**Water compositions and additional data for Known geothermal resource areas (KGRA) and identified hydrothermal resource areas (IHRA) in southern Idaho and southeastern Oregon**

Ghanashyam Neupane1,2, Travis, L. McLing1,2, Earl D. Mattson1, Patrick F. Dobson3, Nic Spycher3, Mark E. Conrad3, Thomas R. Wood2,4, Cary R. Lindsey4, and Jerry P. Fairley4

1Idaho National Laboratory, Idaho Falls, ID, USA

2Center for Advanced Energy Studies (CAES), Idaho Falls, ID, USA

3Lawrence Berkeley National Laboratory, Berkeley, CA, USA

4University of Idaho, Moscow, ID, USA

**1. General**

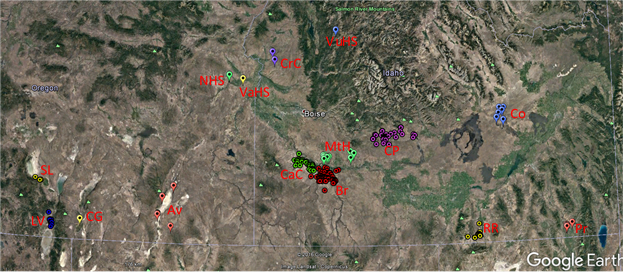
Significant advancement in geothermal energy production in the U.S. must include development of sites that are hidden or are currently overlooked. For more than 30 years, multiple sites in western states in the US have been listed as “Known Geothermal Resource Areas” (KGRA) or “Identified Hydrothermal Resource Areas” (IHRA) (White and Williams, 1975; Muffler, 1979; Burkhardt et al., 1980; Williams et al., 2008). In southeastern Oregon and southern Idaho, over a dozen of such sites have been identified (Figure 1, Table 1). However, currently, only three such areas host geothermal power plants [Raft River, Neal Hot Springs, and Summer Lake (Paisley)] generating a combined net electricity of about 37 MWe. Rest of other areas are poorly defined and haven’t been rigorously explored. Previous exploration of these areas are mostly limited to geologic mapping and conventional geothermometry using chemical compositions of thermal waters from hot springs and wells. Because these conventional exploration approaches mostly failed to confirm the existence of commercial temperature resources, majority of the KGRAs in southeastern Oregon and southern Idaho failed to attract new industry-led explorations or were overlooked for years. As evidenced by the presence of hot springs and relatively high regional heat flow, the region continues to present tantalizing signatures that electrical grade resources may exist in the area.

The magnitude of the potential geothermal resources warrants a closer look at these KGRAs with new methods. As a first screening tool to select the best possible sites for having a potential electrical grade resources, we have assembled a series of available data and used them for statistical analysis. Specifically, compositions of thermal water samples from these areas, geologic structures, and regional heat flow values are used for cluster and principal component analyses. The statistical results of the overlooked KGRAs were compared with the KGRAs currently having power production plants. The results of the statistical analyses were included in a separate manuscript (Lindsey et al., 2017) that is currently being under the review process for publication in *Geothermics*. In this note, we present all data compiled for that statistical work. We also present a brief description for each southern Idaho and southeastern Oregon KGRA/IHRA.

**2. Short descriptions of KGRA/IHRA in southern Idaho and southeastern Oregon**

**2.1. Alvord geothermal area**

The Alvord Basin, a north-northeast-trending graben in southeastern Oregon, is a KGRA with three groups of high (70-95°C) temperature thermal features (Mickey HS., Alvord HS, and Borax Lake). Phillips Geothermal conducted an extensive exploration program in the area in the 1970s, including geochemical surveys, gradient-hole data, AMT and MT surveys, and geologic mapping. An exploration well drilled in 1989 to a depth of 451 m flowed at a rate of 400 gpm with a flowing temperature of 152°C (Cummings et al., 1993). Cation geothermometry using high-temperature spring water compositions indicates subsurface equilibration temperatures of 200-250°C (Nicholson et al., 2004). Studies of fault zone hydrology have shown strong lateral variations in permeability with localized fast paths for fluid flow (Fairley and Hinds, 2004), with mapped faults controlling the distribution of hot springs (Hess et al., 2004). Environmental restrictions have resulted in no additional commercial exploration in this area, but it still serves as a viable site for testing exploration methods.



