

PRELIMINARY GEOLOGICAL AND GEOPHYSICAL CHARACTERISTICS OF THE PUMPERNICKEL VALLEY GEOTHERMAL SYSTEM

Adam Szybinski¹ and Greg Shore²

¹Nevada Geothermal Power Inc., 900-409 Granville St., Vancouver, B.C. V6C 1T2, Canada

²Premier Geophysics Inc., 53 Duncton Wood Crescent, Aurora, Ontario, L4G 7T4, Canada
¹e-mail: adam@nevadageothermal.com; ²e-mail: gashore@premiergeophysics.com

ABSTRACT

Pumpnickel Valley geothermal project area is located in the Basin and Range province, within the structurally complex Winnemucca fold and thrust belt of north-central Nevada. The project area is cut by a series of normal faults, two of which, the Pumpnickel Valley fault and Edna Mountain fault, are range-bounding faults, which also display some characteristics typical of strike-slip fault systems.

Within the project area, abundant hot springs, seepages, and wet ground/vegetation anomalies are present next to the Pumpnickel Valley fault. The widespread hydration and alteration around the fault indicate that it focuses the fluid up-flow, whereas the nearby, down dropped structural blocks may define an immediate reservoir.

A 3D resistivity survey, which included both main faults and all geothermal features, was carried out within the project area. The survey results delineated a broad conductive zone associated with two highly conductive anomalies and numerous, unexposed echelon structures. Combined with the geological data, the resistivity results are interpreted to indicate the presence of a complex pull-apart basin, formed within the releasing bend of the Pumpnickel Valley – Edna Mountain fault system.

Following the geological and geophysical surveys on the property, Nevada Geothermal Power Company/Inovision Solutions Inc. drilled four temperature gradient boreholes, three of which were located within the large conductive zone. The preliminary geothermal data from this drilling outlined a field with thermal gradients in excess of 100°C/km. Together, a substantial body of evidence exists to suggest that the pull-apart basin hosts an extensive geothermal field.

INTRODUCTION

This paper presents the results of preliminary work by Nevada Geothermal Power Company and Inovision Solutions Inc., with funding from the U.S. DOE (GRED III – Phase I, Award DE-FG36-04GO 12340), on the Pumpnickel Valley geothermal project area, near Winnemucca, Humboldt County, north-central Nevada. The project is located in the central portion of Pumpnickel Valley (Fig.1), on eastern slopes of the Sonoma Range, in the Basin and Range geomorphic province. The area surrounds two clusters of hot springs and wet ground/vegetation anomalies that occur from 1464 to 1481 meters elevation above sea level.

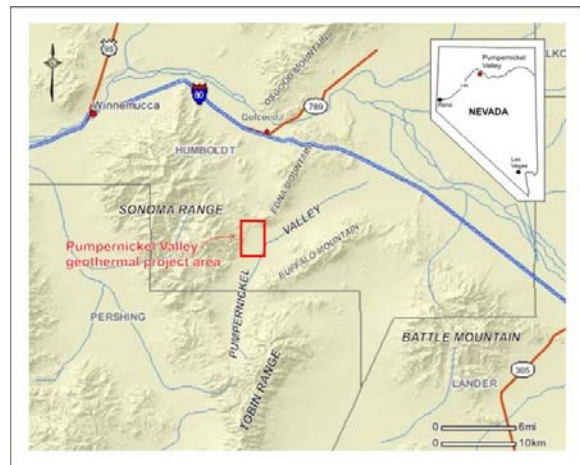


Fig. 1. Location of the Pumpnickel Valley geothermal project area in north-central Nevada.

PREVIOUS WORK

The geothermal exploration in Pumpnickel Valley was initiated in 1974 by Magma Power Co., which drilled a single geothermal well to a depth of 919.6m at Tipton Ranch (Garside and Schilling, 1979; Shevenell and Garside (2003). The recorded bottom-hole temperature was 135°C, with the last 91 m having a geothermal gradient of 160°C/km (S.

Matlick, personal comm. *in* Shevenell and Garside, 2003).

In 1981-1982, the University of Nevada System (UNS) completed a regional geothermal assessment of the Pumpernickel Valley area (Trexler et al., 1982). Temperature data were gathered by the UNS crew from the pre-existing uncased mineral exploration holes located within the present project area. The calculated geothermal gradients from five of these holes range from 66 to 249°C/km for wells west of the fault, and 505°C/km for a well near the fault (Sadlier-Brown, 2004).

