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# The Preston Geothermal Resources; Renewed Interest in a Known Geothermal Resource Area

## Fourtieth Workshop on Geothermal Reservoir Engineering

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# The Preston Geothermal Resources; Renewed Interest in a Known Geothermal Resource Area

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## ABSTRACT

The Preston Geothermal prospect is located in northern Cache Valley approximately 8 kilometers north of the city of Preston, in southeast Idaho. The Cache Valley is a structural graben of the northern portion of the Basin and Range Province, just south of the border with the Eastern Snake River Plain (ESRP). This is a known geothermal resource area (KGRA) that was evaluated in the 1970's by the State of Idaho Department of Water Resources (IDWR) and by exploratory wells drilled by Sunedco Energy Development. The resource is poorly defined but current interpretations suggest that it is associated with the Cache Valley structural graben. Thermal waters moving upward along steeply dipping northwest trending basin and range faults emanate in numerous hot springs in the area. Springs reach temperatures as hot as 84° C. Traditional geothermometry models estimated reservoir temperatures of approximately 125° C in the 1970's study.

In January of 2014, interest was renewed in the areas when a water well drilled to 79 m (260 ft) yielded a bottom hole temperature of 104° C (217° F). The well was sampled in June of 2014 to investigate the chemical composition of the water for modeling geothermometry reservoir temperature. Traditional magnesium corrected Na-K-Ca geothermometry estimates this new well to be tapping water from a thermal reservoir of 227° C (440° F). Even without the application of improved predictive methods, the results indicate much higher temperatures present at much shallower depths than previously thought. This new data provides strong support for further investigation and sampling of wells and springs in the Northern Cache Valley, proposed for the summer of 2015. The results of the water will be analyzed utilizing a new multicomponent equilibrium geothermometry (MEG) tool called Reservoir Temperature Estimate (RTEst) to obtain an improved estimate of the reservoir temperature. The new data suggest that other KGRAs and overlooked areas may need to be investigated using improved geothermal exploration methods.

## 1. INTRODUCTION AND BACKGROUND

The northern Cache Valley has been the subject of many geological studies throughout the last 150 years. The studies began in the 1870s with the Hayden expedition when enroute to the Yellowstone area described the lithology along the valley walls and the active geothermal springs (Hayden, 1872). Over fifty years later, Coulter documented the stratigraphy and geology of the Bear River Range and the Cache Valley for a Yale University study (Coulter, 1956). In 1962 Williams described Lake Bonneville's lasting influence on Cache Valley (Williams, 1962). McGreevy and Bjorklund authored two papers for the U.S. Geological Survey summarizing the hydrogeologic data from hydrothermal expressions in 1970 and 1971 (McGreevy & Bjorklund, 1970; McGreevy & Bjorklund, 1971). Peterson and Oriel explored the subsurface of the valley using gravity (Peterson & Oriel, 1970). In 1976, Robert Mitchell of the Idaho Department of Water Resources (IDWR), investigated the potential for geothermal power production in the valley (Mitchell, 1976). The Mitchell (1976) report remains a significant geothermal reference for Northern Cache Valley. In the Mitchell study, seventeen samples were collected from the thermal waters of eight sites. The measured temperatures ranged from 35° C to 84° C with a mean temperature of 61° C. Data from the Mitchell report will be re-examined later in this paper using a modern multiple-component equilibrium geothermometer (MEG).

The Sunoco Energy Development Company took a commercial interest in the valley in the late 1970s, drilling two deep test wells. Test results and data from the Sunoco Stock 1-A and Bert Winn #1 test wells are summarized by McIntyre and Koenig (McIntyre & Koenig, 1978; McIntyre & Koenig, 1980). The low-temperature geothermal potential of the valley was investigated in 1982 by de Vries (de Vries, 1982), and in 1987 Avery examined the thermal waters of the valley and predicted reservoir temperatures using traditional geothermometers. Interest in the geothermal waters of the valley were renewed 21 years later, when Carl Austin authored an unpublished consultant's report detailing the possibility of power production using a subsurface heat source near Preston, ID. Most recently, in 2013, the valley was part of an analysis of the structural controls influencing thermal springs in Southeastern Idaho by Young and others (Young et al., 2013). The new data presented in this paper are part of a joint project sponsored by the Department of Energy characterizing geothermal resources in southeast Idaho. Our partners in this research include the Center for Advanced Energy Studies (CAES), University of Idaho, the Idaho National Laboratory and Lawrence Berkeley National Laboratory.

## 2. REGIONAL GEOLOGY

The Cache Valley is a northward trending valley located in southeastern Idaho (Figure 1). It is situated at the confluence of several geologic terrains on the northeastern extent of the Basin and Range Province where the Basin and Range meets the Sevier orogenic belt and Rocky Mountains. The juncture of these provinces is characterized by seismic activity and clusters of hot springs (Sbar et al., 1972).

The North Cache Valley (NCV) is underlain by the western portion of the Idaho Thrust belt, which formed in the Sevier orogeny, active from late Jurassic to the late Eocene, 140 - 70 million years ago (m.y.) (Figure 2) (Grubbs & Van Der Voo, 1976). During the compressional Sevier orogeny, folding and faulting of the predominantly Paleozoic marine sediments occurred along the western edge of the North American plate as the oceanic Farallon plate was subducted at a shallow angle; creating a zone of deformation stretching from central British Columbia to southeastern California. As the North American plate moved further west, the subduction angle of the underlying Farallon plate changed, starting a period of mountain building known as the Laramide orogeny, lasting from the late Cretaceous (70-80 m.a.) to the early/late Eocene (35-55 m.a.), resulting in the formation of the Rocky Mountains (Liu, 2008).

Basin and Range extension began in the early Eocene, approximately 45 m.a., and continues to the present. The province is characterized by repeating sequences of paired normal faults (i.e. graben forming), accommodating the extensional forces and stretching the area to double that of its original width. These paired normal faults allow for the formation of successive series of valleys and mountains. The valleys, or graben, move downward in relation to the mountains, or horsts (Figure 3). As these extensional forces and mechanics thin the continental crust, it may be predicted that the crust would subside. This is not the case however, as the northern Basin and Range remains relatively high above sea level. This is possibly the result of long term subduction of the Farallon plate beneath the North American plate, effectively buoying the continental crust and helping to keep it floating higher on the mantle. Another theory suggests the higher elevation may be the result of the Yellowstone Hot Spot emplacing buoyant asthenosphere underneath the northern section of the Great Basin.

Because the NCV is located at the convergence of structurally distinct and active provinces, it is influenced by many forces and processes that may influence the occurrence of sources of geothermal energy and secondary sources of permeability. Crust that was deformed and shortened during the Sevier orogeny has been reshaped and stretched by Basin and Range extension to form the mountains bounding the NCV on the east and west. The border of the Basin and Range with the Rocky Mountains and the Colorado Plateau runs from southwestern Montana to southern Nevada and displays high levels of seismicity in comparison to adjacent areas (Figure 4). This area is commonly referred to as the Intermountain Seismic Belt (ISB) and the seismicity may indicate that the Rocky Mountains are still rising with respect to the Basin and Range province (Smith & Sbar, 1974; Parsons, 1995). The potential impacts of mountain building forces at the scale of a geothermal prospect are discussed in the following sections.

## 3. LOCAL GEOLOGY

The Portneuf, Bear River and Bannock mountain ranges are horst complexes bounding the NCV (Figure 1). The Bannock mountain range is made up primarily of the Precambrian Scout Mountain member of the Pocatello formation. This member is characterized by diamictite featuring angular, silt and sand sized grains of quartz and feldspar within a chloritic or sericitic groundmass punctuated by large granule to boulder sized clasts. Less prominent units associated with the Scout Mountain member include a purer quartzite, phyllite, fine-grained green-schist and thin beds of calcite and dolomite marble (McIntyre and Koenig, 1978). On the west side of the valley, the Oxford-Dayton fault stretches along the base of the Bannock mountain range (Figure 5). This east-dipping, north-trending normal fault is the dominant structure in the North end of the valley and acts as the master fault of the local active Basin and Range system (Janecke & Evans, 1999).