**Figure 1.** Google Earth map showing distribution of water samples (Table 2) from several southeastern Oregon and southern Idaho KGRAs and control (non-geothermal) area. (Abbreviations used for different KGRAs on the map are SL: Summer Lake, LV: Lakeview, CG: Crump Geyser, Av: Alvord, NHS: Neal Hot Springs, VaHS: Vale Hot Springs, Crc: Crane Creek, VuHS: Vulcan Hot Springs, CaC: Castle Creek, Br: Bruneau, MtH: Mountain Home, CP: Camas Prairie, RR: Raft River, Pr: Preston, and Co: Control area).

**Table 1**. Size of the officially designated KGRAs and IHRAs in southern Idaho and southeastern Oregon (Burkhardt et al., 1980; Williams et al., 2008)

|  |  |
| --- | --- |
| KGRA/IHRA1 | Area (km2) |
| Bruneau (Idaho) | 10.5 |
| Castle Creek (Idaho) | 322.6 |
| Crane Creek (Idaho) | 17.6 |
| Mt. Home (Idaho) | 38.52 |
| Raft River (Idaho) | 122.3 |
| Vulcan Hot Springs (Idaho) | 15.5 |
| Alvord (Oregon) | 715.6 |
| Crump Geyser (Oregon) | 346.7 |
| Lakeview (Oregon) | 49.2 |
| Summer Lake Hot Springs (Oregon) | 39.5 |
| Vale Hot Springs (Oregon) | 93.1 |
| Preston3 (Idaho) | - |
| Camas3 (Idaho) | - |
| Neal Hot Springs3 (Oregon) | - |
| Control area (non-thermal samples) (Idaho) | - |
| 1. Officially designated KGRAs. Some geothermal areas (Camas, Neal Hot Springs, and Preston) included in this study have one or multiple IHRAs.  2. This are only represents the area included in the officially designated Mt. Home KGRA. In this study, we have extended the area further west to Mt. Home Air Force Base.  3. Previously defined as IHRAs but not as KGRAs. Both Preston and Camas areas include multiple IHRAs. | |

**2.2. Bruneau geothermal area**

The geothermal potential of the Bruneau area was first recognized by Piper (1924), and the area was classified as a KGRA for its geothermal resources in the early 1970s (Young and Mitchell, 1973). In subsequent years, additional field studies (Young et al., 1975; Rightmire et al., 1976) were conducted, with multiple water samples obtained from hot springs and wells around Bruneau (and Grand View) area with field temperatures 22-54°C. Most hot springs in the area are linked to northwest trending normal faults. In general, shallow wells that get water from the volcanic-rock aquifer are reported to produce hotter water than wells sourced from the sedimentary aquifer (Young and Whitehead, 1975). Although early assessments (e.g., Young and Mitchell, 1973; Young and Whitehead, 1975; Rightmire et al., 1976) indicated the geothermal potential of the area, with predicted reservoir temperatures reaching up to 190°C, the area failed to entice investors. Since the 1970s, there have been no additional detailed studies carried out in the area.

**2.3. Camas Prairie geothermal area**

Camas Prairie is an east-west elongated (about 50 km by 15 km) valley in Blaine, Camas, and Elmore Counties in south-central Idaho. The prairie is bounded by the Mount Bennett Hills to the south and the Soldier Mountains to the north. The Mount Bennett Hills represents an east-west trending horst that runs parallel to the Camas Prairie. On the south side of Mount Bennett Hills lies the central parts of the Snake River Plain, which is a magmatic region of high heat flow with great potential for significant geothermal resources. Similarly, the Soldier Mountains to the north of Camas Prairie represents a large area of central Idaho with faulted mountains associated with Cretaceous-Miocene magmatic/volcanic activity.

