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Mixing Effects on Geothermometric Calculations of the Newdale Geothermal Area in the Eastern Snake River Plain, Idaho

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ABSTRACT

The Newdale geothermal area in Madison and Fremont Counties in Idaho is a known geothermal resource area whose thermal anomaly is expressed by high thermal gradients and numerous wells producing hot water (up to 51 °C). Geologically, the Newdale geothermal area is located within the Eastern Snake River Plain (ESRP) that has a time-transgressive history of sustained volcanic activities associated with the passage of Yellowstone Hotspot from the southwestern part of Idaho to its current position underneath Yellowstone National Park in Wyoming. Locally, the Newdale geothermal area is located within an area that was subjected to several overlapping and nested caldera complexes. The Tertiary caldera forming volcanic activities and associated rocks have been buried underneath Quaternary flood basalts and felsic volcanic rocks. Two southeast dipping young faults (Teton Dam Fault and an unnamed fault) provide the structural control for this localized thermal anomaly zone. Geochemically, water samples from numerous wells in the area can be divided into two broad groups – Na-HCO_3 and Ca-(Mg)-HCO_3 type waters. Each type of water can further be subdivided into two groups depending on their degree of mixing with other water types or interaction with other rocks. For example, some bivariate plots indicate that some Ca-(Mg)-HCO_3 water samples have interacted only with basalts whereas some samples of this water type also show limited interaction with rhyolite or mixing with Na-HCO_3 type water. Traditional geothermometers [e.g., silica variants, Na-K-Ca (Mg-corrected)] indicate lower temperatures for this area; however, a traditional silica-enthalpy mixing model results in higher reservoir temperatures. We applied a new multicomponent equilibrium geothermometry tool (e.g., Reservoir Temperature Estimator, RTEst) that is based on inverse geochemical modeling which explicitly accounts for boiling, mixing, and CO_2 degassing. RTEst modeling results indicate that the well water samples are mixed with up to 75% of the near surface groundwater. Relatively, the Ca-(Mg)-HCO_3 type water samples are more diluted than the Na-HCO_3 type water samples. However, both water types result in similar reservoir temperatures, up to 150 °C. Samples in the vicinity of faults produced higher reservoir temperatures than samples away from the faults. Although both the silica-enthalpy mixing and RTEst models indicated promising geothermal reservoir temperatures, evaluation of the subsurface permeability and extent of the thermal anomaly is needed to better define the hydrothermal potential of the Newdale geothermal resource.

1. INTRODUCTION

The Newdale geothermal area in Madison and Fremont Counties in Idaho represents a blind geothermal system in the north-eastern part of Eastern Snake River Plain (ESRP) (Figure 1). The ESRP is a region of high heat flow with great potential for significant geothermal resources (Brott et al., 1976; Blackwell, 1989). In general, the ESRP consists of thick volcanic ash-flow tuffs, which are overlain by >1 km of Quaternary basaltic flows (Hughes et al., 1999; Anders et al., 2014; McLing et al., 2014). The felsic volcanic rocks at depth are the product of super volcanic eruptions associated with the Yellowstone Hotspot. These rocks progressively become younger to the northeast towards the Yellowstone Plateau (Pierce and Morgan, 1992; Hughes et al., 1999). The younger basalt layers are the result of several low-volume, fissure type or monogenetic shield-forming eruptions of short-duration that emanated from northwest trending volcanic rifts in the wake of the Yellowstone Hot Spot (Hughes et al., 1999). The thick sequences of coalescing basalt flows with interlayered fluvial and eolian sediments in the ESRP constitute a very productive aquifer system above the volcanic ash-flow tuffs (Whitehead, 1992).

The geothermal potential of Newdale area was identified in 1970s by several researchers (e.g., Brott et al., 1976), specifically, with the discovery of relatively high heat flow (167 mW/m^2). Subsequent studies on geology, geophysics, and geochemistry of the area identified a zone called Newdale thermal anomaly zone (Mabey, 1978; Prostka and Embree, 1978; Mitchel et al., 1980). The area around the town of Newdale and NE across the Teton River (Figure 1) has been considered as a potential area for geothermal energy (Brott et al., 1976, GeothermEx, 2010). During 1979-1981, Union Oil of California (Unocal) drilled several geothermal test wells in the area ranging in depth from 183 m to 1025 m (Well St 08 in Figure 1). The highest recorded temperature in Unocal wells was 87.2 °C (Well St-07 in Figure 1). Currently, Standard Steam Trust LLC (SST) holds a set of leases for further exploration and development in an area of about 53.4 km^2 around Newdale and defines this area as 'Newdale geothermal energy prospect' (GeothermEx, 2010).

In this paper, we present geochemical and geothermometric assessments of the Newdale geothermal area. The geochemical evaluation of the area was conducted by employing graphical presentations of water compositions of hot shallow wells. Specifically, the ternary and bivariate plots of various aqueous species and their ratios were used to understand types of water and mixing trends in the area. Geothermometric evaluation of the area was conducted using traditional as well as multicomponent equilibrium geothermometry (MEG) tools. Specifically, the effect of mixing of cooler water in the thermal water on geothermometric results was evaluated with an MEG code, Reservoir Temperature Estimator (RTEst) (Palmer et al., 2014).