Along the northeastern and eastern edge of the valley are low rolling foothills overlying the base of the Portneuf and the Bear River mountain ranges (Figure 5). These foothills are comprised of Miocene to Pliocene aged, east-northeast dipping Salt Lake formation deposits overlying Cambrian to Ordovician aged carbonates, which have been faulted overtop Neoproterozoic to Cambrian aged Brigham group quartzite (McIntyre and Koenig, 1978). Separating the foothills on the east side of the valley from the Bear River range is a system of inactive, northeast trending, west to southwest dipping normal faults which flatten at shallow depths (Janecke & Evans, 1999). The stratigraphy of the Bear River range consists of marine sedimentary units of Ordovician through Silurian age situated atop large sequences of Cambrian aged carbonates. These in turn are underlain by upper Precambrian and lower Cambrian meta-sedimentary rocks of the Brigham group. Structures found in these mountains are complex, complicated by fold structures such as roll over anticlines to the northeast and east-northeast plunging synclines and anticlines (Janecke and Evans, 1999).

Two main north-trending normal fault systems run along the east and west flanks of the valley at the base of the Bannock and Bear River mountain ranges (Figure 5). The displacement of these faults may be between 2,400 and 3,000 meters. Subsidiary faults, such as those associated with the Little Mountain Horst complex, run throughout the graben (McIntyre and Koenig, 1978). Also present is a linear structure described by Mitchell (1976) as the “Mink Creek-Bear River Lineament”. The lineament begins in the Bear River Range, cuts across the valley, north of Preston, south of the southern toe of the Bannock Range, over the Malad Range and into Utah (Mitchell, 1976, Figure 6). The lineament is consistent with the trend of the Bear River northeast of Battle Creek Hot Springs trending toward the Ben Meek Well (Figures 1 and 6). Austin (2008) postulates the lineament may be a vertical structure contributing to shear stresses or another type of fault. Further information on this structure is sparse, though the positioning of the recently drilled Bosen thermal well and Battle Creek and Squaw hot springs are coincident with the lineament’s inferred path. In his report, Mitchell (1976) speculated on the possible interaction of the feature with the Battle Creek and Squaw hot springs of the central valley, noting, “The intersection of this Mink Creek-Bear River lineament and the Clifton Hill boundary faults could be the controlling structure or focal point for the hot spring activity in this area.” He also used landsat false color infared imagery to define the lineament. As part of the ongoing study, we will perform additional characterization of the lineament using more recently acquired remotely sensed data.

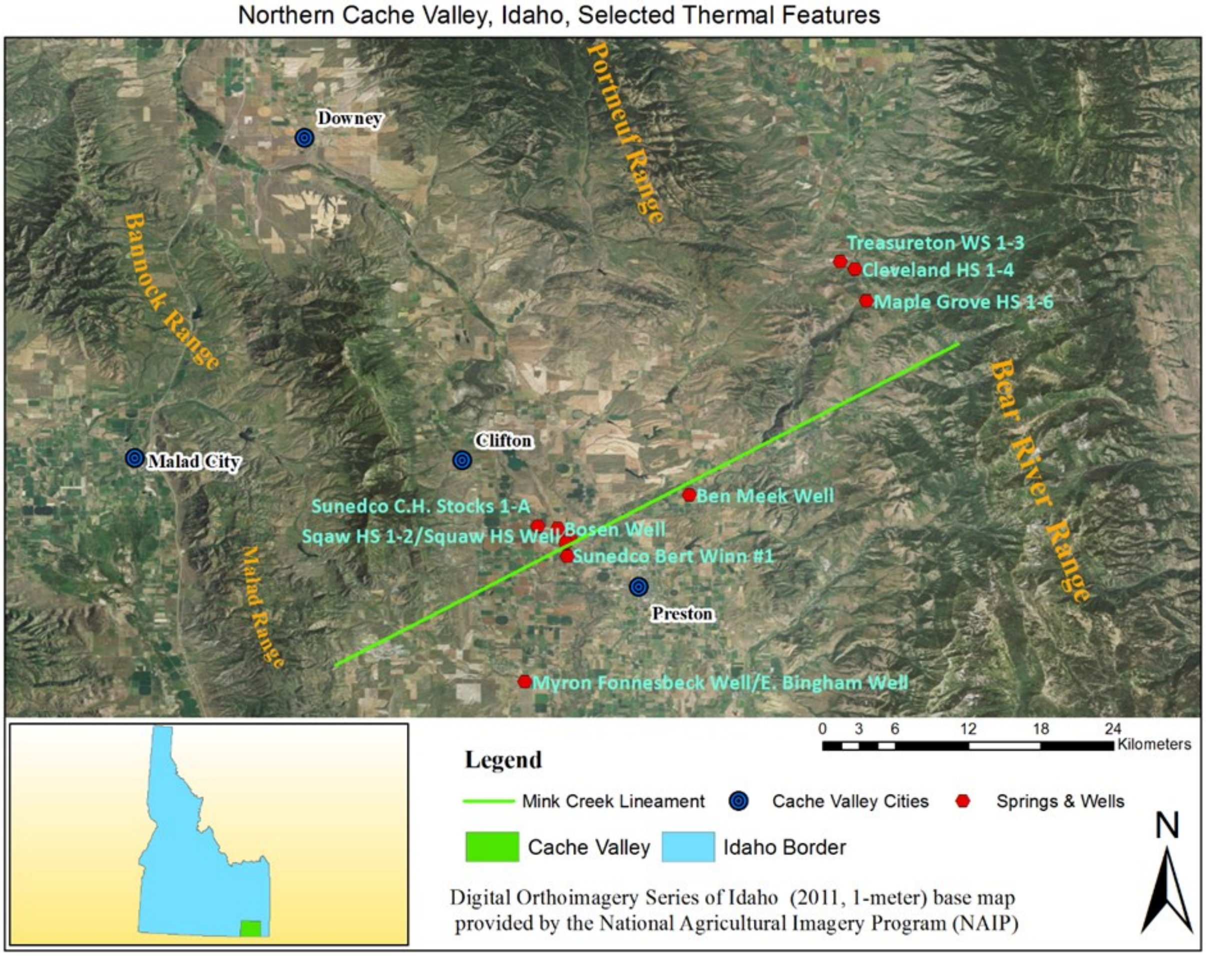


**Figure 1: Selected thermal features, bounding mountain ranges, nearby towns and structural lineament of the North Cache Valley, ID.**

During the Pleistocene the Salt Lake Valley was filled by a large inland lake, Lake Bonneville; which also inundated the NCV and left behind numerous lacustrine deposits and layers of unconsolidated sediment. The thickness of this sediment varies widely, nearing 100 meters in some portions of the valley. A Sunoco Energy development test well, located approximately 6 miles northeast of Preston, encountered 104 meters of these sediments (McIntyre & Koenig, 1978). Underlying the Lake Bonneville sediments is a thick sedimentary sequence of Tertiary age Salt Lake formation. Gravity data, near Preston, ID, suggests these deposits are in excess of 1,675 meters thick, and thicken to more than 2,400 meters further south near the Idaho-Utah border (Peterson and Oriel, 1970). These late Tertiary deposits are of a fluvial and lacustrine origin and comprised of silt and bentonitic clay thinly interbedded with sand. The formation also contains a tuffaceous material which may be the product of Snake River Plain (SRP) volcanism. The Salt Lake Formation sits atop the Precambrian basement rock of the Pocatello formation.