Camas Prairie is filled with sediments and basalt layers over granites/granodiorites of the Cretaceous Idaho Batholith (Garwood et al., 2014). Mitchell (1976) considered this area as a simple depression in the granitic surface of the Idaho Batholith that has been filled in with valley alluvium and colluvium from the hills/mountains on both sides. This structural setting was thought to be supported by outcrops of granite on the northern and southern borders and granite found at a shallow depth beneath alluvium in the center of the prairie (Mitchell, 1976a). However, previously, Smith (1966) referred the basin as a fault-bounded graben. Cluer and Cluer (1986) compiled a suite of geologic and topographic evidence and suggested that the prairie is a result of failed rifting of the area controlled by north-south extensional tectonics. They made an argument for a “Camas Prairie Rift” which was believed to have occurred between 2-5 Ma and lasted for a relatively short time. The loading and down-warping of the Snake River Plain to the south created an extensional regime along the Camas Prairie region that created marginal faulting and development of a rift valley separating the Snake River Plain from the Idaho Batholith region. Subsequently, basalt and sediment layers filled in the rift valley and shaped the present day Camas Prairie.

Although this area was not a designated KGRA, but the occurrence of several clusters of hot springs (IHRAs) within and along the margins of the prairie suggest the presence of geothermal resources in the Camas Prairie (Mitchell, 1976a; Shervais et al., 2017; Neupane et al., 2017). Specifically, five local areas with hot-spring activity are identified as having geothermal potential in the area. The Magic Hot Springs and the Elk Creek Hot Springs areas are located in eastern and northeastern sides of Camas Prairie, whereas the Sheep and Wolf Hot Springs (~50 ºC) are located in western part of Camas Prairie. Another area with geothermal potential is associated with the Wardrop Hot Springs (60 °C) located in the north-central part of the prairie near the base of the Soldier Mountains. The fifth hot springs area in Camas Prairie is represented by the Barron Hot Springs (73 °C) area located on the southern side of the prairie near the base of the Mount Bennett Hills.

**2.4. Castle Creek geothermal area**

The Castle Greek geothermal area is a designated KGRA in Owyhee County in southwestern Idaho (Burkhardt et al., 1980). This area is located west and northwest from Mt. Home and Bruneau geothermal areas, respectively. Most of the geothermal area lies between two small Idaho towns, Grandview to the east and Oreana to the west.

Geographically, the area is located along the southern margins of the western Snake River Plain. The elevation of the area range from 700 m to 1000 m. The area sits along the downthrown side of the NE dipping SE-NW faults. A series of parallel SE-NW striking faults is mapped in the area (Jenks et al., 1998). Furthermore, multiple NE-SW striking faults that intersect the SE-NW faults are also present in the area. Several hot springs and artesian wells are reported from this area (Young et al., 1975; Moore et al., 1979). These geothermal features issue water with field temperatures 23 - 83 ºC.

Miocene rhyolitic rocks are present to the immediate south of the area in Owyhee Mountains. The geothermal area consists of basalt flows underlain by fluvial and lacustrine sediments. Similar rhyolitic volcanic rocks exposed in the Owyhee Mountains are likely present underneath the basalt/sediment layers.

**2.5. Control area (non-thermal)**

The control group of samples represent the Eastern Snake River Plain (ESRP) groundwater. Thick sequences of basalt flows over the rhyolitic ash-flows in the ESRP constitute a very prolific regional aquifer systems. The aquifer rapidly transports cold water from the Yellowstone Plateau and surrounding mountain basins to springs along the Snake River Canyon west of Twin Falls, Idaho (Whitehead, 1992). Specifically, the control samples selected for this study are distributed within the desert site of Idaho National Laboratory in Idaho (Bartholomay and Twining, 2010). These are Ca-HCO3 type water (typical ESRP groundwater; Mcling et al., 2002) with field temperature ranging from 11-16 ºC.

**2.6. Crane Creek geothermal area**

The Crane Creek geothermal area is located about 18 km northeast from Weiser in Washington County, Idaho. This area is located along the northern margins of the western Snake River Plain. Two groups of hot springs are identified in the area: Crane Creek Hot Springs (92 ºC) and Cove Creek Hot Springs (74 ºC).

