	NNE and E-W	Yes	low-sulfidation epithermal	banded quartz veins, silica sinter
Esmeralda County												
ES-M1	Eastside	NV	Esmeralda	38.207402	-117.615991	Displacement Transfer Zone	Fault Intersection	5	N and NE	Yes	volcanic-hosted low-sulfidation epithermal	quartz veins with adularia, near rhyolite dome margins; steam overprint
ES-M2	Tip Top	NV	Esmeralda	37.933008	-118.306056	Fault-Intrusion Intersection	Fault Intersection	7	N and ENE	Yes	volcanic-hosted low-sulfidation epithermal	quartz-calcite-adularia veins and silicified stockworks/breccias
ES-M3	Palmetto (red Rock)	NV	Esmeralda	37.849962	-118.222561	Fault Termination	Fault Intersection	9	NW, WNW, and NNE	Yes	low-sulfidation epithermal	
ES-M4	Silver Peak, Red Mtn (16 to 1 Mine)	NV	Esmeralda	37.716044	-117.784496	Pull-apart	Fault-caldera intersection	7	NE	Yes	volcanic-hosted intermediate-sulfidation veins	wide, continuous, multistage quartz-calcite-sulfide veins in faults

Table 3. Late Miocene (~8 Ma) to Quaternary epithermal mineral deposits of Nevada. For each deposit, information is provided on name, location (latitude, longitude, NAD83), type of structural setting, certainty of structural setting, primary fault orientation(s), whether magmatic-heated, hydrothermal setting, form of mineralization, mineralogy, host rocks, approximate age, method of dating, gold production, and references. IDs shown in first column on the left are configured for each county in Nevada and correspond to labels shown on plate 2. Structural setting types are shown in figure 2. Certainty of structural setting is qualitative, with 1 the least certain and 10 the most certain. Primary fault orientations are estimates derived from existing maps or imagery, with groupings the same as in table 1. Magmatic-heated systems are inferred from ages of deposits relative to ages of proximal volcanic rocks.

TABLE 3. (CONTINUED)