The Na-K-Ca geothermometer based on recent geochemical samples from hot springs in Pumpernickel Valley indicated the thermal-aquifer temperature of 175 to 192°C (Shevenell and Garside, 2003). A more conservative estimate based on the chalcedony geothermometer suggested a geothermal resource with a temperature of 125°C (*op cit*).

GEOLOGY OF THE PUMPERNICKEL VALLEY AREA

Tectonic setting

The Pumpernickel Valley is located within an extensive zone of recent deformation, the Humboldt structural zone (HSZ) (e.g. Faulds et al., 2004). The HSZ includes mainly ENE-striking faults shown to accommodate sinistral and/or normal slip; it is thought to be related to the WNW-oriented extension within the Basin and Range province. The HSZ roughly parallels the Battle Mountain heat-flow high and this trend correlates well with geothermal activity and productive geothermal systems, which include Steamboat, Desert Peak, Brady's Hot Springs, Soda Lake, Rye Patch, and Dixie Valley.

Tectonic extension and high heat flow in northwestern Nevada result most likely from the shallow depth of the Moho (e.g. Louie et al., 2004; Lerch et al., 2004). A new crustal refraction profile detected anomalously thin crust in the Battle Mountain area, immediately east of Pumpernickel Valley, with a Moho depth of 19-23 km over a region of approximately 150 km wide that is surrounded by more typical, 30-km-thick crust (Louie et al., 2004).

Regional geology

The Pumpernickel Valley geothermal project area is positioned within the structurally complex Winnemucca fold and thrust belt (Speed et al., 1982; Stahl, 1989) of north-central Nevada that includes three different tectono-stratigraphic units or allochthons. These regionally extensive units continue almost uninterrupted throughout numerous NE-trending ranges and are comprised of early

Triassic Golconda, the Paleozoic Roberts Mountains, and the post-Triassic Mesozoic Winnemucca allochthon (Fig.2).

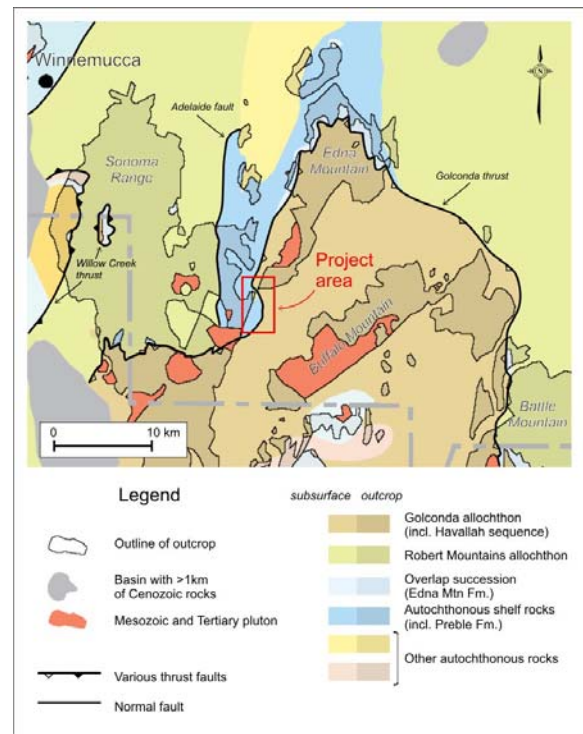


Fig. 2. Regional tectono-stratigraphic map of north-central Nevada and Winnemucca belt; modified from Ludington et al. (1996).

A post-Winnemucca, Jurassic or Cretaceous orogenic event, characterized by N-S shortening affected the entire Winnemucca belt (Stahl, 1989). All of these rocks are locally covered by Tertiary tuffs and other volcanic rocks, and cut by abundant high-angle faults related to the extensional Basin and Range tectonics.

Geology of the project area

The Pumpernickel Valley geothermal project area is underlain by Paleozoic strata included in three major units: the Preble Fm., the Havallah sequence, and the Edna Mountain Fm (Fig.2). Rocks in the western part of the property (eastern slopes of the Sonoma Range) belong to the Preble Formation (Marsh and Erickson, 1978) and consist mainly of olive-grey phyllites, quartz mica schists, quartzites, mudstones, and variably dolomitized limestones. The northern portion of the property encompasses the southern tip of Edna Mountain, which is the type area of the Golconda thrust. The rock assemblage within the hanging wall of the Golconda thrust consists of cherts, argillites, quartzite, and minor limestone, and is combined as the Havallah sequence (Silberling, 1975; Stahl, 1987). Rocks of the Edna formation crop out along the eastern portion of the Sonoma

Range and the range-bounding fault (Marsh and Erickson, 1978; this work).

