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A Play Fairway Approach to Geothermal Exploration in Crescent Valley, Nevada

Emma G. McConville[1], James E. Faulds[1], Nicholas H. Hinz[1], Alan R. Ramelli[1], Mark F. Coolbaugh[1,2], Lisa Shevenell[2], Drew L. Siler[3], and Jade Bourdeau-Hernikl[1]

[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno, NV 89557
[2]ATLAS Geosciences, Inc., Reno, NV 89509
[3]U.S. Geological Survey, Menlo Park, CA

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ABSTRACT

Crescent Valley received one of the highest favorability scores in phase I of the DOE-sponsored Nevada play fairway analysis project and was therefore selected for detailed study in phase II. As part of the detailed study, geological, geochemical, and geophysical data were collected, synthesized, and analyzed to identify favorable structural settings for geothermal fluids in the basin. A total of eight favorable structural settings were identified. Two host known geothermal systems, and six could potentially host blind geothermal systems. In phase II a predictive geothermal potential model was conducted for each favorable structural setting. The highest-ranking areas in Crescent Valley are in the Dann Hot Springs step-over (relay ramp), followed by the two northern step-overs along the Cortez Mountains front, as well as a fault intersection at Hot Springs Point.

1. Introduction

Crescent Valley received one of the highest favorability scores in phase I of the DOE-sponsored Nevada play fairway analysis project (Faulds et al., 2015, 2016) and was therefore selected for detailed study in phase II. The Crescent Valley study area (Figure 1) encompasses ~600 km^2 of north-central Nevada, including the Dry Hills and the northern portion of the Cortez Mountains. Our detailed study of Crescent Valley included 1) a detailed Quaternary fault map covering ~500 km^2, 2) slip and dilation tendency analysis of ~360 km of newly mapped Quaternary faults, 3) new detailed logging of 4 wells (2,638 m) and integration of ~20,000 m of existing logs from 39 wells, 4) integration of 22 temperature gradient wells, 5) a new gravity survey of 236 stations that was merged with ~3,000 legacy stations (Figure 2), 6) development of 4 depth to basement gravity inversion profiles based on the new gravity data, 7) a shallow temperature survey (31 stations), 8) interpretation of 4 seismic reflection profiles totaling 92 km, and 9) geochemical analyses of 23 water samples. Our Quaternary fault map significantly enhances previously completed mapping in the area (Muffler, 1964; USGS, 2010).