ID	Name	State	County	Lat_n83	Long_n83	Mineralogy	Host Rocks	Site Reference	Age Ma	Age Method	Host for Dating	Age Reference	Production Au
Washoe County													
WA-M1	Wind Mountain	NV	Washoe	40.427080	-119.391727	silica, pyrite, Fe oxides, native sulfur, alunite	Tertiary sediments and basalt	Wood, 1991	<5.0			Rhodes, 2011	production 0.1–1.0 Moz
WA-M2	Steamboat Springs	NV	Washoe	39.380922	-119.761048	opal, cinnabar, stibnite, native sulfur	Pre-tertiary granodiorite and metasediments, Tertiary volcanics	White et al., 1964	>2.5-0.0	K-Ar, geologic relations	basaltic andesite	Silberman et al., 1979	prospect
Humboldt County													
HU-M1	Blue Mountain	NV	Humboldt	40.991832	-118.126512	silica, barite, fluorite, pyrite, calcite, native sulfur, cinnabar, arsenopyrite, alunite	Triassic metasediments	Parr and Percival, 1991	3.9	K-Ar	alunite	Garside et al., 1993	resource calculated
HU-M2	Northern East Range	NV	Humboldt	40.871301	-117.937465		Quaternary alluvium	P Vikre, pers. Communication	Quaternary?	geologic relations			prospect
Pershing County													
PE-M1	Hycroft	NV	Pershing	40.874566	-118.686398	silica, adularia, pyrite, marcasite, cinnabar, sulfur	Tertiary sediments and volcanics	Ebert and Rye, 1997	3.9–3.8	Ar/Ar		Ebert and Rye, 1997	production >1 Moz
PE-M2	Scossa	NV	Pershing	40.733930	-118.588740	quartz, alunite, adularia, pyrite, marcasite, arsenopyrite, electrum	Triassic/Jurassic metasediments; Tertiary fanglomerate	Robbins, 1985; Miller, 1993	6.5	K-Ar	alunite	Noble et al., 1987	production <0.1 Moz
PE-M3	Humboldt House	NV	Pershing	40.594788	-118.265097	silica, Fe oxides	Quaternary sediments	R Parratt, pers. Communication	Quaternary	geologic relations		Coolbaugh et al., 2005a	prospect
PE-M4	Florida Canyon	NV	Pershing	40.577515	-118.238838	quartz, adularia, pyrite, marcasite, cinnabar, sulfur	Triassic siliciclastics	Fifarek et al., 2011	5.1–4.6	Ar/Ar		Fifarek et al., 2011	production >1 Moz
PE-M5	Colado	NV	Pershing	40.260396	-118.360730	silica, clay, pyrite, adularia, fluorite, barite, calcite	Tertiary volcanics, Mesozoic sediments	Conelea and Howald, 2011	Quaternary	geologic relations			resource calculated
PE-M6	Willard	NV	Pershing	40.248500	-118.336840	quartz, calcite, adularia, calcite, pyrite, barite, electrum	Mesozoic sediments	Conelea and Howald, 2011	6.1	K-Ar	adularia	Noble et al., 1987	production <0.1 Moz
PE-M7	Red Edge	NV	Pershing	40.002504	-118.513642		Quaternary/Tertiary sediments	R Parratt, pers. Communication	Quaternary?	geologic relations			prospect
PE-M8	New York Canyon	NV	Pershing	40.046142	-118.017478	silica, kaolinite, native sulfur, cinnabar	Triassic metasediments	Vikre, 2000	Quaternary?	geologic relations			prospect
PE-M9	Jersey Valley	NV	Pershing	40.179590	-117.472738	silica, native sulfur, cinnabar	Mesozoic metasediments, fault breccia	Vikre, 2000	Quaternary	geologic relations			prospect
Churchill County													
CH-M1	Dixie Valley-Senator	NV	Churchill	39.994510	-117.853138	silica, native sulfur	Quaternary/Tertiary colluvium	R Parratt, pers. Communication	Quaternary	geologic relations			prospect
CH-M2	Dixie Comstock	NV	Churchill	39.865697	-118.017496	quartz, pyrite, chalcopyrite, cinnabar, molybdenite, naumannite, electrum	Jurassic gabbro and fault breccia	Vikre, 1994	Quaternary	geologic, U-series	calcite	Vikre, 1994	production <0.1 Moz
Lyon County													
LY-M1	Patua Hot Springs	NV	Lyon	39.594076	-119.112204	silica	Quaternary alluvium	R Parratt, pers. Communication	Quaternary?	geologic relations			prospect
LY-M2	Como	NV	Lyon	39.171626	-119.477563	sulfides: pyrite, marcasite, tetrahedrite, stibnite, chalcopyrite, pyargyrite, electrum	Tertiary andesitic volcanics	Vikre and McKee, 1994	7.0–6.6	Ar/Ar	vein K feldspar	Vikre and McKee, 1994	production <0.1 Moz
LY-M3	Rockland	NV	Lyon	38.648784	-119.095123	quartz, silica, pyrite, pyrargrite, acanthite, electrum	Tertiary rhyolite domes, Jurassic granodiorite, Cenozoic sediments	Eng et al., 2015	~7	K-Ar, geologic relations	rhyolite domes	Eng et al., 2015	production <0.1 Moz
Lander County													
LA-M1	McGinniss Hills	NV	Lander	39.599986	-116.904863	chalcedony, fluorite, adularia, stibnite	Paleozoic chert, quartzite; Tertiary andesite	Casaceli, et al., 1986; Nordquist and Delwiche, 2013	3.2–2.2	K-Ar	adularia	Casaceli et al., 1986	prospect
Eureka County													
EU-M1	Beowawe-White Canyon	NV	Eureka	40.565565	-116.565015		Tertiary volcanics/sediments	Struhsacker, 1986	Quaternary	geologic relations		Struhsacker, 1986	prospect
Mineral County													
MI-M1	Alkali Flat (Don Campbell)	NV	Mineral	38.837042	-118.325206	quartz, chalcedony, pyrite	Tertiary sediments and volcanics	Vikre and Koutz, 2013	Quaternary?	geologic relations		Vikre and Koutz, 2013	prospect
MI-M2	Spring Peak	NV	Mineral	38.249444	-118.855804	quartz, opal, stibnite, cinnabar	Mesozoic quartz monzodiorite	Silberman, 1995	≤2.5	geologic relations	andesite	Silberman, 1995	prospect
Esmeralda County													
ES-M1	Eastside	NV	Esmeralda	38.207402	-117.615991	quartz, silica, jarosite, adularia, tourmaline, cryptomelane, pyrolusite, barite, alunite	Tertiary rhyolite domes, lesser andesite, sediments	Ristorcelli and Unger, 2020	7.2	K-Ar	rhyolite vitrophyre	Stewart et al., 1994	resource calculated
ES-M2	Tip Top	NV	Esmeralda	37.933008	-118.306056	quartz, adularia, calcite, pyrite	Tertiary volcanic rocks	Barnard, 2014	~6	geologic relations	based on similarities with Silver Peak Range volcanics	Crowder et al., 1972	production <0.1 Moz
ES-M3	Palmetto (red Rock)	NV	Esmeralda	37.849962	-118.222561		Paleozoic metasediments, minor Tertiary volcanics	ML Gold Corp., 2018	~6	geologic relations	based on similarities with Silver Peak Range volcanics	Crowder et al., 1972	resource calculated
ES-M4	Silver Peak, Red Mtn (16 to 1 Mine)	NV	Esmeralda	37.716044	-117.784496	quartz, calcite, Mn-carbonate, pyrite, galena, sphalerite, acanthite, native silver	Tertiary volcanics	Cline, 1986	5	K-Ar	adularia	Keith, 1977; Cline, 1986	production >10 Moz (Ag)