Several hills are expressed on the floor of the NCV. Of particular interest is Clifton Hill, a narrow ridge that extends from Twin Lakes reservoir 8 km to the southeast (Figure 6). The genesis of Clifton Hill is attributed to high angle faulting on both its east and west sides (Petersen and Oriel, 1970, and Oriel and Platt, 1968). Situated between two normal faults, Clifton hill represents a small secondary horst complex located within the larger Cache Valley graben. The west bounding fault trends towards a bend in the Bear River and the locations of several hot springs including Squaw Creek 1 and 2 and the Squaw Creek Well (Figure 6). Gravity data indicate that the bounding faults may extend southward as far as Squaw and Battle Creek hot springs (Mitchell, 1976).

Drilling in the late 1970's by Sunedco included the C.H. Stocks 1-A and Bert Winn #1 wells. The C.H. Stocks 1-A well was drilled first in the summer of 1978 to a depth of 1.7 km (5,479 ft) at a location about 0.6 km west of Clifton Hill (Figure 6). The location was picked based on magnetotelluric mapping. The well penetrated less than 104 m (340 ft) of Tertiary Salt lake Formation and terminated in Precambrian Pocatello Formation. The highest temperatures obtained were 122° C (252° F) and 1600 m (5,250 ft), 60 hours after breaking circulation and, the following day, 118° C (245° F) at 1530 m (5,015 ft) about 6 hours after breaking circulation. Although a drilling problem prevented the hole from being drilled deeper, it was concluded that the depth was sufficient to test the upper part of the magnetotelluric anomaly. Two possible anomalous conditions were found: 1) elevated concentrations of pyrite and other metallic minerals at several horizons in the Precambrian; and 2) the questionable occurrence of moderately saline warm water in fractures in the same section (McIntyre and Koenig, 1978).

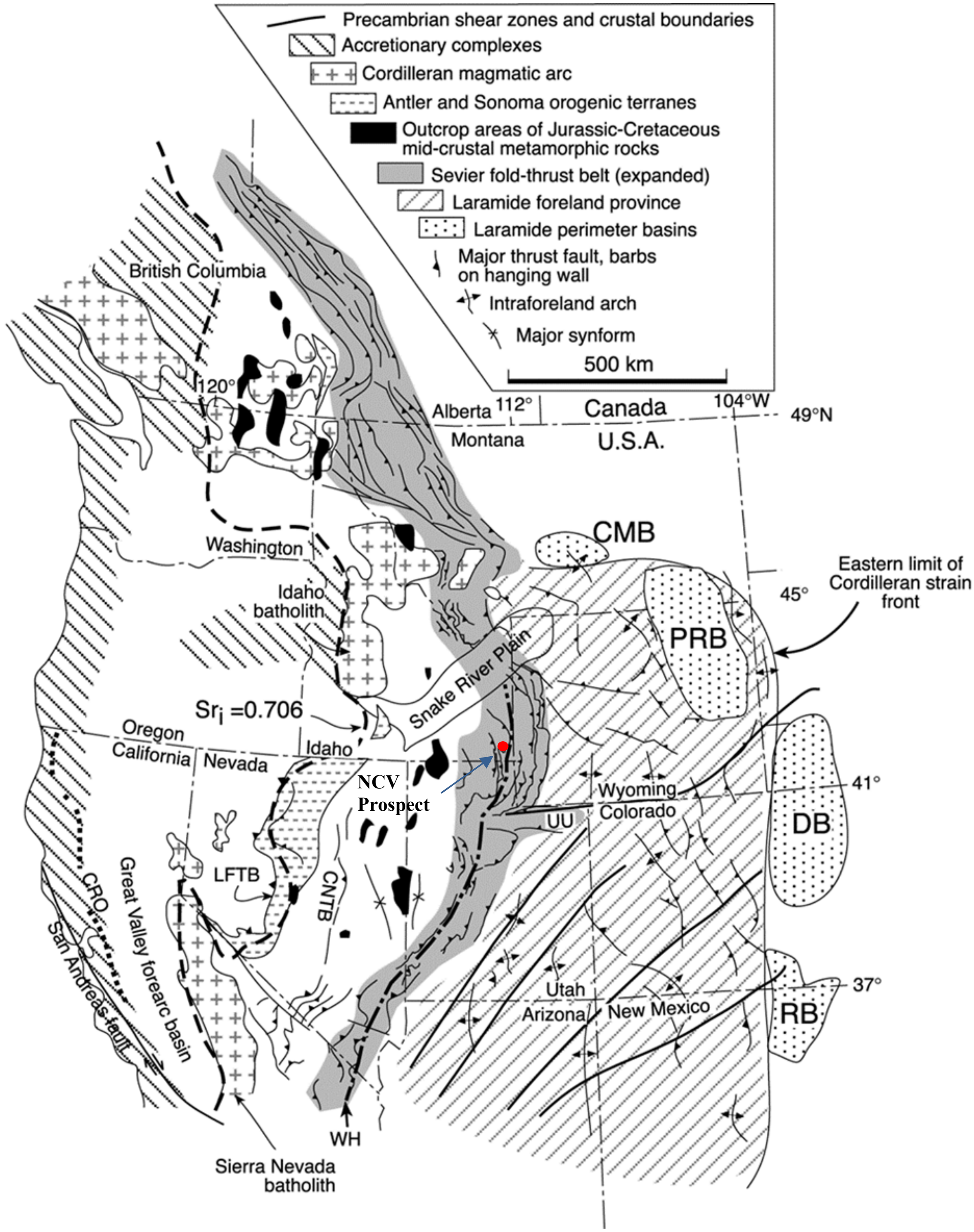


**Figure 2: Extent of the Sevier fold-thrust belt (Sevier orogenic belt) in relation to the western United States and Canadian Provinces. The North Cache Valley lies within a range of the fold-thrust belt referred to locally as the Idaho Thrust belt, following the eastern border of Idaho with the western borders of Wyoming and Montana. Abbreviations are as follows: CRO, Coast Range ophiolite; LFTB, Luning-Fencemaker thrust belt; CNTB, Central Nevada thrust belt; WH, Wasatch hinge line; UU, Uinta Mountains uplift; CMB, Crazy Mountains basin; PRB, Powder River basin; DB, Denver basin; RB, Raton basin. Modified from DeCelles, 2004.**

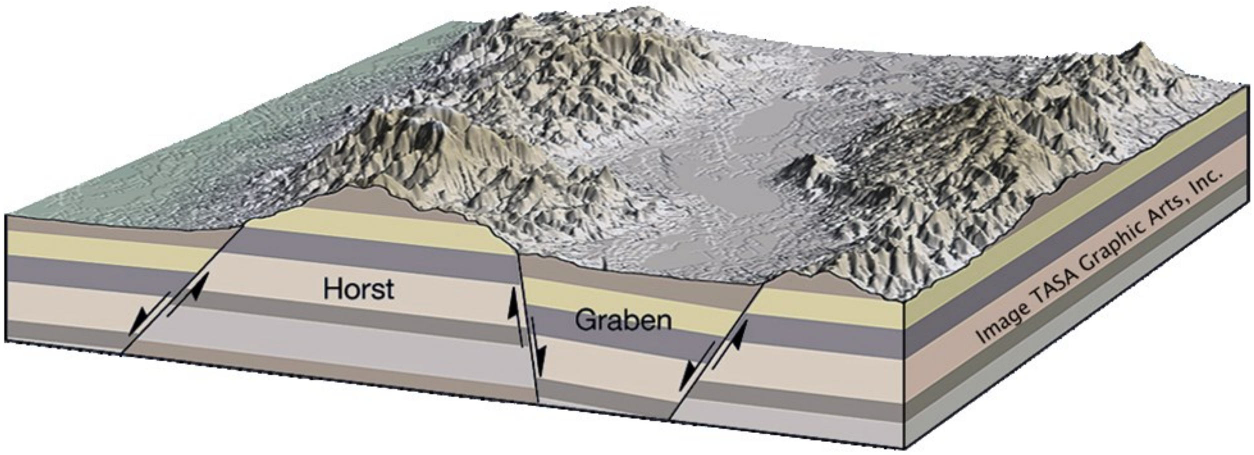


**Figure 3: Cross-sectional diagram depicting horst and graben structure and behavior typical of the Basin and Range province. Source: http://geology.isu.edu/Alamo/devonian/basin_range.php**