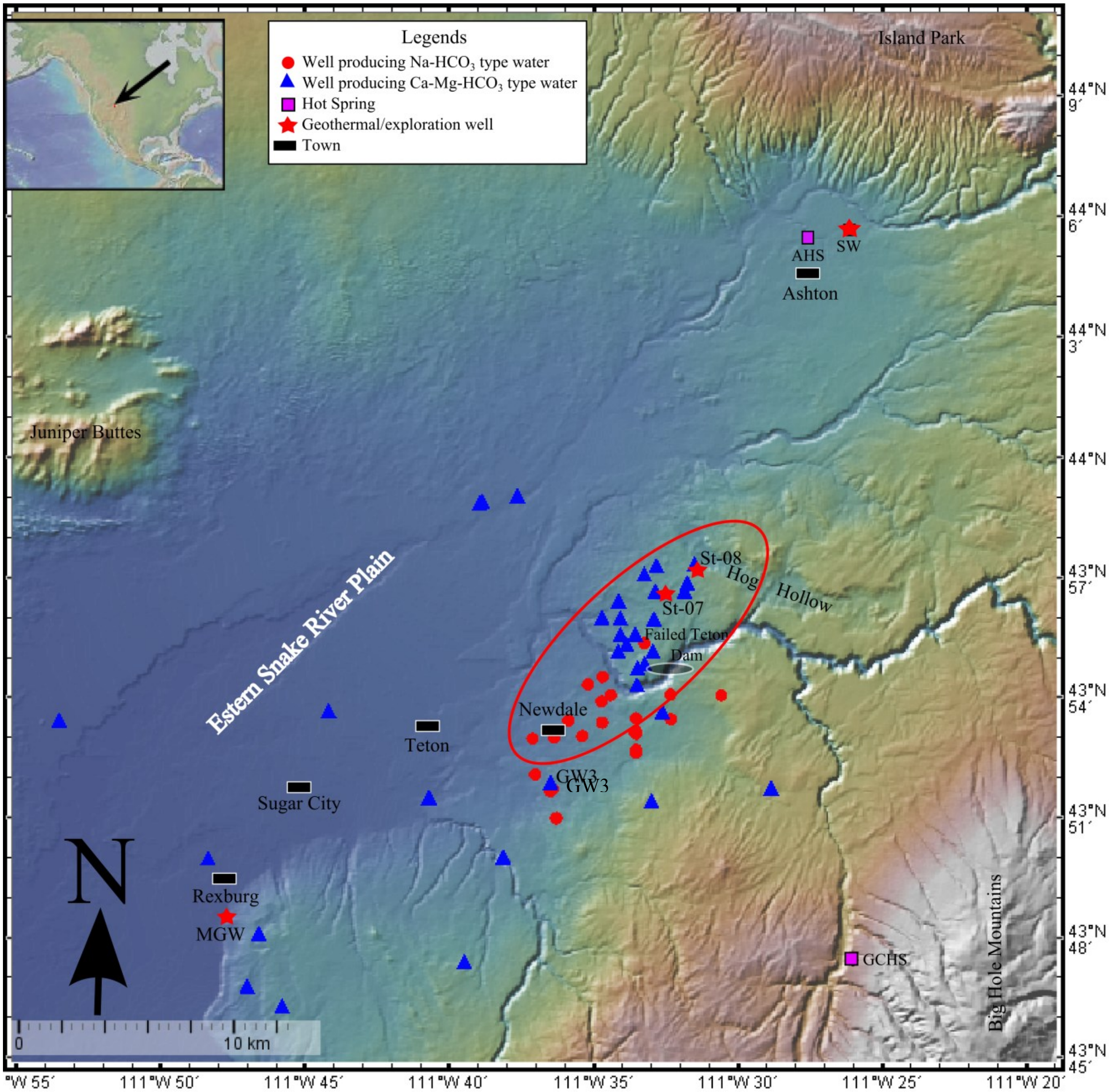

Figure 1. Location of Newdale geothermal prospect in the Eastern Snake River Plain. St-07: State 2591-07-79-1 well, St-08: State 2591-08-79-1 well, MGW: Madison Geothermal well (1204 m), SW: Sturm Well, AHS: Ashton Hot Spring, and GCHS: Green Canyon Hot Spring. GW3 is a groundwater well. Hog Hollow is a geographically depressed area in the northeastern part of prospect.

2. GEOLOGIC SETTING

Surficial geologic map of this area shows presence of Quaternary sediments, Quaternary flood basalts, and Quaternary felsic volcanic rocks (Bond, 1978; Link, 2002; Embree et al., 2011). Early Pleistocene flood basalts are mapped around the town of Newdale whereas felsic volcanic rocks of similar ages are mapped NE from Newdale. In geologic cross-section, Embree et al. (2011) show Huckleberry Ridge Tuff lying underneath the Early Pleistocene basalt at Newdale. Below the Huckleberry Ridge Tuff lie the Tertiary sediments intercalated with Tertiary basalt (Figure 2). Subsurface lithologic records of numerous wells in the area as compiled by the Idaho Geological Survey indicate the presence of thick sequences of rhyolites and tuff at greater depths.

Based on geologic, geomorphologic (Prostka and Embree, 1978) and gravity anomaly features (Mabey, 1978), a series of overlapping and intersecting calderas that developed during 4.45-6.62 Ma (Morgan and McIntosh, 2005) have been inferred as Rexburg Caldera Complex (RCC) covering a large area including Rexburg, Teton, Sugar City, and Newdale areas, and possibly even extending north to the Ashton area (Malde, 1991; Blackwell et al., 1992; Anders et al., 2014). Specifically, the Newdale geothermal area is located along the three inferred caldera margins (Prostka and Embree, 1978). Recently, Anders et al. (2014) mapped the Blacktail Creek Tuff caldera (a caldera unit of RCC) rim that passes through the Newdale geothermal area along the Teton River. It is important to note that the Teton River within the thermal anomaly area acts as a boundary for surficial rock types (Embree et al., 2011) as well as geochemical boundary for the water types (Figure 1). Specifically, the surficial rocks to the north/northeastern side of the river are felsic volcanic rocks associated with the Quaternary Huckleberry Ridge Tuff (Qyh in Figure 2) whereas surficial rocks to the southern side are Quaternary flood basalts. The geologic cross-section (Figure 2) does not show any surficial basalts because it traverses exclusively through the northern part of the prospect where the Quaternary Huckleberry Ridge Tuff and Quaternary sediments are mapped as surficial rocks (Embree et al., 2011).