TABLE 4. EPITHERMAL STATISTICS

Structural Setting Type	Epithermal (n)	Average Abundance (%) of Each Setting for All Epithermal Systems	Geothermal (n)	Average Abundance (%) of Each Setting for All Geothermal Systems
Accommodation Zones	2	7.7	10	5.2
Displacement Transfer Zones	4	15.4	8	4.2
Pull Aparts	1	3.8	8	4.2
Step-Overs	10	38.5	76	39.3
Fault Intersections	2	7.7	40	19.9
Fault Terminations	5	19.2	45	23.6
Fault Bends	1	3.8	2	1.0
Major Normal Faults	0	0.0	2	1.0
Hot Sedimentary Aquifers	---	---	3	1.6
Fault-Intrusion Intersection	1	3.8	---	---
Sum	26	100.0	194	100.0

Table 4. Summary of structural settings inferred for 26 late Miocene (~8 Ma) to Quaternary epithermal mineral deposits in Nevada. The systems were grouped into nine types of settings, as shown on the left, with findings from currently active geothermal systems (tables 1 and 2) shown on the right for comparison. Table 3 provides details of each epithermal deposit, and locations are shown on plates 2 and 3.

types of alteration, mineral assemblages, and production of precious metals) are shown in table 3.

The database provides examples of how knowledge of the structural setting can help guide exploration for epithermal deposits. At the Rockland Mine area in the Pine Grove mining district, Lyon County, an oval-shaped, 120 km^2, late Miocene rhyolite dome field hosts northeast-striking precious metal-bearing faults and veins (Eng et al., 2015). As documented by Eng et al. (2015), the mineralized structures define a distinctive 5-km-long, east-trending corridor of northeast-striking structures that occupy just 5% of the dome field. These structures lie between, and within, a series of en échelon north-northwest-striking strands of the Pine Grove fault zone that collectively define a broad step in the fault system. Thus, mineralization appears largely confined to the region of overlap of the dome field with a step-over in a normal fault zone.