Numerous porphyritic dykes and quartz diorite dykes, sills, and stocks of probable Upper Cretaceous age intrude rocks of the Preble Formation and the Havallah sequence. Partly welded Tertiary rhyolite ash-flow tuffs and basaltic flows, together with a high level, poorly sorted, boulder-rich Tertiary gravel, cover many ridges in the project area (Fig.3). Quaternary alluvium (clay, silt, sand and gravel) fills the Pumpernickel Valley and it is covered with gravel fans and pediment veneer along the range-bounding faults.

Structure of the project area

The lithological units comprised within the Winnemucca fold-and-thrust belt were deformed by several regional deformation events. The units occur repeated in a number of discrete, large polyphase fold panels bounded by thrust fault zones and are characterized locally by contrasting structural styles. There are at least two, and possibly up to four fold generations, with younger, more open folds refolding earlier tight and isoclinal folds.

A series of approximately NNE-striking faults in the eastern Sonoma Range and western Edna Mountain are superimposed on the earlier structures (Fig.3). These faults further divide the outcrop into numerous blocks and are responsible for the final overall geometry and distribution of pre-existing structural features in the area.

Major faults

The Pumpernickel Valley is in part defined by two major faults, the Pumpernickel Valley fault and the Edna Mountain fault (Fig.4), which most likely represent one fault system (Anderson, 2000). Both faults intersect each other at a wide angle and are characterized by zones of high density lesser faults and fractures; both are discontinuous, very steep (probably $> 75^\circ$), vary in strike, height, and shape.

The Pumpernickel Valley fault is the prominent NNE-trending structure and forms the structural break between the eastern Sonoma Range and western Edna Mountain, and between the Sonoma and southern Pumpernickel Valley basin. Further north, beyond the Edna Mountain fault, a probable extension of the Pumpernickel Valley fault juxtaposes Tertiary volcanic rocks against Paleozoic. The Pumpernickel Valley fault displays a very gradual geomorphic expression typical of an inactive fault front.

The Edna Mountain fault is a discontinuous, in general ENE- to NE-trending structure, which defines the boundary between Edna Mountain and

Pumpernickel Valley and juxtaposes bedrock against Quaternary alluvium. The ENE-trending portion of the Edna Mountain fault shows a relatively sharp piedmont-to-range break in slope, more typical of the recently active major mountain fronts.

The down-dip component of movement on both faults is clearly normal. The strike-slip component of the latest movement on the Edna Mountain fault has been dextral strike-slip, as indicated by the nearly vertical, quartz-filled gashes developed in quartzites along the fault trace. On the Pumpernickel Valley fault, in the eastern Sonoma Range, extension has been relatively large and is reflected by the stratigraphic displacements of Tertiary volcanic rocks (Fig. 3). It seems that both faults formed concurrently with the Basin and Range tectonism.

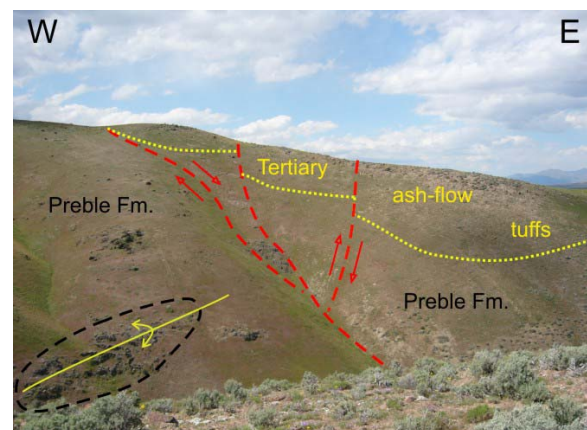


Fig. 3. The E-W section through the Preble Fm. and Tertiary ash-flow tuffs west of the Pumpernickel Valley fault. The Preble rocks are characterized by a series of the pre-Tertiary tight folds; red dashed lines indicate the post-Tertiary normal faults; yellow dotted lines represent approximate contacts between the Preble sequence and the overlying Tertiary ash-flow tuffs.