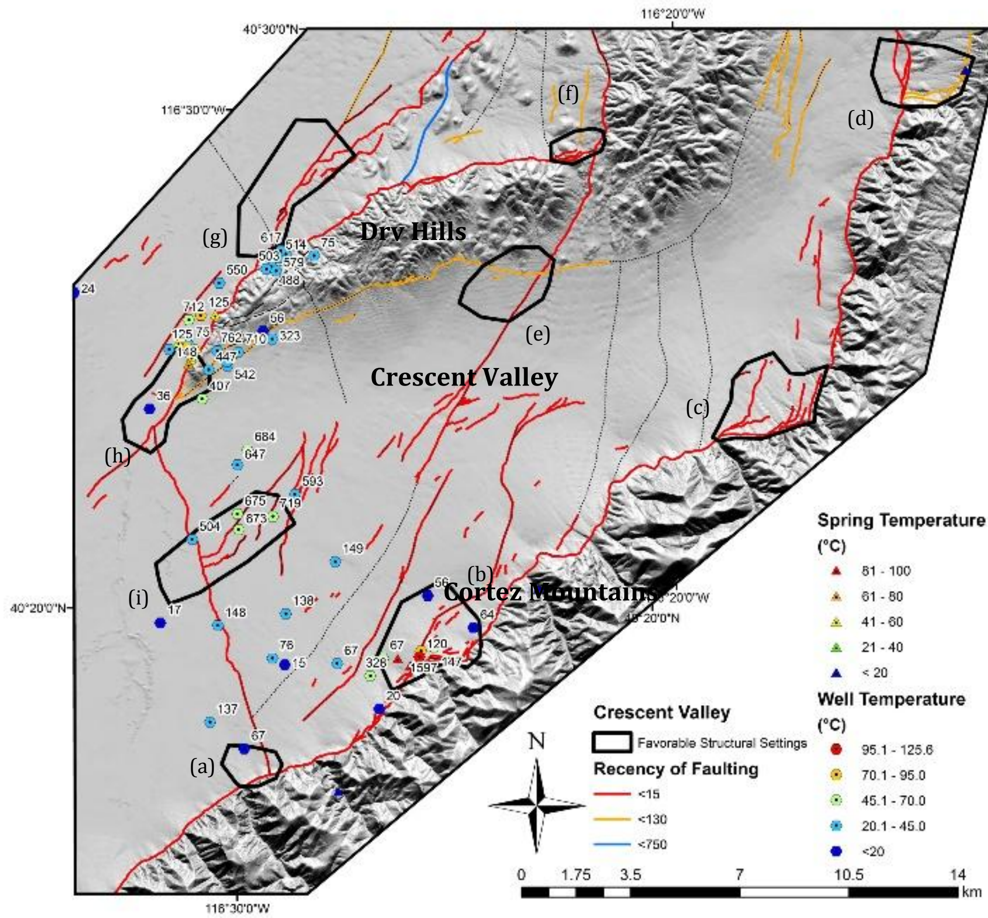


Figure 1: Crescent Valley detailed study area fault map. Black polygons are favorable structural settings for geothermal exploration. Faults are colored based on rupture recency (red <15 ka, yellow <130, and blue <750 ka). Springs are represented by triangles and are colored based on measured temperature. Wells are represented by hexagons and are colored based on measured bottom hole temperature. The labels next to the wells denote the depth of the well in meters.

2. Stratigraphy

The stratigraphy of Crescent Valley consists of Paleozoic and Mesozoic metasedimentary units nonconformably overlain by Tertiary volcanic and sedimentary rocks. The Paleozoic units are dominated by siliceous sedimentary rocks with lesser dolomite, rhyodacite, and volcanic units. The Mesozoic rocks are dominantly comprised of intermediate to felsic intrusive and volcanic rocks. The Tertiary units consist of rhyodacite flows, ash-flow tuffs, and basaltic andesite flows. The Quaternary units include alluvial fan deposits proximal to the mountain fronts and fluviolacustrine silts in more distal areas. Gravity, seismic reflection data, and depth to basement estimates by Watt et al. (2007) collectively indicate that the Crescent Valley basin between the

Dry Hills and the Cortez Mountains deepens from ~0.7 km in the northeast to ~5 km in the southwest portion of the study area.