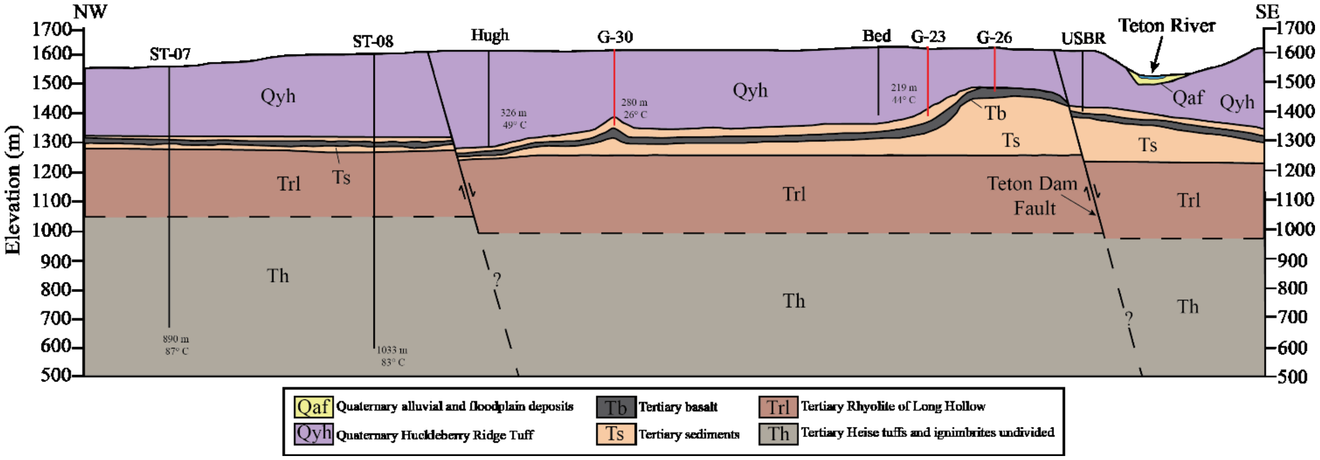

Figure 2. Geologic cross-section through Newdale geothermal area. The cross-section line passes through between two Unocal wells (St-07 and St-08 in Figure 1) and does not encounter Quarternary basalts. Stratigraphic architecture of the cross-section is constrained with available lithologic records of wells and geologic cross-section of Embree et al. (2011). The locations of two faults were adapted from geologic map (Embree et al., 2011).

It is likely that this area has highly fractured zones at depth because of the presence of intersecting caldera-ring fractures (Prostka and Embree, 1978; Anders et al., 2014). However, at present, the fractured zone has been buried underneath the thick sequences of post-RCC volcanic and sedimentary sequences. Besides the likely presence of buried caldera ring fractures at depth, two southeast dipping parallel faults are mapped in the area (Embree et al., 2011). Specifically, the Teton Dam Fault has been traced along a stretch of Teton River near the failed Teton dam (Figure 1) and extended further to NE and SW (Prostka and Embree, 1978; Embree et al., 2011). The other fault is located NW of the Teton Dam Fault. Prostka and Embree (1978) also show a NW striking and SW dipping fault (Warm Creek Fault) that extends from the Big Hole Mountains to the SE and intersects the NE terminus of the Teton Dam Fault. However, this fault has not been shown on the new geologic map prepared by Embree et al. (2011). Moreover, Embree and Hogan (1999) show a series of shallow and short faults inferred from surface lineaments that transect the Hog Hollow area (Figure 1) located in the northeastern part of the Newdale geothermal area. The significance of Teton Dam Fault and other associated faults for the Newdale geothermal system has yet to be fully evaluated. In general, these faults may act as structural control for the geothermal setting by providing upward pathways for migration of hotter fluid from depth. However, the Teton Dam Fault and the other faults in the area may have a limited role in circulating hotter fluids from depth to the surface such that these faults may have been located within the post-RCC zone without providing a continuous flow path from ring fracture zones to the surface. Moreover, the lack of surface expressions (e.g., hot springs) in the area may be related to a lack of sufficient hydraulic/convective head gradient because the water table in the area is located several tens of meters below ground surface.

3. GEOTHERMOMETRY

One of the prospecting tools for geothermal resources is geothermometry, which uses the chemical compositions of water from springs and wells to estimate reservoir temperature. As an exploration tool, geothermometry offers a cost effective method to decrease exploration risk by evaluating a potential geothermal reservoir's temperature. To conduct geothermometry, measured chemical composition of water from wells and springs that exhibit some level of elevated temperatures are needed. The application of geothermometry requires several assumptions. The most important assumptions are that the reservoir minerals and fluid attain a chemical equilibrium and as the water moves from the reservoir to sampled location, it retains its chemical compositions (Fournier et al., 1974). The first assumption is generally valid (provided a long residence time); however, the second assumption is more likely to be violated because of composition altering processes, such as, re-equilibration at lower temperature, dilution (mixing), and loss of fluids (boiling) and volatiles (e.g., CO_2) with the decrease in pressure.

Traditional geothermometers such as silica geothermometers, Na/K geothermometer, etc., are empirical to semi-empirical approaches where a user enters the measured concentrations of certain component(s) into the geothermometer equation. The reliability, sensitivity, and responsiveness of traditional geothermometers to various composition altering processes vary. For example, geothermometers based on cation concentration ratios (e.g., Na/K geothermometer) are minimally sensitive to boiling or mixing with dilute water; while geothermometers based directly on the concentration of component(s) (e.g., quartz geothermometer) are highly sensitive to these processes (D'Amore and Arnórsson, 2000). A drawback of many existing geothermometry approaches is that they do not adequately account for physical processes (e.g., mixing, boiling) and geochemical processes (e.g., mineral dissolution, precipitation, degassing) that may occur after the water leaves the reservoir and thereby alter its composition. If these changes are not taken into account, predictions of in-situ reservoir conditions (e.g., temperature, fCO_2) based on the chemical composition of water samples taken from shallower depths or at the surface may be erroneous, or too imprecise to be useful.

In addition, it is difficult to quantify uncertainties associated with temperatures estimated with these geothermometers. As a result, it is not uncommon to find diverse temperature estimates for the same water using multiple traditional geothermometers. Nevertheless, because these geothermometers are easy to use and sometimes provide good results, they are considered to be an essential part of the geothermal exploration toolkit (D'Amore and Arnórsson, 2000).

A more advanced geothermometric approach is MEG. This approach utilizes multiple chemical constituents measured in water samples for inverse geochemical modeling considering a suite of selected minerals (selected based on some knowledge of the system) so as to provide more robust temperature estimates with quantifiable uncertainties. Geothermal temperature predictions using MEG provide apparent improvement in reliability and predictability of temperature over traditional geothermometers. The basic concept of this method was developed in 1980s (e.g., Michard and Roekens, 1983; Reed and Spycher, 1984). Some previous investigators (e.g., D'Amore et al., 1987; Hull et al., 1987; Tole et al., 1993) have used this technique for predicting reservoir temperature in various geothermal sites. Other researchers have used the basic principles of this method for reconstructing the composition of geothermal fluids and formation brines (Pang and Reed, 1998; Palandri and Reed, 2001). More recent efforts by some researchers (e.g., Bethke, 2008; Spycher et al., 2011; Smith et al., 2012; Cooper et al., 2013; Neupane et al., 2013, 2014; Cannon et al., 2014; Spycher et al., 2014; Peiffer et al., 2014; Palmer et al., 2014; Neupane et al., 2015a,b,c; Mattson et al., 2015; Neupane et al., 2016a,b) have been focused on improving temperature predictability of the MEG.