Prior geophysical and geochemical evidence indicate that there is at least one, and possibly more buried faults east of and sub-parallel to the main trace of the Pumpernickel Valley fault (Marsh and Erickson 1978; Erdman et al., 1991). Recently collected magnetotelluric data and a 2-D resistivity model that includes the project area, suggests a NE-trending, deep-seated, possibly crustal fault zone northeast of the project area (Rodriguez and Williams, 2002).

PUMPERNICKEL VALLEY GEOTHERMAL FEATURES

The active and fossil thermal features in the Pumpernickel Valley include both hot and cold springs and seepages, wet soil spots and/or vegetation concentrations, accumulation of salt minerals and sinter/silcrete on the surface, and hydrothermal

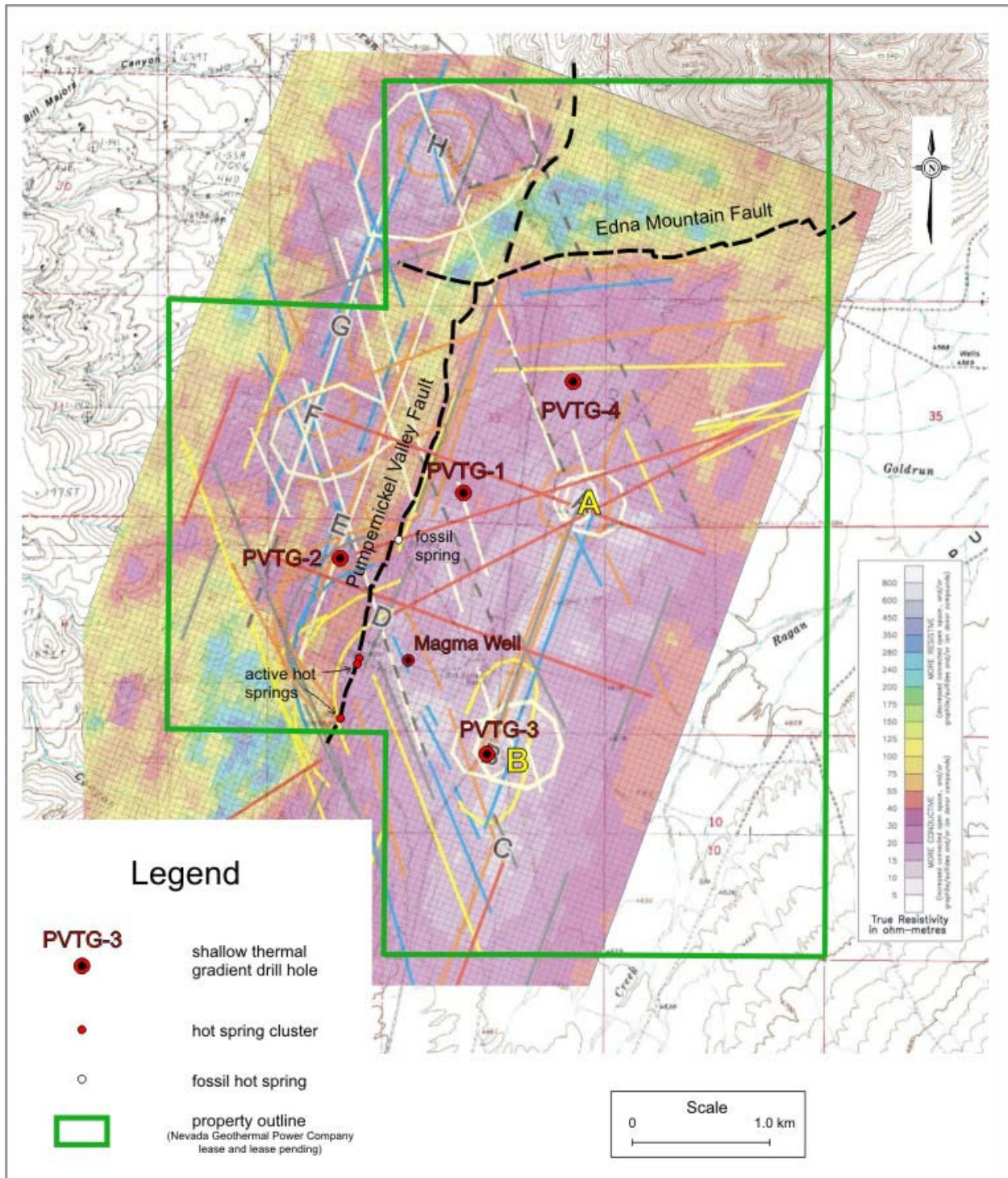


Fig. 4. Location of the Pumpnickel Valley fault and Edna Mountain fault (black dashed lines), and hot spring clusters in Pumpnickel Valley superimposed on the resistivity map 50 to 75 m below surface contour. The linear features represent resistivity edges and breaks - colours of the linears should be ignored (modified from Shore, 2005); the yellow letters A and B refer to the deep, low resistivity anomalies.

alteration. All of these are located immediately on or east of the Pumpnickel Valley fault (Fig. 4).