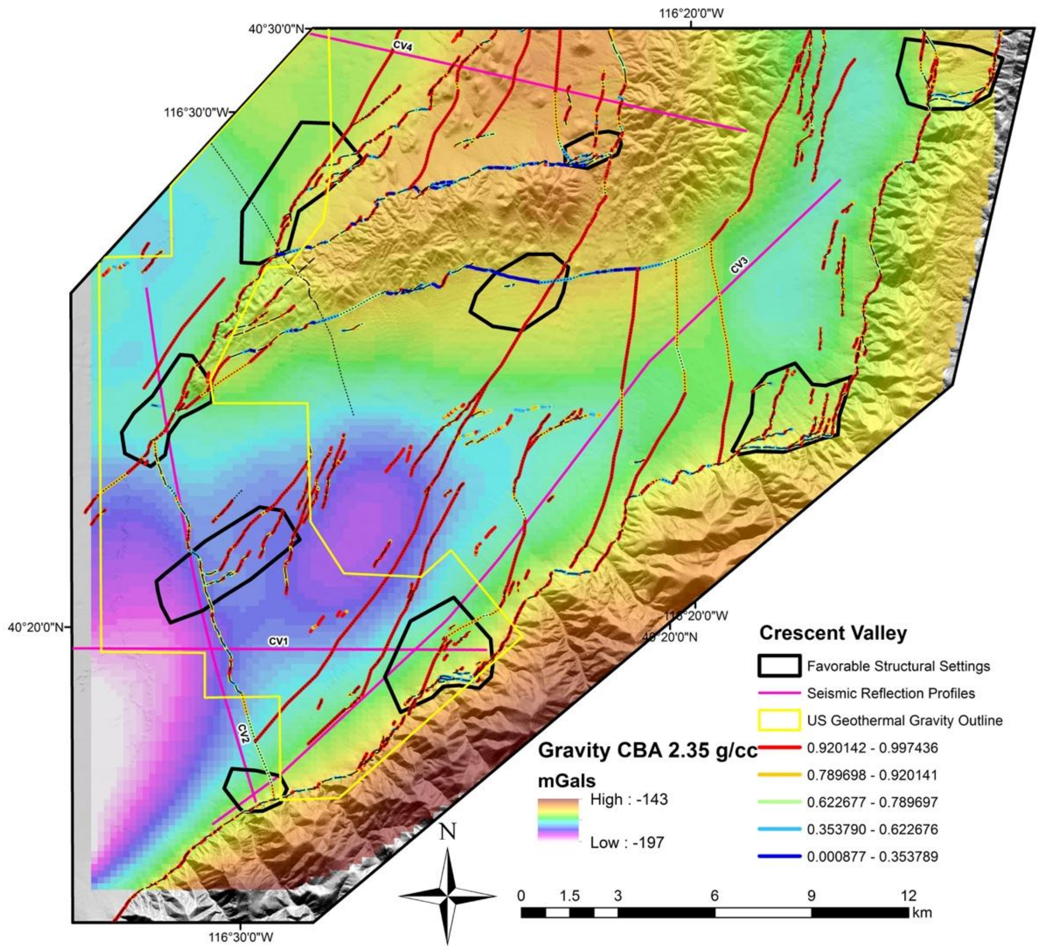


Figure 2: Complete Bouguer Anomaly gravity map of the Crescent Valley study area. Gravity measurements were calculated using a density of 2.35 g/cc. Warm colors indicate gravity highs, and cool colors indicate gravity lows. Black polygons are favorable structural settings for geothermal exploration. Faults are colored based on slip and dilation tendency, with warm colors indicating high slip and dilation tendency and cool colors representing low slip and dilation tendency. Pink lines indicate the location of seismic reflection profiles interpreted in this study.

3. Structural Framework

The structural framework of Crescent Valley consists of a series of east-tilted half grabens bounded on the east by the northwest-dipping Crescent Valley fault. Four discrete right step-overs (relay ramps) occur along the Cortez Mountains. One of these step-overs encompasses Dann Hot Springs that has a surface temperature of 87^{o}C and silica geothermometry of ~180^{o}C. Northwest of the Cortez Mountains is the Dry Hills, a horst block that is bounded to the south by a continuous northeast- to east-striking fault. To the north, the Dry Hills are bounded by the north-dipping Dry Hills fault that accommodates uplift of Paleozoic and Mesozoic units in the footwall. Hot Springs Point is located at the southwestern tip of the Dry Hills, where the Dry Hills fault intersects a north-northwest striking, west-dipping fault that bisects the basin. This intrabasinal fault continues southward from the intersection with the Dry Hills fault at Hot Springs Point to the Cortez Mountains, where it terminates against the Crescent Valley fault.

4. Quaternary Faulting

The most active Quaternary fault in the Crescent Valley area is the major range-front fault bounding the northwest side of the Cortez Mountains, the Crescent Valley fault. The Crescent Valley fault ruptured during one Holocene event, with surface offset of >4 m (Friedrich et al., 2004). The longer term history of the Crescent Valley fault is poorly constrained, but it is estimated to have a late Quaternary slip rate of ~0.2 mm/yr. Paleoseismic studies indicate that the fault bounding the Dry Hills on the northwest has ruptured three times over the past 30 ka, with offsets ranging from 0.5 to 1.5 m per event (Wesnousky et al., 2005), indicating a slip rate of ~0.1 mm/yr. Other faults in the area have recent activity but much smaller displacements. These faults are likely secondary ruptures during events on the main faults, and they have estimated slip rates ranging from 0.01 to 0.001 mm/yr.