For this study, both traditional [e.g., quartz (no steam loss) (Fournier, 1977), chalcedony (Fournier, 1977), and Na-K-Ca (Truesdell and Fournier, 1973; Fournier and Potter, 1979)] and RTEst (Palmer et al., 2014; Mattson et al., 2015) geothermometric approaches were applied to estimate reservoir temperatures. For the silica geothermometers, pH correction on silica concentrations was not applied. While applying RTEst to each water sample, a mineral assemblage consisting of 5-7 representative minerals was used for the development of reservoir temperature estimate using the LLNL based thermodynamic database (thermo.dat database of Geochemist's Workbench). In general, the mineral assemblage was selected based on available information such as water chemistry (e.g., pH), likely reservoir rock types and temperature range, etc. For more detailed information on selection of the mineral assemblage, see Palmer et al. (2014).

4. WATER SAMPLES

4.1 General

Locations of Newdale area water samples are shown in Figure 1. The water compositions used in this study represent both wells producing waters at elevated temperatures (≥20 ºC) and cooler water (<20 ºC). The temperatures of the wells with warmer water range from 21-51 °C whereas temperatures of cooler wells range from 8.5-17.5 °C.

4.2 Water Chemistry

All Newdale area wells produce dilute (TDS ranging from 200 to 520 mg/kg with an average value of 375±80 mg/kg) and near-neutral (pH ranging from 6.4 to 8.5) water. Major cations in Newdale water samples are Na, Ca, and Mg whereas major anions are HCO_3, Cl, F, and SO_4. Water samples in the area are of two types: Na-HCO_3 and Ca-(Mg)-HCO_3 (Figure 3). In the ESRP, the Na-HCO_3 and Ca-(Mg)-HCO_3 type waters are often related to deeper water that have interacted with rhyolite at relatively higher temperature and shallower ESRP groundwater that have mostly interacted with basalt at cooler temperature, respectively (Mann, 1986; McLing et al., 2002; Welhan, 2015). Recently, Cannon (2015) showed that the Ca-Mg-HCO_3 groundwater gradually changes to Na-HCO_3 type water when interacted with ESRP basalts at 70 ºC for a long time. Therefore, the water types in the ESRP region are more likely to reflect the degree of thermal influence on water-rock interaction independent of rock types. The Na-HCO_3 waters have slightly higher TDS (ranging from 340 to 520 mg/kg with an average value of 440±60 mg/kg) than Ca-(Mg)-HCO_3 waters (ranging from 200 to 480 mg/kg with an average value of 330±60 mg/kg).

The cations ternary and the diamond plots in Figure 3 show that these two groups of water aligned along a trend from Na+K vertex to Ca-Mg baseline; however, such trend is missing in the anions ternary plot. Nevertheless, the anions ternary diagram shows a type-water independent trend that extends from the HCO_3 vertex towards the Cl-SO_4 baseline. A similar type-water independent trend can be found on a bivariate plot constructed for HCO_3 and Cl (Figure 4a). The trend depicted in Figure 4a reflects the intensity of water-rock interaction (regardless of the rock types) that a water sample might have experienced. In general, the higher the degree of water-rock interaction, the higher the concentrations of HCO_3 and Cl in water. Other bivariate plots (Figure 4b through Figure 4e), however, show linear alignment of Na-HCO_3 and Ca-(Mg)-HCO_3 type water samples. Traditionally, such linear alignment of water samples on bivariate plots is considered to be the result of mixing of the two end member water compositions at different proportions. Figure 4f indicates that the both Na-HCO_3 and Ca-(Mg)-HCO_3 type waters are meteoric in origin and the variations in major ion concentrations in them is a reflection of the varying degrees of water-rock interaction involving different rock types, temperatures, and mixing with other water types.

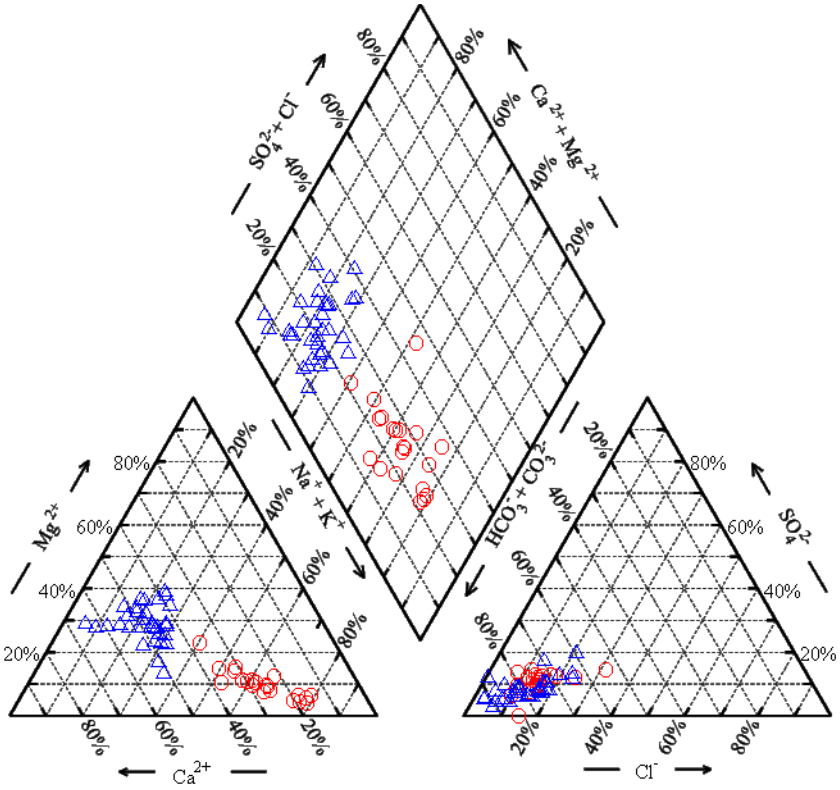

Figure 3. Piper diagram representing chemistry of water samples from Newdale geothermal area. Red circles and blue triangles represent Na-HCO_3 and Ca-(Mg)-HCO_3 type waters, respectively.