The Bert Winn #1 well was drilled in the spring of 1980 to a depth of 2433 m (7,981 ft) at a location 1.1 km southeast of the southern toe of Clifton Hill (Figure 6). After review of the geophysical data after drilling the C.H. Stocks 1-A well resulted in the choice of the Bert Winn #1 wellsite as a better location to test the resistivity anomaly. The maximum temperature was recorded at the total depth of 7,981 ft, 24 hours after breaking circulation, was 104° C (220° F). Thirty seven hours after breaking circulation, temperature at 2271 m (7,450 ft) (deepest probe penetration) was 117° C (243° F) and still rising. The Bert Winn #1 well was drilled along the Clifton Hill trend; structurally it was interpreted to have penetrated the horst footwall block (McIntyre and Koenig, 1980). Unfortunately, drilling at this location took the hole progressively away from the fault plane thought to carry water to shallower depths. McIntyre and Koenig (1980) concluded that neither C.H. Stocks 1-A well or the Bert Winn #1 tested the Preston anomaly satisfactorily. They came to this conclusion because, first, a reservoir of hot saline fluid with minimum temperatures above 149° C (300° F) was predicted from the geochemistry of nearby Wayland and Squaw Hot Springs waters. Second, neither well encountered conditions which could account for the low resistivity found in the surface surveys, at the depth penetrated. Third, no major range-bounding fault was intercepted in the deeper section, as indicated by the low temperature gradient, the absence of hydrothermal mineralization or $H_2S$ gas occurrences and the low incidence of $CO_2$ gas (McIntyre and Koenig, 1980 p. 19). Based on the results of these two deep geothermal test wells McIntyre and Koenig (1980) speculated that it may be necessary to drill to over 3 km to encounter temperatures over 204° C (400° F).

After Sundeco terminated its operations in the NCV, geothermal investigations entered a long hiatus until recently when a local rancher installed a stock watering well at the south end of Clifton Hill and encountered elevated water temperatures at a relatively shallow depth. The Bosen Well location is shown in Figure 6.

In the first ten days of March 2014, Independent Drilling Company used an air rotary drilling rig to install a stock watering well for Mr. David Bosen. The well completion is 15.24 cm (6-inch) diameter steel from land surface to a depth of 60 meters (198 m) with a nominal 15.25 cm (6-inch) open hole from 60 m (198 ft) to 79 m (260 ft). The well drillers report lists the static depth to water as 40 m (130 ft) below land surface and the rock type is described as predominantly grey wacke. Near the drill site, a rock out crop was observed that appeared to be a greenschist. The rock outcrop is most likely Precambrian age metagraywacke as described by Oriel and Platt, 1980. These rocks form the core of Clifton Hill and are the oldest rocks within the Preston Quadrangle.

IDWR measured the temperature of the Bosen well in March of 2014 using HOBO U12-015 stainless steel temperature probe (Erickson, 2014). The probe was lowered to the bottom of the well and until the temperature began to level off. The measured temperature was 102.9° C (217.2° F).

The fault on the east side of the Clifton Horst trends towards Battle Creek and Wayland Hot Springs (see Figure 6). The flow pathway for thermal waters that are tapped by the Bosen Well appears to be similar to the flow pathways supplying water to the Squaw Creek Springs and Wells and probably similar water may be found in the east Clifton fault that appears to daylight at the Battle Creek and Wayland Hot springs. Alternatively, the flow of thermal water is associated with the Mink Creek-Bear River lineament, or as suggested by Mitchell it is associated with the intersection of these two structural trends.

The deep source of heat for the prospect is not known with certainty. Despite the Cenozoic volcanic activity of the SRP to the north and northeast and the Blackfoot Volcanic field to the north, there has been no evidence found of volcanic activity that might be capable of acting as a heat source for geothermal water in the NCV. Typical mechanisms of heat transport in the Basin and Range province involve the deep circulation of ground water along fault planes. In the following section we evaluate the geochemistry of the area to further characterize the geothermal reservoir waters and deep ground water flow pathways.

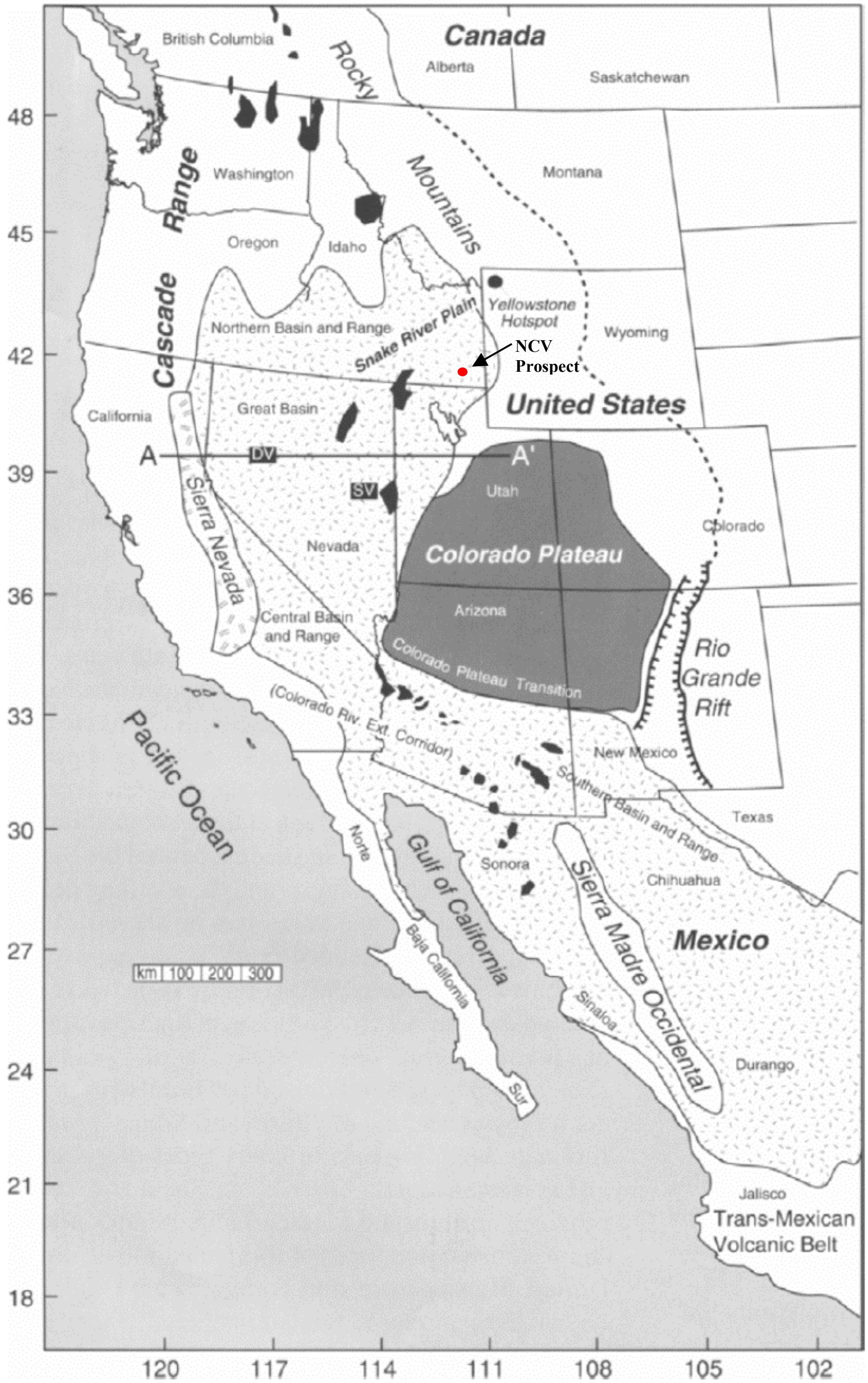


**Figure 4: Extent and borders of the Basin and Range province. Red dot represents the location of the North Cache Valley prospect. Black areas represent regions of metamorphic core complexes. A-A' represents a cross-sectional line not explored in this publication. Modified from Parson, 1995.**