5. Favorable Structural Settings

The geologic and geophysical data indicate at least 8 discrete favorable structural settings capable of hosting geothermal fluids in the Crescent Valley area (Figure 1). These include a major fault intersection (a) and three discrete step-overs (b, c, d) along the Crescent Valley fault and west flank of the Cortez Mountains, two fault intersections in the central part of the Dry Hills (e,f), a major fault intersection along the northwestern flank of the Dry Hills (g), a fault intersection near Hot Springs Point (h), and an intrabasinal fault intersection between a SSW-dipping fault and NW-dipping faults to the south of Hot Springs Point (i).

Slip and dilation tendency calculated for late Cenozoic faults at Crescent Valley indicate that NNE-striking normal faults have the highest slip and dilation tendency, with a maximum on normal faults striking N26^{o}E. Thus, many of the normal faults in the Crescent study area are well oriented for slip and dilation, including faults in each of the structural target areas. The ENE-striking oblique-slip faults in the area are at relatively low angles to the Sh_{min} direction (~116°), so they are generally poorly oriented for dilation. Slip tendency, on the other hand is relatively high on the NE-striking, oblique-slip fault segments in the central part of the study area.

6. Temperature Data

6.1 Wells, springs, and geothermometry

The Crescent Valley study area is located ~13 km southeast of the 210°C, 18.5 MW geothermal system at Beowawe. Crescent Valley contains two known thermal fluid areas: Hot Springs Point (HSP) in the central part of the valley at the south end of the Dry Hills, and Dann Ranch on the east side of the valley. There are 10 known springs at HSP with temperatures between 41.2 and 60.8°C, whereas the Dann Ranch area hosts the highest temperature springs (89.4°C) and wells (125.5°C) known in the study area. This subarea is currently being explored by U.S. Geothermal for potential power production (Figure 1).