Although bivariate plots shown in Figure 4b through Figure 4f depict the apparent linear alignment of Na-HCO_3 and Ca-(Mg)-HCO_3 type waters, some additional bivariate plots with other components and ratios (Figure 5a through Figure 5f) show two distinct mixing (and/or degree of water rock interactions) trends, one for the Na-HCO_3 and other for the Ca-(Mg)-HCO_3 type waters. These diagrams indicate that for Ca-(Mg)-HCO_3 type waters, one end-member (dilute one) can be represented by a pristine water (rain/snow melt). However, the composition of other end member (towards higher TDS) is not known, but such composition for each sample can be reconstructed with RTEst modeling. All intermediate waters have formed either by mixing of low and high TDS end-member waters at various proportions, or by varying degree of water-rock interaction.

Some bivariate plots (e.g., Figure 5b, d, and f) that includes Cl (concentration or as part of ratio) in their construction indicate that the cooler end member water that mixed with the Na-HCO_3 type waters is very dilute Ca-(Mg)-HCO_3 type water or pristine water. However, other bivariate plots that do not include Cl in their construction (e.g., Figure 5a, c, and e) indicate that the end member water that mixed with Na-HCO_3 type waters may have a composition similar to some intermediate Ca-(Mg)-HCO_3 type water. Since RTEst does not handle complex geochemical behavior (e.g., precipitation, cation exchange, and so on), we assume that some variant of intermediate Ca-(Mg)-HCO_3 type water is the end member water that is mixed with Na-HCO_3 type waters. As with the cases of Ca-(Mg)-HCO_3 type waters, the higher TDS end member composition of Na-HCO_3 type waters are not known, and for each sample, the original thermal water is reconstructed with RTEst modeling.

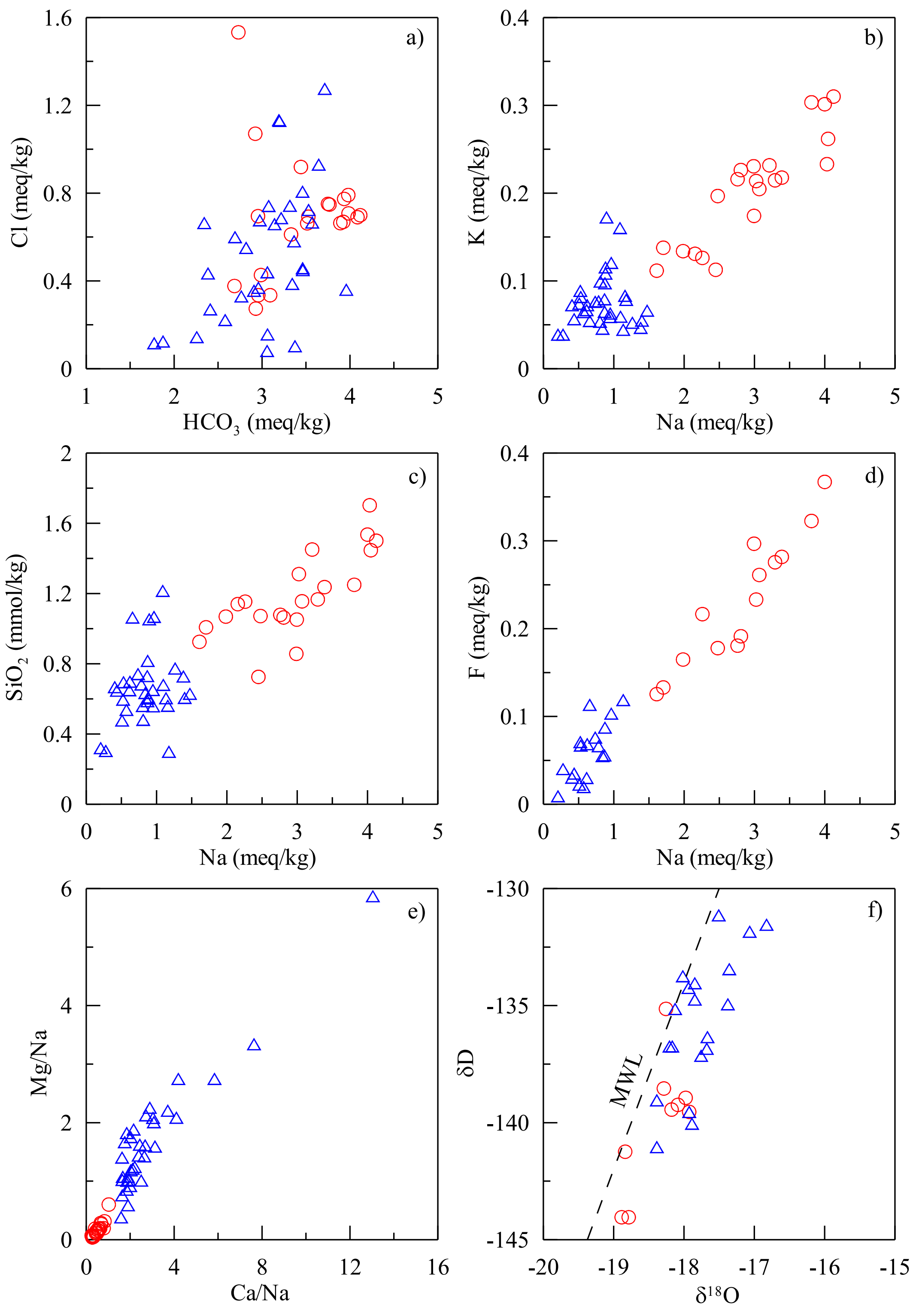

Figure 4. Bivariate diagrams constructed for some components, isotopes, and components ratios in Newdale and surrounding area water samples. Red circles and blue triangles represent Na-HCO$_3$ and Ca-(Mg)-HCO$_3$ type waters, respectively.

Bivariate plots shown on Figure 6 also supports this assumption that some intermediate Ca-(Mg)-HCO$_3$ type water is likely to be the end member water that is mixed with Na-HCO$_3$ type waters at different proportions. Figure 6a indicate that the Na-HCO$_3$ type water may be divided into two groups showing slightly different mixing trends. Figure 6b indicates that the Ca-(Mg)-HCO$_3$ waters may have two sub-groups with two mixing/water rock interaction trends. The first group of Ca-(Mg)-HCO$_3$ type water samples has low F, and these water samples do not show further enrichment in F with progression of water-rock interaction. On the other hand, the second group of water samples shows a tendency of slightly increasing F with increasing concentration of Ca (and TDS as well, figure not shown); however, it may be difficult to discern whether the increasing F concentration merely reflects the fact that these waters may have had limited water-rhyolite interaction or they receive increasing amounts of Na-HCO_3 type water.