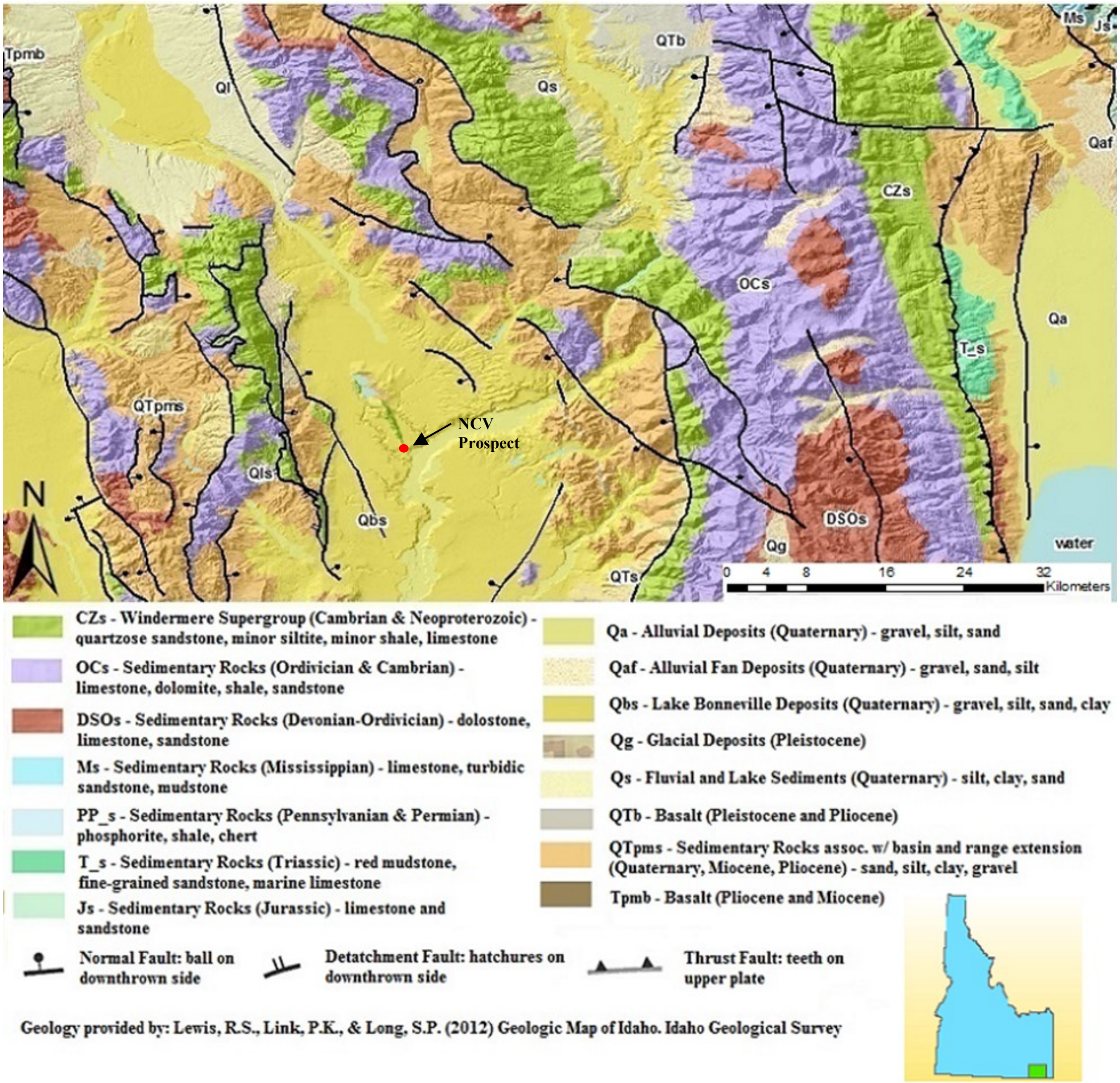


**Figure 5: Geologic map of the North Cache Valley area.**

## 4. GEOCHEMISTRY

Natural springs are found at numerous locations throughout the valley. For the purposes of this study, attention was focused on the data collected by Mitchell (1976), Ralston (1981) and Young and Mitchell (1973). These wells and springs are clustered in the central area of the valley, just south of the southern tip of Clifton Hill and northwest of Preston, ID around the Oneida Reservoir (Figure 1). Cleveland and Maple hot springs can be found near the western shore Oneida Reservoir and on the north end of the reservoir is Treasureton hot springs. Other warm water wells are found near Preston, ID; the Ben Meek well is located 8 km (5 mi) to the northwest, and the Fonnesbeck and E. Bingham wells can be found 10.5 km (6.5 mi) to the southwest. Water temperature tends to be hottest in the central valley, with the Bosen well, Battle Creek, Squaw and Wayland hot springs yielding the warmest samples.

Seventeen wells and springs from the Northern Cache valley were sampled and compiled by Mitchell (1976), those results, along with selected data from Dion (1969), Young & Mitchell (1963) and Ralston (1981) are summarized in Table 1 (Dion, 1969; Young & Mitchell, 1973; Mitchell, 1976; Ralston, 1981; Table 1). The range of chemical constituents analyzed for included, silica (SiO2), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO3), sulfate (SO4), chloride (Cl) and fluoride (F).