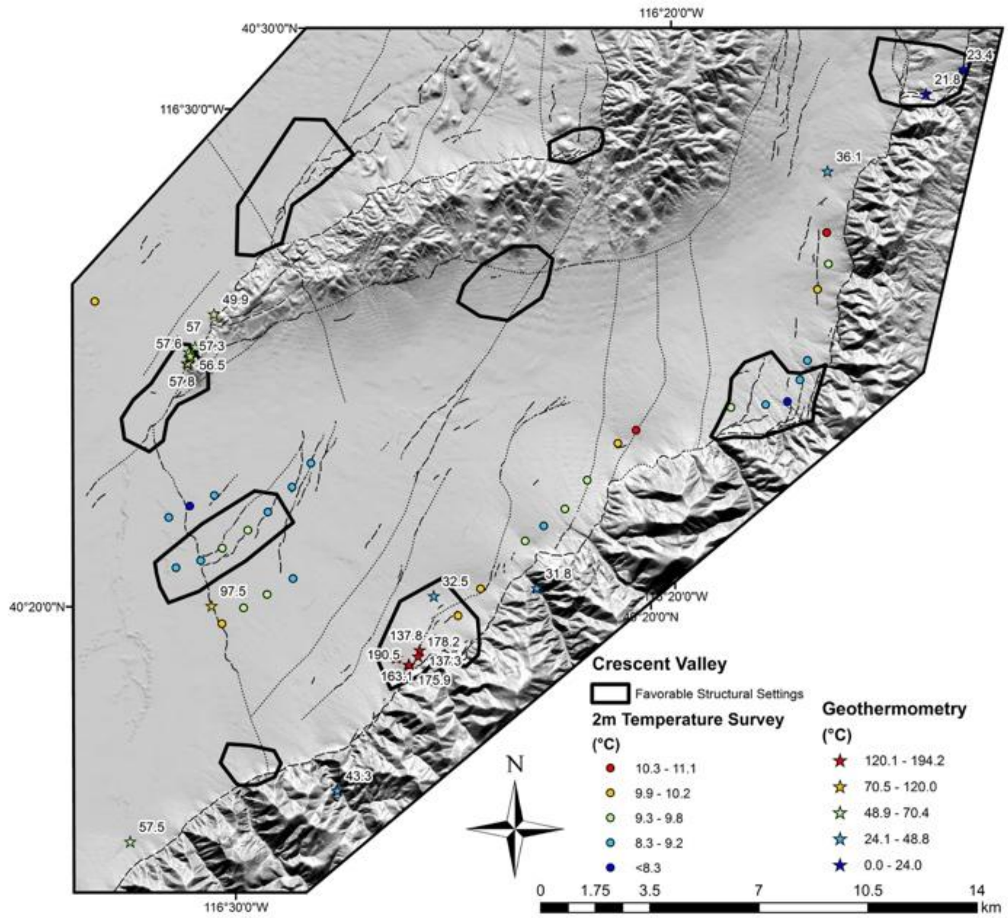


Figure 3: Crescent Valley study area fault map. Black polygons are structural settings favorable for geothermal exploration. Circles represent 2-meter temperature stations and are colored by temperature. Geothermometry samples are represented by stars. Each geothermometry sample is labeled with the preferred geothermometer determined by ATLAS Geosciences, Inc.

Thirty-one water analyses are available in the Crescent Valley study area. Geochemical data were obtained from historical (8), company files (15; US Geothermal), and new samples collected in this study (8 sites) (Figure 3). Although data from the Hot Springs Point area indicate relatively low temperatures with traditional geothermometers (~90-100°C with chalcedony and K/Mg geothermometers), temperatures in excess of 180°C (possibly 200°C) are indicated in the Dann Ranch area. The Dann Ranch and Hot Springs Point areas appear to be separate systems such that Hot Springs Point does not represent an outflow of the higher temperature system on the east side of the valley. A new sample location southeast of Hot Springs Point in the center of the basin collected in this study shows indications of thermal water contributions. Although the water is a cold (8°C) seep, temperatures of at least 100°C are indicated with traditional geothermometry (chalcedony, Na-K-Ca, Mg-correction). However, the suggested elevated temperature is likely an artifact of at least limited shallow fluid interaction with evaporite deposits in the basin center, as the Cl and B contents are 3.2 and 4 times those measured in the highest temperature (125.5°C) well in the Dann Ranch area, and over 10 and 8 times the Cl and B, respectively, of springs at HSP. Unequilibrated mineral wells with bottom-hole temperatures of 45-50°C at 407-719 m depth indicate anomalous high subsurface temperatures near the fault intersection in the center of the basin (Figure 4). Furthermore, the highest temperature mineral wells were abandoned due to high temperatures and fluid pressure. The mineral well temperatures and high fluid pressures lend credence to a potential blind geothermal system near the fault intersection in the center of the basin (personal correspondences with Ian Warren, U.S. Geothermal Inc.). The results of this study verify the high temperatures expected in the Dann Ranch area and suggest the presence of a blind geothermal system in Crescent Valley.