Another example of structural control in an epithermal district is provided by the recently discovered Eastside gold deposit in Esmeralda County. At Eastside, mineralization is closely associated both in time and space with rhyolite dome extrusion (Ristorcelli and Unger, 2020). More than 40 domes follow a distinctly linear, 15-km-long belt defined in part by normal faults (Stewart et al., 1994; Whitehead, 2015; Ristorcelli and Unger, 2020). The largest gold deposit identified to date occurs where this belt changes strike from north-northeast (south of the deposit) to north-northwest (north of the deposit). Thus, at the district scale, the deposit lies at the intersection of two major structural trends. The orientations of these two trends are consistent with a displacement transfer zone within the Walker Lane, whereby the north-northwest trend may be related to a northwest-striking dextral fault (e.g., Stewart et al., 1994) that terminates in an array of north-northeast striking normal faults that may have facilitated emplacement of the domes. Most gold mineralization drilled to date occurs in the broad intersection zone between the two structural trends, and this broad zone corresponds to the region of greatest expected structural complexity in a displacement transfer zone.

DISCUSSION AND IMPLICATIONS

Geothermal systems in Nevada are relatively rare along the displacement-maxima zones or mid-segments of major normal faults (i.e., major range-front faults), possibly due to both reduced permeability in thick zones of clay gouge and periodic release of stress in

major earthquakes. Instead, geothermal systems most commonly occur in belts of intermeshing, overlapping, or intersecting faults. Step-overs (relay ramps), terminations, intersections, and accommodation zones in normal fault systems correspond to long-term, critically stressed areas, where fluid pathways are more likely to remain open in networks of closely-spaced, breccia-dominated fractures (e.g., Micklethwaite and Cox, 2004; Faulds and Hinz, 2015; Siler et al., 2018). Enhanced strain rates and increased structural complexity in displacement transfer zones and pull-aparts (or releasing bends) are two additional favorable structural settings for geothermal activity within or adjacent to strike-slip fault zones.

These findings may help to guide geothermal exploration within the actively extending Great Basin region of Nevada and neighboring states and facilitate discovery and development of blind geothermal systems. This includes selecting the location of individual production wells within a broader geothermal field. For example, a logical site for a production well within a field may be the horsetailing end of a major normal fault or dilational part of a fault intersection. This work should be coupled with slip and dilation tendency analysis of fault zones and where possible 3D modeling (e.g., Siler et al., 2016, 2019).

It is also important to note that the structural setting is only one key feature of a geothermal field. Understanding the detailed geometries and kinematics of such settings and even identifying the location of favorable settings within Neogene basins requires integration of geologic, geophysical, and geochemical datasets. A successful exploration program typically requires integration of such datasets at multiple scales (e.g., local and regional), as well as appropriate ranking of the various parameters based on geostatistical analysis. Geothermal play fairway analysis is an emerging methodology by which to integrate multiple datasets and has achieved initial success in the Great Basin region of Nevada (e.g., Faulds et al., 2016, 2018).

Young (≤8 Ma) epithermal systems in Nevada, similar to active geothermal systems, are rarely found along the displacement-maxima zones or mid-segments of major normal faults. Instead, they are associated with more complex structural settings, including step-overs, displacement transfer zones, accommodation zones, and fault terminations. The limited number of young (≤8 Ma) epithermal systems evaluated in this study (n=26) limits the ability to identify correlations with the size or grade of deposits, but it is clear that the formation of epithermal precious metal deposits, which typically requires temperatures in the range of 160 to 270°C (Hedenquist et al., 2000), is favored by complex settings that are conducive to deep fluid flow.

These data can be useful for guiding exploration strategies for precious metal resources, because economical concentrations of gold and silver typically occupy a small percentage of the individual mining districts. Furthermore, many of the young epithermal systems of the Great Basin region only have shallow expressions, because erosional processes have not had time to expose the deeper levels where precious metal horizons are found. Knowledge of structural settings can therefore help to identify zones of permeable structural complexity, where fluid flow may have been concentrated.

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