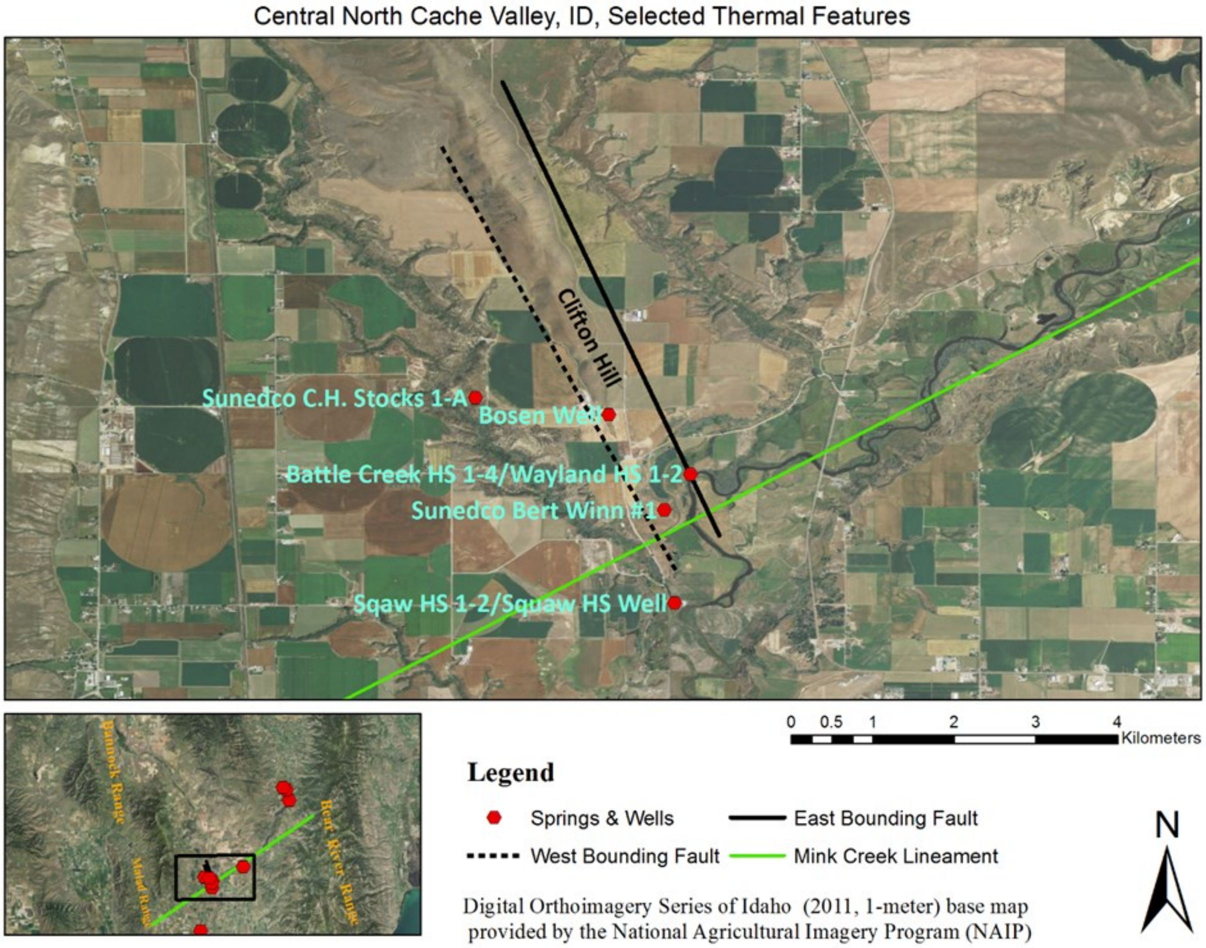


**Figure 6: Close up of the central north Cache Valley, ID, with selected thermal features and structural lineament.**

Sampling of the Bosen well was completed in July 2014 as part of field work for geothermometry mapping of Southeast Idaho (Cannon et al., 2014). The water was analyzed for boron (B), lithium (Li), beryllium (Be), aluminum (Al), arsenic (As), selenium (Se), rubidium (Rb), strontium (Sr), barium (Ba), bismuth (Bi), carbonate ($CO_3$), nitrite ($NO_2$) and bromide ($Br^-$) in addition to the range of chemical components listed above for Mitchell's 1976 study. Some of these constituents are required for temperature modeling using RTEst, which is an inverse multi-component equilibrium geothermometer (MEG) with the capability of evaluating the effects of secondary processes, including boiling, dillution and loss of $CO_2$. The method is described and detailed in other publications (e.g., Palmer, 2013; Neupane et al., 2014).

Thermal waters of the NCV fall into two main types, the largest group, a Na-Cl water, encompasses all the samples analyzed but one (Figure 7). The waters of Battle Creek, Wayland and Squaw Creek hot springs, as well as those from the E. Bingham and Bosen wells are the most extreme of this type, these waters also appear to be only partially equilibrated with the host rock. All other samples were categorized as immature waters (Figure 8).

Reservoir temperatures were estimated using four traditional geothermometers, quartz (Fournier, 1977), chalcedony (Fournier, 1977), silica (Arnórsson et al. 1983), and Na-K-Ca (Fournier and Truesdell, 1973) with a Mg correction applied according to Fournier and Potter II (1979), and summarized in Table 2. Calculated temperatures range from 67° C to 227° C, the highest temperature is unlikely though due to the high concentrations of Mg. RTEst values range from 95±1° C to 179±9° C (Table 2).

In addition to the high amounts of Na and Ca in the Cache Valley waters, there is also a high concentration of Mg (Table 1). High Mg concentrations lead to anomalously high temperatures using the cation geothermometers (Fournier and Potter, 1979). Most high temperature geothermal fluids usually contain <0.2 ppm Mg. More saline fluids, like the Bosen Well water (Na-K-Cl-$SO_4$), have much higher concentrations of Mg but are relatively low in proportion to the concentrations of constituents. For waters with high magnesium values, a Mg correction was developed by Fournier and Potter (1979).

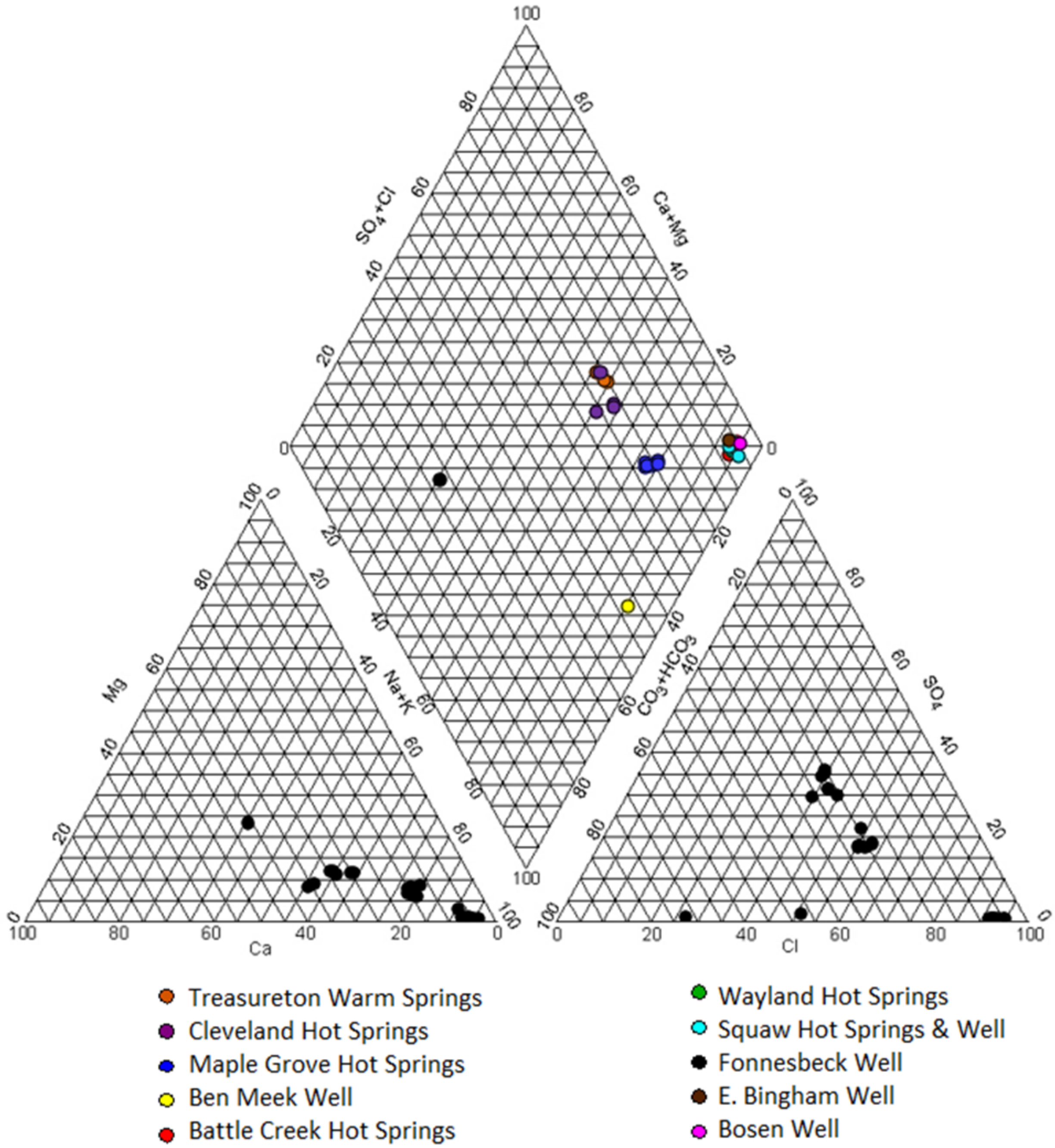


**Figure 7: Piper diagram mapping the springs and wells of the NCV. Wayland and Battle Creek hot springs are hidden by the cluster of samples plotting on the extreme right hand side of the diagram.**

Although the newly discovered Bosen Well has an abnormally high geothermal gradient, surrounding temperature gradients suggest that water may need to circulate to significant depth, up to 3.7 km (12,000 ft), to reach temperatures near 200° C (McIntyre and Koenig, 1980). This suggests that the likely thermal reservoir rock are the basement metasedimentary rocks and carbonates. Although primary reservoir rock type is important, it is generally considered to have less effect on alteration minerals than temperature, water type, and permeability. Regardless of rock type, the predominant alteration minerals in high-temperature geothermal systems have proven to be quartz, albite, k-feldspar, illite, calcite, Fe-epidote, and pyrite (Browne 1978; Henley and Ellis, 1983). Given the metasedimentary and carbonate basement rocks of the Cache Valley system combined with neutral pH waters, the alteration mineral assemblage is likely to be comprised of illite, calcite, paragonite, mordenite-k and SiO2 (quartz/chalcedony). This mineral assemblage is based on that used by RTEst (Palmer, 2014).