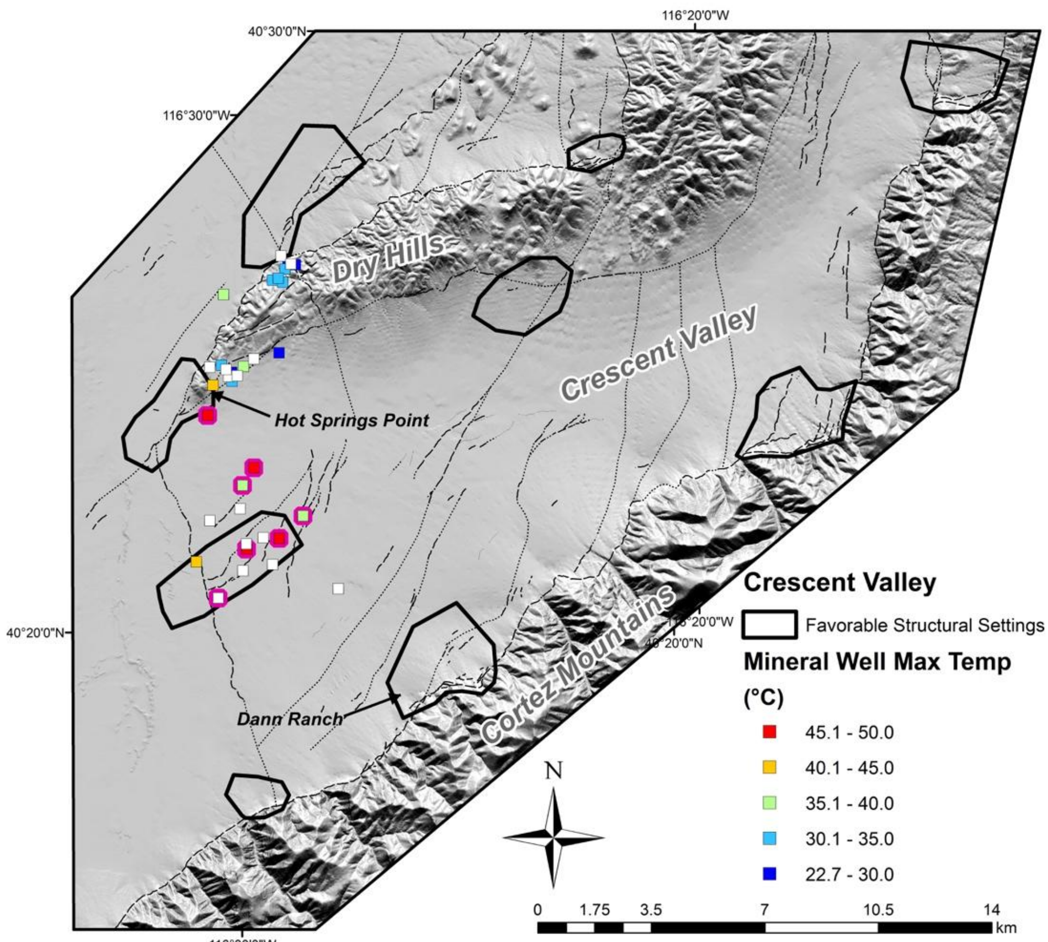


Figure 4: Crescent Valley study area fault map. Black polygons are structural settings favorable for geothermal exploration. Squares represent unequilibrated bottom-hole mineral well temperatures and are colored according to temperature. Wells with no temperature data are represented in white. Wells highlighted in pink represent the mineral wells abandoned due to high temperature and pressure conditions.