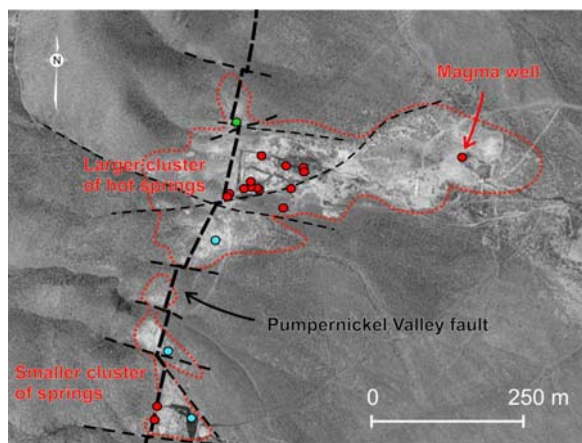


Fig. 5. Air photo map with the geothermal features and faults; tufa mound is delineated by the dotted red line; hot springs and seepages shown as red dots; cold spring and seepages shown in blue; anomalous vegetation spot shown in green; thicker dashed line represents the Pumpnickel Valley fault trace.

The larger of the two hot spring clusters contains numerous active vents that follow a low lying, east-trending and elongate mound of calcareous tufa (Fig. 5). The mound seems to be structurally controlled and bounded by a system of faults. The smaller cluster of springs and seepages is located south of the main cluster (Fig. 5). At least one cold spring and two seepages are located in the same area indicating that both geothermal and surface waters utilize the same fault/fracture system associated with the Pumpnickel Valley fault. There is a significant amount of fluid flow from the hot springs near the Pumpnickel Valley fault directly into the valley fill.

Temperature data and geochemistry

The collected data from the springs and seepages indicate temperatures range from 68 to 88.5°C in the main cluster of springs and 94.5°C in the wellhead of the Magma well. The temperature recorded in the hot spring in the southern cluster of springs was 49°C, whereas the cool spring and nearby seepages have temperatures of ~18°C. Water in four irrigation wells in the eastern part of the project area, each ~183 m deep, have some geothermal component but also a large proportion of meteoric water and lower temperature readings in a range of 20.3 to 22.75°C.

The brine from several hot springs and seepages was sampled and the geochemical results indicate they are bicarbonate rich with high proportions of B, Li and much lower Cl. The low temperature geothermometers (K-Mg, chalcedony) range from

94-122°C (K-Mg) to 103-139°C (chalcedony). Na/K trends to 233°C, suggesting that the source water may achieve this temperature and then pick up Mg and Ca on its way to the surface (T. Powell, personal comm., 2005).

E-SCAN® 3D RESISTIVITY SURVEY

The 3D resistivity survey, using the E-SCAN® technology of Premier Geophysics Inc., performed specifically within the project area by Shore (2005) shows a broad, resistivity-low anomaly associated with the western section of the Pumpnickel Valley (Fig. 4). Two highly conductive areas, A and B, define the center of the anomaly. The anomaly is bounded by numerous linear features arranged in an echelon mode that form two main trends. One trend is NNE and coincides with the trace of the Pumpnickel Valley fault, whereas the other is WNW and oblique to the main trends of faults in the area. The northern portion of the anomaly is clearly bounded by the Edna Mountain fault and linear features parallel and oblique to it. It is believed that this anomaly represents an aquifer and the points A and B may represent structural feeders (*op cit*).

The overall fault pattern indicated by the resistivity anomaly, a complex rhomb and trapezoid shaped area in Fig. 4, is most likely indicative of a releasing step-over or pull-apart basin. The numerous en echelon linear features are thought to represent extensional fans of fault-bounded blocks arranged in a stepping-down fashion. A sketch of the envisaged basin, which occurs between two sets of approximately NNE- and NNW-trending faults, is shown in Fig. 6. The A and B anomalies are interpreted to reflect subsidence centers of this proposed basin.