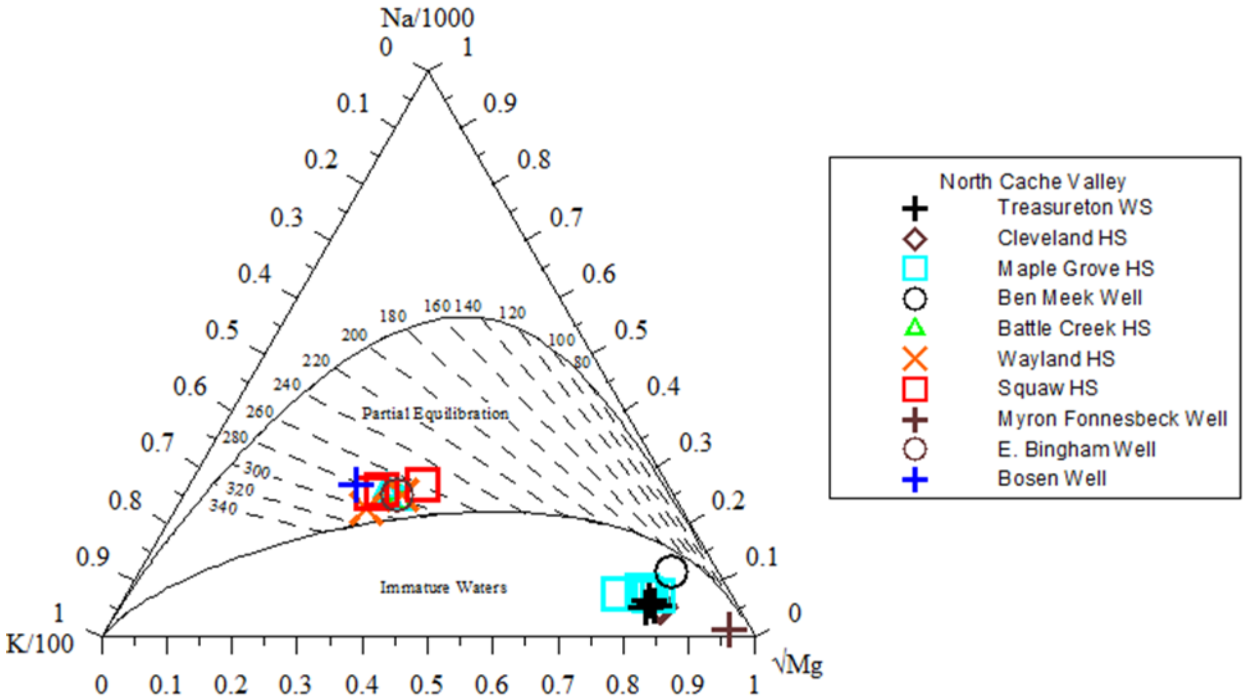


**Figure 8: Giggenbach diagram depicting spring and welll water of the NCV.**

The likely alteration minerals of the thermal reservoir support the conversion of alumino-silicates to calcite and the high calcium concentrations in the water samples. Additionally, the high magnesium concentrations of the waters in the Cache Valley suggest that the use of the Mg corrected Na-K-Ca geothermometer (Fournier and Potter, 1979) is appropriate in this circumstance. The silica geothermometers coupled with the silica-enthalpy mixing model to account for boiling/dilution (Fournier, 1977) may also be appropriate. However, the most accurate reservoir temperature estimate will likely come from the use of the entire reservoir mineral assemblage with a multicomponent equilibrium geothermometry application, such as RTEst.

## 5. DISCUSSION

The recent discovery of 104° C water at a depth of 76 m by a rancher drilling a stock irrigation well has renewed geothermal interest in the NCV area. Although thermal waters are expected in this area, this high of a temperature so shallow is surprising. Two Sundeco geothermal exploration wells drilled within a few kilometers of the Bosen Well site in the late 1970's had less impressive results. The C. H. Stocks 1-A encountered 122° C water at a depth of 1539 m and the Bert Win #1 measured 104° C water at a depth of 2273 m. By comparison, our MEG calculations of reservoir temperature using RTEst indicate a reservoir temp of 174±5° C. Nearly all of the natural springs in the Squaw Creek, Battle Creek and Wayland Spring cluster have RTEst temperatures in the range of 175° C and are of similar water type (Table 2). Technologies for generating electrical power from water with lower temperatures have advanced significantly since the late 1970's. New geothermal technologies may make the NCV geothermal prospect viable in modern times where in the past it was not.

We view the NCV geothermal study as an interesting and valuable case study for several reasons. First, it is interesting in its own right as a highly faulted location near the juncture of three tectonic regimes. Understanding it is likely to shed light on other geothermal sites along these same trends in the western U.S. Second, this area was studied in the past and, although investigators deemed the characterization effort as incomplete at the time, it has gone decades without additional study until a water well driller "accidently" hit thermal water as shallow depths. It is natural to wonder how many other overlooked or understudied areas exist in the western U.S. to be re-evaluated with new technologies. Will new exploration techniques, like RTEst, illuminate prospects and reduce uncertainty in some previously investigated areas? Third, the NCV prospect may be an example of a previously studied area that was not economically viable with technology 30 years ago, but may be viable now using new engineering and technology approaches. Are there other geothermal prospects in the Western U.S. that warrant re-evaluation using an economic framework based on new technologies?

## 6. PLANS FOR FUTURE STUDY

Our planned studies will serve multiple purposes and generally consists of two major components. We will continue charactering the NCV case study area. A field sampling campaign is currently being planned for the summer of 2015. Potential locations of interest include springs and wells discovered and drilled in the area since Mitchell's 1976 investigation. Initial reconnaissance is in progress and involves identification of potential sites via investigation of well drilling reports and collaboration with area experts. Future preparations and research will involve field investigations and walk-throughs, interviews with local residents and sampling of identified sites of desired water sample data. We will continue to fine tune our conceptual model of the site as new or re-discovered data become available.

We also will take a broader look across southern Idaho and into eastern Oregon and compile past studies and data, to gain a better understanding how geothermal resources may go overlooked. Using our lesson learned from the NCV we propose to develop ranking criteria and other factors in an effort to classify and prioritize the study of known geothermal resource areas (KGRAs) that may contain understudied or overlooked resources. This broader effort will also serve to communicate methods employed in the study of the geothermal resources of the NCV to other sites throughout southern Idaho and eastern Oregon.