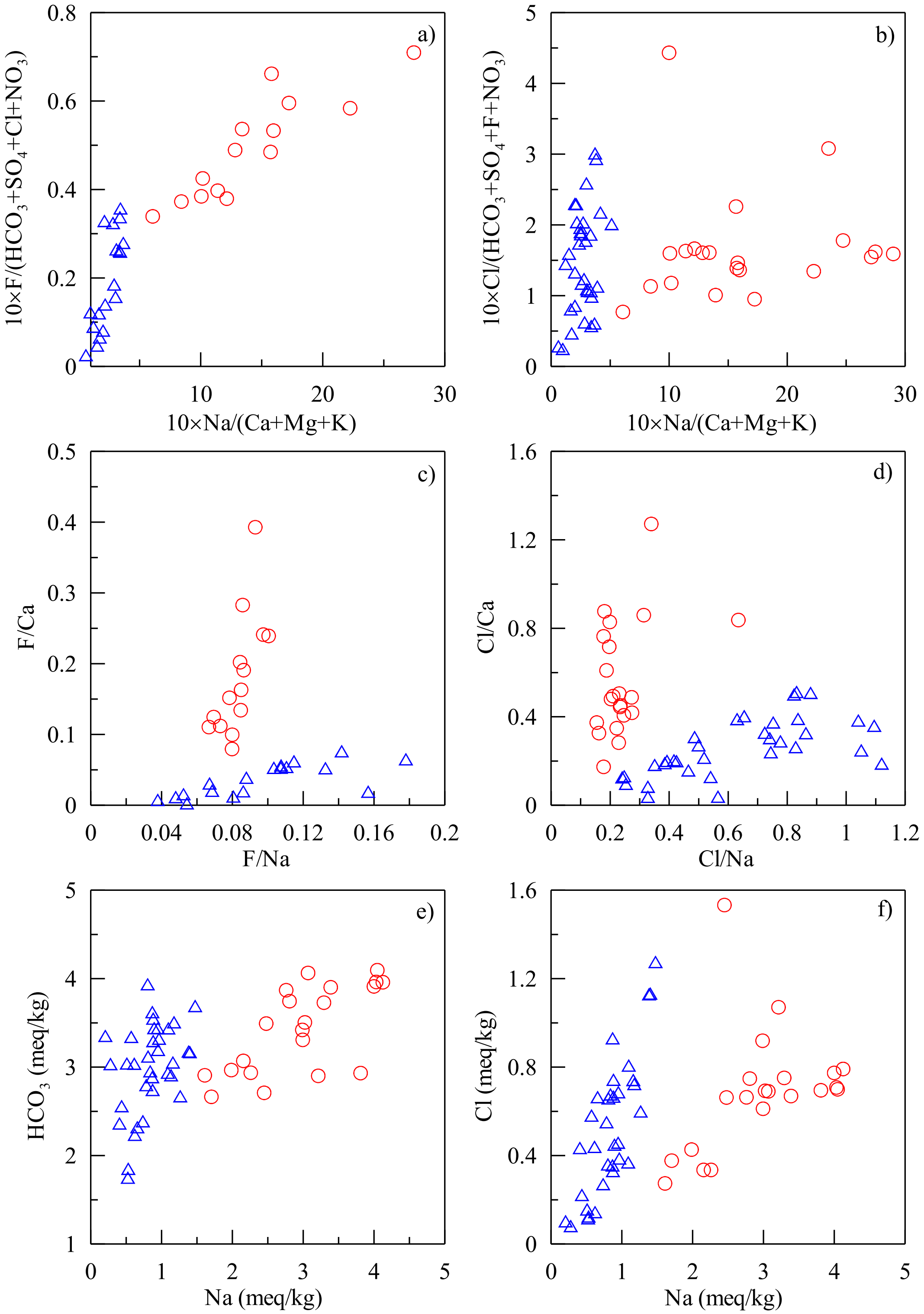

Figure 5. Bivariate diagrams constructed for some components and components ratios in Newdale and surrounding area water samples. Red circles and blue triangles represent Na-HCO_3 and Ca-(Mg)-HCO_3 type waters, respectively.

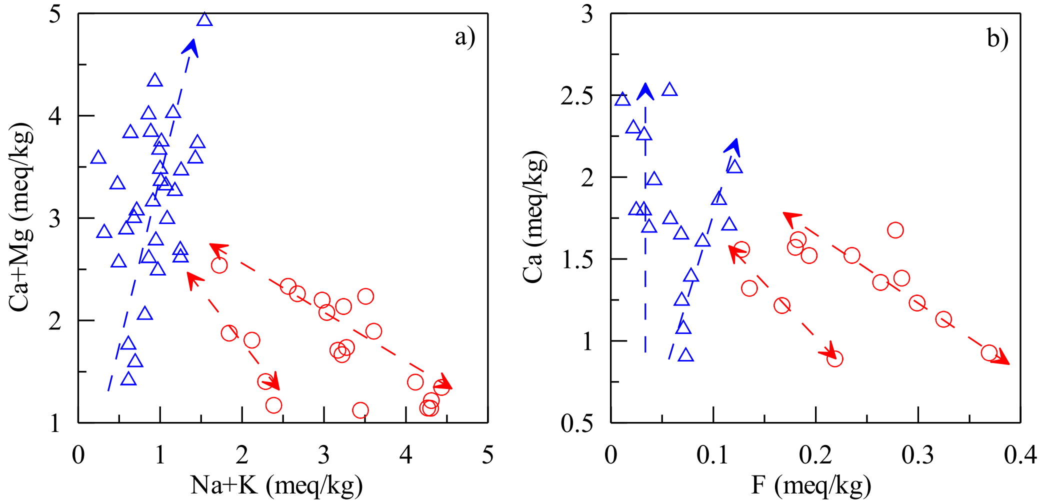

Figure 6. Bivariate diagrams constructed for some components in Newdale and surrounding area water samples. Red circles and blue triangles represent Na-HCO_3 and Ca-(Mg)-HCO_3 type waters, respectively.

Concentration of F in water samples is highly influenced by the degree of past interaction with felsic volcanic rocks. However, the majority of low F water samples are from the area north of Teton River where the subsurface lithology is dominated with felsic rocks. At first, it appears incongruent with the near surface rock types, however, the wells located north of Teton River tap water from a sediment-basalt aquifer sandwiched between pre-Huckleberry Ridge and Huckleberry Ridge felsic volcanic rocks (Figure 2). Similarly, wells distributed on the southern side of the Teton River where near surface rocks are basalts mostly tap Na-HCO_3 type water from felsic volcanic rock units underneath the basalts.