STRUCTURAL SETTING OF THE PUMPERNICKEL VALLEY GEOTHERMAL SYSTEM

Discussion and conclusions

Individual geothermal systems in Nevada are generally associated with stepovers in north-northeast-striking faults systems, but also form near the intersections of major normal faults with northwest-striking dextral faults or east-north-east-striking sinistral faults (e.g. Faulds et al. 2004). It has been suggested that the abrupt spatial change in the regional tendency of Quaternary fault orientations is related to geothermal activity in the HSZ and there is a significant spatial correlation of geothermal activity with the magnitude of fault-normal extensional strain and high heat flow, probably resulting from the shallow depth of the Moho (e.g. Blewitt et al., 2003).

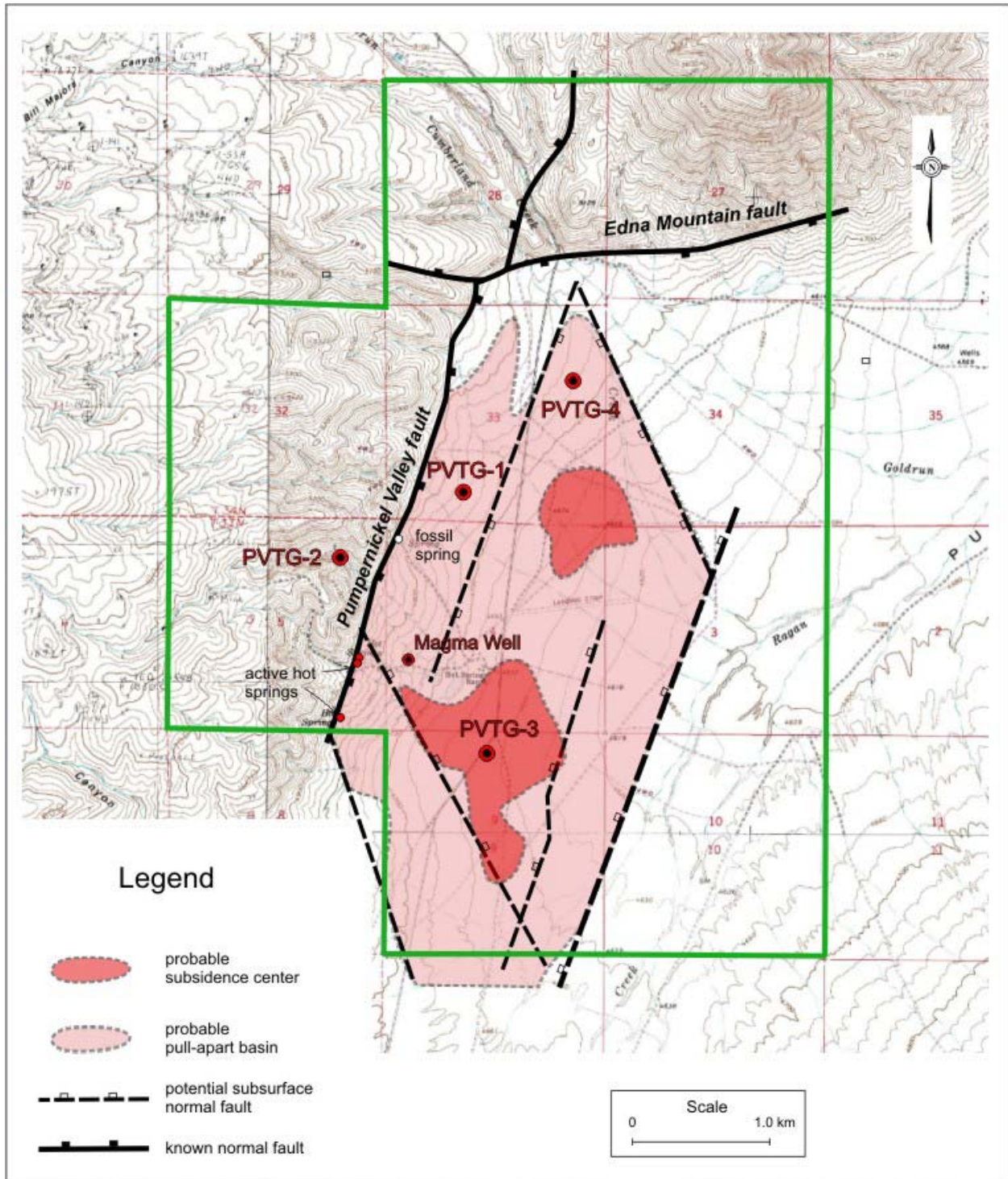


Fig. 6. Schematic map of the probable pull-apart basin in Pumpernickel Valley and basin bounding faults (from Szybinski, 2005). See legend in Fig. 5 for other symbols.