## 7. ACKNOWLEDGMENTS

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**Table 1: Temperatures and chemical data for wells and springs of the North Cache Valley.**

| Springs/Wells | T(°C) | pH | Ca | Na | Mg | K | Cl | SiO2 | SO4 | HCO3 | F | Units | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treasureton Warm Springs 1 | 35 | 6.6 | 265 | 563 | 68 | 127 | 632 | 54 | 788 | 704 | 2.2 | mg/L | Mitchell, 1976 |
| Treasureton Warm Springs 2 | 40 | 6.4 | 336 | 542 | 48 | 110 | 626 | 54 | 735 | 726 | 2 | mg/L | Ralston, 1981 |
| Treasureton Warm Springs 3 | 33 | 6.6 | 259 | 517 | 64 | 137 | 633 | 52 | 755 | 704 | 1.9 | mg/L | Mitchell, 1976 |
| Cleveland Hot Springs 1 | 55 | 6.2 | 259 | 444 | 41 | 90 | 574 | 62 | 517 | 565 | 1.7 | mg/L | Ralston, 1981 |
| Cleveland Hot Springs 2 | 66 | 6.4 | 208 | 458 | 50 | 98 | 532 | 60 | 533 | 718 | 1.9 | mg/L | Mitchell, 1976 |
| Cleveland Hot Springs 3 | 61 | 6.5 | 178 | 460 | 50 | 102 | 530 | 64 | 530 | 576 | 1.9 | mg/L | Mitchell, 1976 |
| Cleveland Hot Springs 4 | 56 | 6.5 | 172 | 460 | 50 | 100 | 532 | 63 | 532 | 583 | 1.9 | mg/L | Mitchell, 1976 |
| Maple Grove Hot Springs 1 | 76 | 7.3 | 89 | 490 | 24 | 110 | 630 | 55 | 260 | 491 | 1.1 | mg/L | Young & Mitchell, 1973 |
| Maple Grove Hot Springs 2 | 72 | 6.8 | 93 | 501 | 29 | 82 | 601 | 85 | 261 | 495 | 1.1 | mg/L | Mitchell, 1976 |
| Maple Grove Hot Springs 3 | 60 | 6.8 | 93 | 492 | 25 | 80 | 584 | 86 | 251 | 494 | 1 | mg/L | Mitchell, 1976 |
| Maple Grove Hot Springs 4 | 71 | 7.8 | 69 | 494 | 31 | 76 | 595 | 52 | 255 | 424 | 0.9 | mg/L | Dion, 1969 |
| Maple Grove Hot Springs 5 | 78 | 6.6 | 85 | 492 | 30 | 82 | 596 | 84 | 256 | 494 | 1.1 | mg/L | Mitchell, 1976 |
| Maple Grove Hot Springs 6 | 62 | 5.9 | 82 | 499 | 22 | 77 | 585 | 64 | 323 | 454 | 1 | mg/L | Ralston, 1981 |
| Ben Meek Well | 40 | 6.9 | 24 | 368 | 6.6 | 22 | 322 | 89 | 13 | 513 | 9.6 | mg/L | Mitchell, 1976 |
| Battle Creek Hot Springs 1 | 82 | 6.7 | 174 | 3161 | 19 | 552 | 5241 | 109 | 35 | 696 | 6 | mg/L | Mitchell, 1976 |
| Battle Creek Hot Springs 2 | 43 | 6.5 | 166 | 3071 | 15 | 535 | 5048 | 107 | 29 | 697 | 6 | mg/L | Mitchell, 1976 |
| Battle Creek Hot Springs 3 | 81 | 6.5 | 162 | 3053 | 19 | 533 | 5034 | 109 | 37 | 757 | 6 | mg/L | Mitchell, 1976 |
| Battle Creek Hot Springs 4 | 84 | 6.8 | 215 | 4184 | 24 | 686 | 6967 | 97 | 33 | 610 | 6.4 | mg/L | Mitchell, 1976 |
| Wayland HS 1 | 77 | 7 | 160 | 3100 | 16 | 660 | 5400 | 80 | 50 | 699 | 12 | mg/L | Young & Mitchell, 1973 |
| Wayland HS 2 | 77 | 6.5 | 179 | 2985 | 16 | 493 | 5092 | 90 | 39 | 681 | 6 | mg/L | Ralston, 1981 |
| Squaw Hot Springs Well | 84 | 6.5 | 279 | 4368 | 24 | 782 | 7398 | 124 | 35 | 791 | 4.3 | mg/L | Mitchell, 1976 |
| Squaw Hot Springs 1 | 69 | 6.5 | 135 | 4184 | 23 | 708 | 6877 | 126 | 27 | 816 | 4.3 | mg/L | Mitchell, 1976 |
| Squaw Hot Springs 2 | 73 | 6.6 | 241 | 3844 | 26 | 533 | 6396 | 126 | 23 | 866 | 4.8 | mg/L | Mitchell, 1976 |
| E. Bingham Well | 23 | 6.2 | 320 | 4600 | 36 | 770 | 7800 | 68 | 48 | 930 | 3.9 | mg/L | Ralston, 1981 |
| Bosen Well | 90 | 6.7 | 207 | 4523 | 18 | 795 | 7129 | 95 | 49 | 583 | 5 | mg/L | Wood et al., 2015 |
| Myron Fonnesbeck Well | 23 | 6.8 | 78 | 68 | 27 | 18 | 91 | 74 | 4.3 | 418 | 0.5 | mg/L | Mitchell, 1976 |

**Table 2: RTEst and traditional geothermometry values for springs and wells from the north Cache Valley.**

**T ± σ is RTEst results ± error.**

**[a]Quartz no steam loss, Fournier (1977); [b]Fournier (1977); [c]Arnórsson et al. (1983); [d]Truesdell and Fournier (1973), Mg correction applied according to Fournier and Potter II (1979). All numerical values are degrees Celsius.**

| Springs/Wells | T ± σ | Quartz [a] | Chalcedony [b] | Silica [c] | Na-K-Ca [d] |
|---|---|---|---|---|---|
| Treasureton Warm Springs 1 | 111 ± 3 | 105 | 76 | 77 | 78 |
| Treasureton Warm Springs 2 | 111 ± 9 | 105 | 76 | 77 | 113 |
| Treasureton Warm Springs 3 | 114 ± 3 | 104 | 74 | 75 | 85 |
| Cleveland Hot Springs 1 | 119 ± 7 | 112 | 83 | 84 | 106 |
| Cleveland Hot Springs 2 | 113 ± 4 | 111 | 81 | 82 | 81 |
| Cleveland Hot Springs 3 | 119 ± 3 | 114 | 85 | 85 | 74 |
| Cleveland Hot Springs 4 | 118 ± 3 | 113 | 84 | 84 | 72 |
| Maple Grove Hot Springs 1 | 126 ± 4 | 106 | 77 | 78 | 97 |
| Maple Grove Hot Springs 2 | 123 ± 4 | 128 | 101 | 100 | 73 |
| Maple Grove Hot Springs 3 | 124 ± 3 | 129 | 101 | 101 | 82 |
| Maple Grove Hot Springs 4 | 115 ± 7 | 104 | 74 | 75 | 54 |
| Maple Grove Hot Springs 5 | 126 ± 6 | 128 | 100 | 99 | 67 |
| Maple Grove Hot Springs 6 | 144 ± 7 | 114 | 85 | 85 | 84 |
| Ben Meek Well | 109 ± 4 | 131 | 103 | 102 | 73 |
| Battle Creek Hot Springs 1 | 169 ± 5 | 142 | 116 | 114 | 205 |
| Battle Creek Hot Springs 2 | 175 ± 6 | 141 | 115 | 113 | 215 |
| Battle Creek Hot Springs 3 | 170 ± 5 | 142 | 116 | 114 | 202 |
| Battle Creek Hot Springs 4 | 171 ± 5 | 136 | 109 | 107 | 204 |
| Wayland HS 1 | 175 ± 5 | 125 | 97 | 97 | 230 |
| Wayland HS 2 | 144 ± 7 | 131 | 104 | 103 | 207 |
| Squaw Hot Springs Well | 174 ± 6 | 150 | 124 | 122 | 217 |
| Squaw Hot Springs 1 | 179 ± 9 | 151 | 125 | 123 | 204 |
| Squaw Hot Springs 2 | 157 ± 6 | 151 | 125 | 123 | 183 |
| E. Bingham Well | 161 ± 4 | 117 | 88 | 88 | 193 |
| Bosen Well | 174 ± 5 | 134 | 107 | 106 | 227 |
| Myron Fonnesbeck Well | 95 ± 1 | 121 | 93 | 93 | 48 |