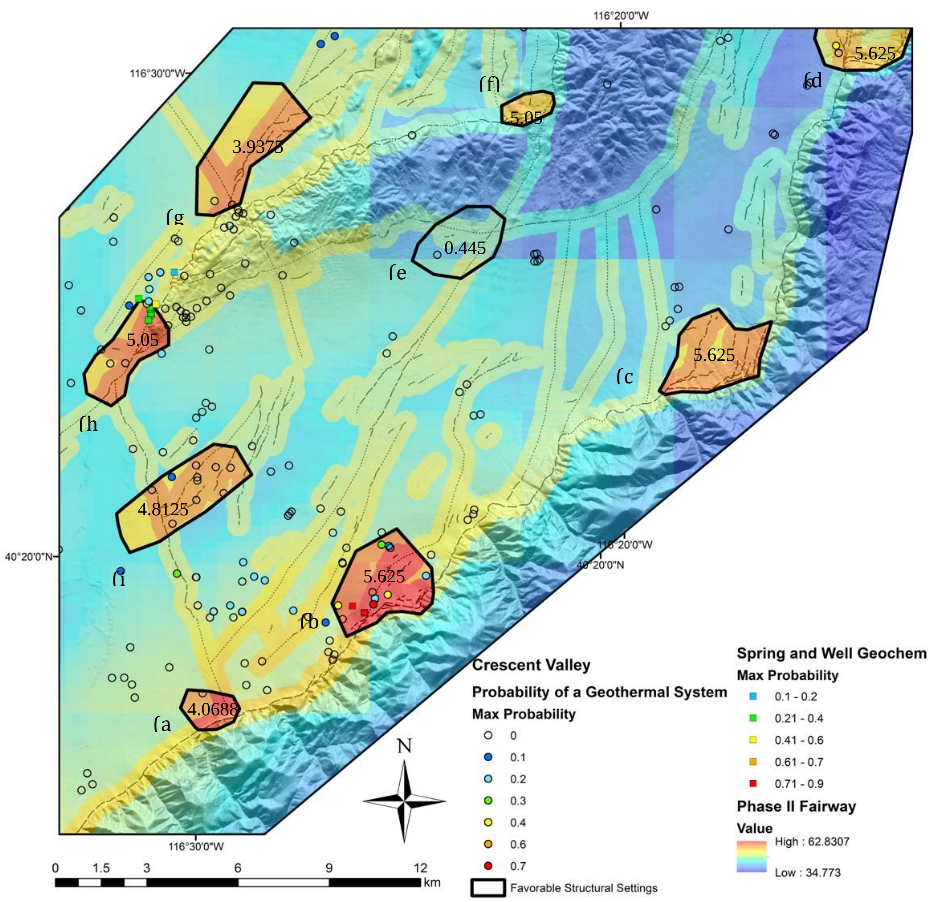
6.2 2-meter temperature survey

A 2-meter temperature survey with 31 stations was completed but did not reveal a shallow temperature anomaly in the basin or along the south and central portions of the Cortez Mountains (Figure 2). However, this past winter northern Nevada experienced much higher than average precipitation, which may have masked all but the strongest thermal anomalies.

7. Play Fairway Analysis

A play fairway predictive map of the Crescent Valley study area was produced using data from phases I and II of the project. The method used to construct the play fairway map in phase II is similar to the methodology used in phase I (Figure 5). However, modifications were made to account for new types of qualitative data (e.g., 2-meter temperature surveys and sinter terraces).

Figure 5: Phase II play fairway map of the Crescent Valley study area. Black polygons represent favorable structural settings. Warm colors on the map correspond to high probabilities, and cool colors correspond to low probabilities. The number inside each favorable structural setting indicates the favorability score for the area. Circles represent wells and are color-coded based on the magnitude of the temperature anomaly derived in Phase II (Faulds et al., 2017). Squares represent spring and well temperatures from geothermometry translated into probability space., whereby, warm colors correspond to high probabilities and cool colors correspond to low probabilities. Refer to Faulds et al. (2017) for more information on the methodology used to derive temperature anomaly probabilities.



The play fairway map for Crescent Valley shows that the Dann Ranch structural setting ranks the highest. High values were also obtained for the two step-overs in the range-front fault north of Dann Ranch, as well as the complex fault intersection at Hot Springs Point. The geothermal potential of the Dann Ranch area is further supported by high geothermometer temperatures and outcrops of sinter.

8. Conclusions

The Quaternary fault map of Crescent Valley identified eight favorable structural settings for geothermal potential. Additional slip and dilation tendency modeling, well temperatures, 2-meter data, and geothermometry suggest that all of the step-overs (b, c, d) in along the Crescent Valley fault and the fault intersections near Hot Spring Point (h) and in the center of the basin (i) are favorable structural settings for geothermal activity. Except for Dann Hot Springs and Hot Springs Point, there is little temperature data for the other favorable settings. Additional 2-meter temperature surveys conducted in the dry season could provide insight into whether blind systems occupy the northeastern portion of Crescent Valley. High mineral well temperatures and historical blowouts suggest that the central part of the basin should be further investigated for the possible existence of a blind geothermal system.

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