Exploring relationships between geologic structures and GPS-geodetic observations of regional tectonic strain, Blewitt et al. (2003) proposed that in the Basin and Range, fault-normal extensional strain results from a favorable orientation of faults in a shear strain field, such as pull-apart grabens in the stepover of a dominant strike-slip structure. These authors concluded that such a shear-strain mechanism most likely controls non-magmatic geothermal systems in the Basin and Range.

In the Pumpnickel Valley area, the easternmost Sonoma Range and southernmost Edna Mountain display many characteristics typical of strike-slip fault systems, including some rotational deformation, superposition of structures, lens-shaped push-up structures, local en echelon arrangement of high-angle faults, and the lithostratigraphic repetitions. Combined with geophysical data of Shore (2005), these characteristics indicate the presence of a pull-apart basin, formed within the releasing bend of the Pumpnickel Valley – Edna Mountain strike-slip system.

Various active and fossil geothermal features, including two areas with hot springs, seepages, and wet ground/vegetation anomalies, are present near the Pumpnickel Valley fault. This widespread hydration and alteration indicate that the fault most likely focuses the fluid up-flow, whereas the nearby, down dropped structural blocks may define an immediate reservoir.

Four geothermal gradient wells were drilled within the project area by Nevada Geothermal Power Company. The temperature data collected from these and the pre-existing wells clearly indicates the presence of a major plume of thermal water centered on the Pumpnickel Valley fault, and suggests that the main plume is controlled, at least in part, by flow from this fault system.

The temperature data defines the geothermal resource with gradients $>100^{\circ}\text{C}/\text{km}$, which covers an area a minimum of 8 km^2 . The geothermal system almost certainly continues beyond the recently drilled holes and might be open to the east and south, whereas the heat source responsible for the temperatures associated with this plume has not been intersected and must be at a depth greater than 920 meters (depth of the Magma well). Thus, a substantial body of evidence exists, in the form of available geothermal, geological and geophysical information, to suggest that the property hosts a structurally controlled, extensive geothermal field with a reservoir suitable for electric power production.

Further exploration of this geothermal field requires additional drilling, especially in the immediate area of the low resistivity anomaly “A” of Shore (2005).

This drilling ought to be combined with a gravity or seismic geophysical survey, in order to map the contact between the valley fill and the basement rocks, and depict the buried structures and their relationship to the geothermal system.

ACKNOWLEDGMENTS

The authors wish to thank the U.S. Department of Energy for their support for this project, which was funded by the GRED III – Phase I Award DE-FG36-04GO 12340. We also thank Kim Niggemann and Jos Hantelmann for constructive reviews of the manuscript.

REFERENCES

Anderson, R.E. (compiler) (2000), “Fault number 1137, Edna Mountain fault”, in *Quaternary fault and fold database of the United States*, ver. 1.0: U.S. Geological Survey Open-File Report 03-417.

Blewitt, G., Coolbaugh, M., Holt, W., Kreemer, C., Davis, J., and Bennett, R. (2003), “Targeting of potential geothermal resources in the Great Basin from regional relationships between geodetic strain and geological structures”, *Geothermal Resources Council Transactions*, Vol. 26, 523-526.

Erdman, J.A., Hoover, D.B., McCarthy, J.H., Jr., Ficklin, W.H., Watterson, J.R., Lovering, T.G., and Owen, R.W. (1991), “Geophysical, Soil-Gas, and Geochemical Evidence of A Concealed, Mineralized Fault near Sb- and W-rich Hot Springs, Pumpnickel Valley, Nevada”, U.S. Geological Survey Open-File Report 91-0582, p. 8.

Faulds, J.E., Coolbaugh, M., Blewitt, G., and Henry, C.D. (2004), “Why is Nevada in hot water? Structural controls and tectonic model of geothermal systems in the Northwestern Great Basin”, *Geothermal Resources Council Transactions*, Vol. 28, 649-654.