4. GEOTHERMOMETRIC CALCULATIONS

4.1.1 Traditional geothermometers

On a Giggenbach diagram, all Newdale water samples plot in immature water field (Figure 7). For this geothermal prospect, this diagram is minimally useful except indicating that these waters may be less suitable for traditional geothermometry.

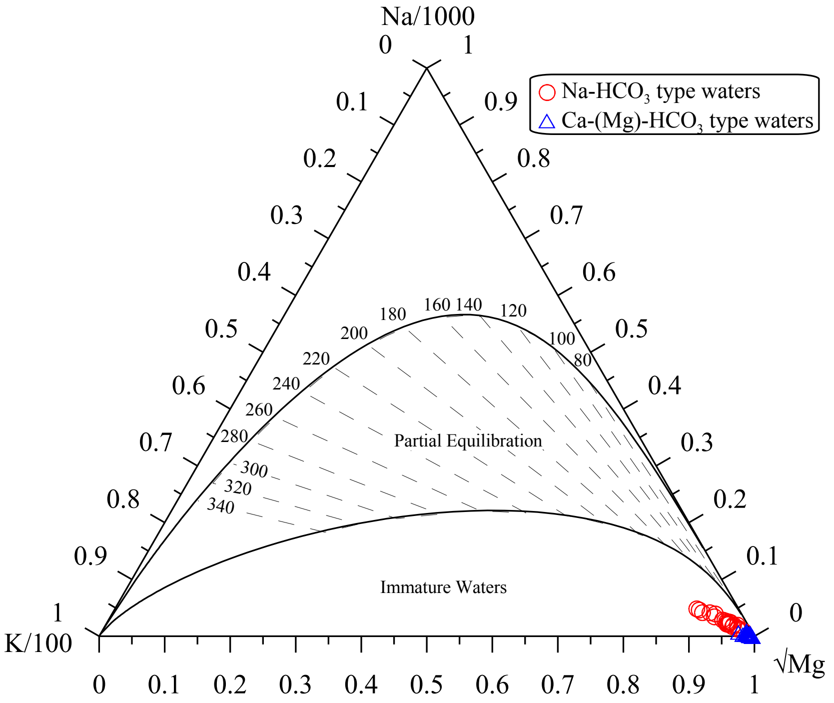

Figure 7. Newdale area water samples plotted on Giggenbach diagram.

Reservoir temperature estimates obtained with quartz, chalcedony, and Na-K-Ca (Mg-corrected) geothermometers for Ca-(Mg)-HCO_3 type waters are lower when compared to the temperature estimates obtained with the respective geothermometers for the Na-HCO_3 type waters (Table 1). The range of temperatures with quartz, chalcedony, and Na-K-Ca (Mg-corrected) geothermometers for Ca-(Mg)-HCO_3 type waters are 66-119 °C, 28-93 °C, 29-81 °C, respectively. Similarly, range of estimated temperature with these geothermometers for Na-HCO_3 type waters are 97-134 °C, 65-112 °C, and 50-111 °C, respectively. A silica (quartz)-enthalpy mixing model (Fournier, 1977; Fournier and Porter, 1982) using all samples resulted in a reservoir temperature of about 224 °C. However, the silica (chalcedony)-enthalpy mixing model resulted in reservoir temperature of about 174 °C (Figure 8).

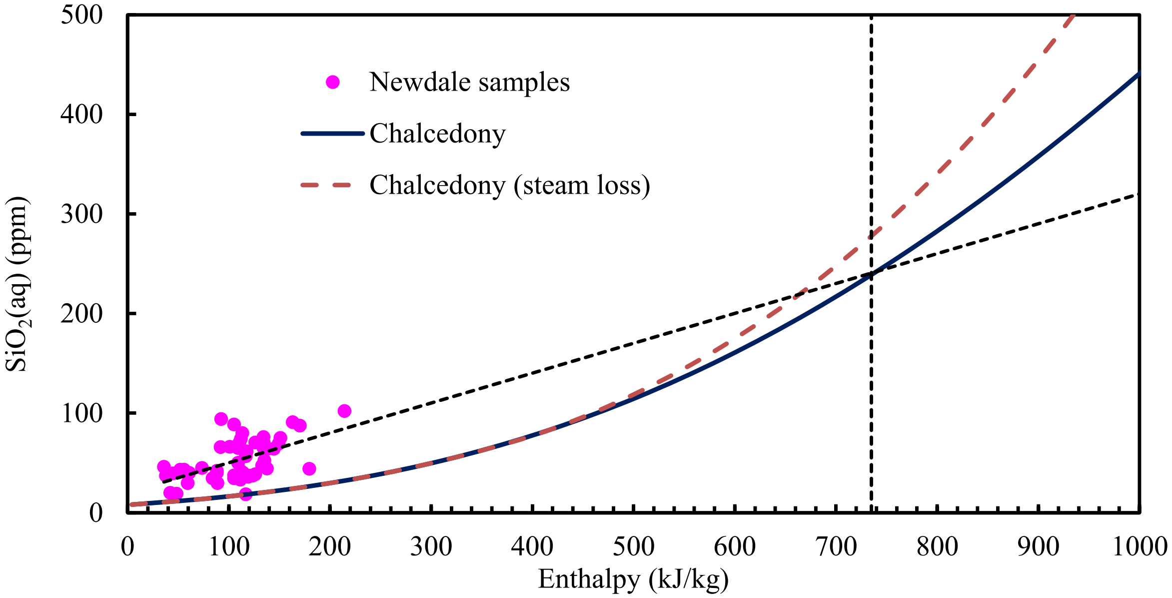

Figure 8. Silica (chalcedony)-enthalpy mixing model (modified from Fournier, 1977; Fournier and Porter, 1982) applied to all Newdale area samples.