Faulds, J., Garside, L., Johnson, G., and Hess, R., Oppliger, G. (2002; updated 2003), “Structural and geophysical analysis of the Desert Peak-Brady Geothermal Field: Identifying links between northeast-trending structures and geothermal anomalies in the Great Basin”, *Desert Peak Final Proposal*, Nevada Bureau of Mines and Geology (NBMG) and Department of Geological Science, UNR, 16 p.

Garside, L. J., and Schilling, J. H. (1979), “Thermal waters of Nevada” Nevada Bureau of Mines and Geology *Bulletin* 91, 163 p.

Lerch, D.W., McWilliams, M.O., Miller, E.L., and Colgan, J.P. (2004), “Structure and magmatic

evolution of the northern Black Rock range, Nevada”, *Preparation for a wide-angle refraction/reflection survey*, Rocky Mountain (56 Annual) and Cordilleran (100 Annual) Joint Meeting, Paper No. 21-12.

Louie, J.N., Thelen, W., Smith, S.B., Scott, J.B., Clark, M., and Pullammanappallil, S. (2004), “The Northern Walker Lane Refraction Experiment, Pn Arrivals and the Northern Sierra Nevada Root”, *Tectonophysics*, v. 388, No.1-4, 253-269.

Luddington, S., McKee, E.H., Cox, D.P., Moring, B.C., and Leonard, K.R. (1996), “Pre-Tertiary geology of Nevada”, in Singer, D. (editor), *An analysis of Nevada’s metal-bearing mineral resources*, Chapter 4, Nevada Bureau of Mines and Geology, Open-file report 96-2, 1-9.

Marsh, S.P. and Erickson, R.L. (1978), “Geologic map of the Goldrun Creek quadrangle, Humboldt County, Nevada. Scale 1:24,000, GQ 1407”, published by U.S. Geological Survey.

McKenna, J.R., Blackwell, D.D., Richards, M.C., and Swenson D.V. (2005), “Natural state modeling, structure, preliminary temperature and chemical synthesis of the Dixie Valley, Nevada geothermal field”, in *Proceedings*, Thirtieth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, 8 p.

Rodriguez, B.D. and Williams, J.M. (2002), “Resistivity structure across the Humboldt River basin, north-central Nevada”, U.S. Geological Survey Open-file report 02-39, 23 p.

Sadler-Brown, T.L. (2004), “A geothermal resource prospect at Hot Spring Ranch, Pumpernickel Valley, Humboldt County, Nevada”, Report for Inovision Solutions Inc., 24 p.

Shevenell, L. and Garside, L. (2003), “Geochemical sampling of thermal waters in Nevada Nevada: Continued evaluation of geothermal resources for electrical power generation and direct-use applications”, Nevada Bureau of Mines and Geology, 7 p.

Shore, G.A. (2005), “E-SCAN 3D resistivity mapping of the Pumpernickel Valley Grid#1, Pumpernickel Project, Humboldt County, Nevada”, Report for Nevada Geothermal Power Inc. by Premier Geophysics (US) Inc. 40 p.

Silberling, N.J. (1975), “Age relationships of the Golconda thrust fault, Sonoma Range, north-central Nevada”, Geological Society of America *Special Paper* 163, 28 p.

Speed, R.C., Elison, M., Engeln, J., Stahl, S., Vaverk, A.E., and Wiens, D. (1982), “Mesozoic Winnemucca fold and thrust belt”, Geological Society of America *Abstracts with Programs (Cordilleran Section)*, v.14, p. 236.

Stahl, S.D. (1987), “Mesozoic structural features in Sonoma Canyon, Sonoma Range, Humboldt and Pershing counties, Nevada”, *Centennial Field Guide Volume 1*, Cordilleran Section of the Geological Society of America, 85–90.

Stahl, S.D. (1989), “Recognition of Jurassic transport of rocks of the Roberts Mountains allochthon: Evidence from the Sonoma Range, north-central Nevada”, *Geology*, Vol. 17, No. 7, 645–648.

Szybinski, Z.A. (2005), “Geological setting and evaluation of the Pumpernickel Valley geothermal project area”, Report for Nevada Geothermal Power Inc. and Inovision Solutions Inc., 45 p.

Trexler, D.T., Flynn, T., Koenig, B.A., Bell, E.J., and Ghusn, G. (1982), “Low- to moderate-temperature geothermal resource assessment for Nevada: area specific studies, Pumpernickel Valley, Carlin and Moana”, Final report for U.S. Department of Energy, 146 p.