4.2 Multicomponent geothermometry

Since Na-HCO_3 type waters show mixing trends (Figure 6) with a variant of Ca-(Mg)-HCO_3 type water; RTEst modeling of these samples were performed using the option that helps reconstruct thermal fluid using mixing, fugacity of CO_2, and T as optimization parameters. The Groundwater well-3 (GW3 in Figure 1) water composition was selected to define the end member cooler water composition for RTEst modeling of Na-HCO_3 type waters. The GW3 water is a Ca-(Mg)-HCO_3 type water that approximately falls along the mixing trends for both types of water on some bivariate plots (Figure 4, Figure 5a,b,e,f). During RTEst modeling, some variant of this water composition is found applicable to all Na-HCO_3 type waters as well as to majority of Ca-(Mg)-HCO_3 type waters. Specifically, SiO_2(aq) concentration in GW3 water, which has unusually high concentration of 46 mg/L at 8.5 °C, was not included in the end member cooler water composition for RTEst modeling. The same approach was used for most of the Ca-(Mg)-HCO_3 type waters, however, for some Ca-(Mg)-HCO_3 type waters (Remington Produce, Schwendiman, Pauline, Mark Ricks, and Lavere Ricks wells), RTEst modeling was performed using pure water to account for the mixing. For these samples, use of GW3 based end member water resulted in similar estimated temperatures as with the pure water but similar or poor convergence (large standard error). As noted in the previous section, the assumption of some pristine water as end member cooler water for Ca-(Mg)-HCO_3 type waters is geochemically satisfactory to all bivariate plots (Figure 4, Figure 5, and Figure 6).

The RTEst estimated temperature for all water compositions are given in Table 1. The ranges of RTEst temperature estimates for Na-HCO_3 and Ca-(Mg)-HCO_3 type waters are 75-152 °C and 85-138 °C, respectively. RTEst results indicate that Newdale area samples contained 10 to 75% of cooler water fractions. Relatively, Ca-(Mg)-HCO_3 type waters have greater fractions (30-75%) of cooler water than Na-HCO_3 type waters (10-50%). The relatively cooler temperatures obtained with the traditional geothermometers for the Ca-(Mg)-HCO_3 type waters may have resulted because they are more diluted with cooler waters than the Na-HCO3 type waters.

The lower RTEst temperature estimates obtained for some samples from this area are similar to the bottom hole temperatures (83-87 °C) measured at two relatively deeper (~1000 m) Unocal wells (St-07 and St-08 in Figure 1). Moreover, it is likely that the area hosts hotter zone at greater depth reaching to the higher RTEst temperature estimates. Assuming an 80 °C thermal gradient (as indicated by two Unocal wells), the higher RTEst temperature estimates would be available at about 2 km depth.

Table 1. Geothermometric reservoir temperatures (in °C) estimated using water compositions from several sampling features in northeastern ESRP

Wells	RTEst T±σ[a]	Quartz (nsl)[b]	Chalcedony[c]	Na-K-Ca[d]
Newdale City W[e]	96±4	117	90	85
Wanda Woods W2	141±7	122	97	65
Walz Enterprises W	131±8	113	86	70
Wanda Woods W1	110±7	114	86	71
Wallace Little W	106±4	120	93	70
Henry Harris W	133±5	113	85	68
Donanld Trupp W	115±3	120	94	108
Wayne Larson W	122±3	130	107	111
Schwendiman W	137±4	111	83	63
Clyde W	139±5	113	86	56
Cinder Block W	119±3	117	90	79
G21	138±3	116	89	69
G23	75±6	97	65	83
G25	135±3	134	112	68
G41	138±3	127	103	79
G43	136±5	117	90	75
G44	102±4	104	74	50
G50	113±3	128	105	110
G54	118±2	126	102	80
G78	152±5	108	78	44
G80	103±2	114	86	60
Remington Produce W[e]	*134±7*	*113*	*86*	*39*
Dean Swindelman W	*129±12*	*113*	*86*	*44*
Pauline W	*85±5*	*94*	*61*	*44*
Mark Ricks W	*125±4*	*103*	*72*	*50*
Lavere Ricks W	*116±8*	*96*	*63*	*49*
G22	*104±10*	*98*	*66*	*53*
G24	*117±6*	*119*	*93*	*74*
G26	*118±13*	*91*	*57*	*49*
G28	*122±2*	*83*	*48*	*29*
G30	*101±10*	*66*	*28*	*33*
G31	*92±7*	*88*	*54*	*41*
G36	*110±8*	*94*	*61*	*31*
G37	*138±3*	*113*	*85*	*41*
G38	*98±3*	*88*	*54*	*46*
G39	*121±1*	*91*	*58*	*44*
G55	*104±5*	*100*	*69*	*81*
G56	*102±8*	*91*	*57*	*57*
G64	*96±4*	*88*	*54*	*58*
G65	*89±7*	*90*	*56*	*45*
G66	*102±7*	*91*	*58*	*49*
G67	*134±12*	*92*	*59*	*33*

[a]RTEst estimated temperature with associated standard error; [b] quartz (no steam loss) geothermometer temperature (Fournier,1977); [c] chalcedony geothermometer temperature (Fournier,1977); [d] Mg-corrected (where applicable) Na-K-Ca geothermometer temperature (Truesdell and Fournier, 1973; Fournier and Potter II, 1979), [e]wells with regular and *italicized* fonts produce Na-HCO$_3$ and *Ca-Mg-HCO$_3$* type waters, respectively.

5. CONCLUSIONS

The Newdale geothermal area in Madison and Fremont Counties in Idaho is a known geothermal resource area whose thermal anomaly is expressed by high thermal gradients and numerous wells producing warm water (up to 51 °C). Geochemical evaluations of water samples from numerous wells in the area indicate that the area has two types of waters – Na-HCO$_3$ and Ca-(Mg)-HCO$_3$. These two water types are considered to be the product of water-interactions involving felsic and basic volcanic rocks and mixing with dilute and cooler groundwater. Each water type can further be subdivided into two groups depending on their degree of mixing with other water types or interaction with other rocks. For example, some bivariate plots indicate that some Ca-(Mg)-HCO$_3$ water samples have interacted only with basalts whereas some samples of this water type also show limited interaction with rhyolite or mixing with Na-HCO$_3$ type water. Traditional geothermometers [e.g., silica variants, Na-K-Ca (Mg-corrected)] indicate lower temperatures for this area; however, a traditional silica-enthalpy mixing model results in higher reservoir temperatures. Multicomponent geothermometry (e.g., RTEst) results indicate that the well water samples are mixed with up to 75% of the near surface groundwater. Relatively, Ca-(Mg)-HCO$_3$ type water samples are more diluted than the Na-HCO$_3$ type water samples. However, both water types result in similar reservoir temperatures, up to 150 °C. Geothermometric results and the available geothermal gradient data of the area indicate that the reservoir is likely to be located at a depth of about 2 km. However, further evaluation of the subsurface permeability and extent of the thermal anomaly is needed to better define the hydrothermal potential of this geothermal resource.

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