The Permian and younger volcanic rocks and Cretaceous Idaho batholith granodiorites are believed to be the basement rocks in the area (Moore et al., 1979; Young and Whitehead, 1975). The exposed rocks in the area include the Miocene-Pliocene sediments of Payette Formations, basaltic rocks of the Columbia River Group, and sediments of the Idaho Group. Landslide debris and alluvial deposits make the youngest sediments in the area.

Unlike the regionally positive gravity anomaly of the western Snake River Plain, and particularly, the positive anomaly area to the west of Weiser, the Crane Creek area has a local negative gravity anomaly. Young and Whitehead (1975) mentions that such negative anomaly may have been related to a high-angle interface between rocks of different density. The area lies along a faulted zone that defines the northern margins of the western Snake River Plain. The high density basaltic rocks to the southwest may get thinner or truncate to this area because of the SW dipping fault structures in the area. Long and Kaufmann (1976) conducted reconnaissance audio-magnetotelluric and telluric current soundings of the areas including Crane Creek and Vale KGRAs. Their study indicated low resistivity local zones around both KGRAs.

**2.7. Crump Geyser geothermal area**

The Crump Geyser geothermal area is located in Lake County in southeastern Oregon. It is a designated KGRA which extends from the Crump Lake to the north to Nevada border to the south. The area was known to have hot springs as an expression of geothermal activities. During late 1950s, a well drilled to 513 m to find hot water turned to a perpetual geyser (Crump Geyser) nearby the town of Adel (Peterson, 1959). Following this incident, multiple geothermal exploration works were conducted by USGS, Oregon Department of Geology and Mineral Industries, US DOE, universities, and private industries (e.g., Slotta 1979; Mariner, 1980; Plouff, 2006; Ponce et al., 2009). Recently, US DOE provided funds for further exploration to the area to Nevada Geothermal Power Company. The DOE funded project, ‘the Crump Geyser Exploration and Drilling Project’ completed a high precision geophysics and detailed structural exploration and a slim-hole well drilling (Nevada Geothermal Power Company, 2015).

This geothermal area lies northern part of the Basin and Range Province, and represents a block-faulted valleys and mountains (Peterson, 1959). The entire geothermal area is extended NE-SW along the Warner’s Valley. Geologically, the area is mostly consists of Tertiary volcanic rocks and associated sedimentary rocks. Geologic maps of the area show the presence of older massive basalt layers containing minor tuff and scoria overlain by fine-grained tuffaceous sedimentary rocks and tuffs. The younger units in the area include another sequences of Tertiary basalt flows (Peterson, 1959; Plouff, 2006). Quaternary colluvial, alluvial, and lacustrine sediments constitute the Warner Valley floor (Peterson, 1959).

A series of SE-NW and SW-NE trending faults systems is mapped in the mountain ranges on both sides of the geothermal area. These fault systems are likely continue underneath the Quaternary valley-fill deposits in the Warner Valley. Normal high-angle faults with the SW-NE trends act as range forming faults in the area (Plouff, 2006). The geothermal system of the Crump Geyser area is controlled by faults intersections (Faulds et al., 2011).

**2.8. Lakeview geothermal area**

The Lakeview geothermal area is located in Lake County in southern Oregon. The geothermal area extends from near the northern shore of the Goose Lake to 15 km north from the town of Lakeview. Multiple hot springs and wells (up to 96 ºC) in the area are identified, and several of them are in use for direct applications (Chaisson, 2011). As in the nearby Crump Geyser geothermal area, the Lakeview geothermal area also has two drilled wells that turned to perpetual geysers (Peterson, 1959).

This geothermal area also lies in the northern part of the Basin and Range Province with characteristics of horst and graben structures. The geothermal features (hot springs/wells) are distributed on the eastern margins of the northern Goose Lake Valley (or western base of the Warner Mountains). Geologically, the area consists of late Mesozoic and Tertiary volcanic rocks (Walker, 1963; Brown et al., 1980). Cretaceous volcanic rocks are encountered along the wells at the base of the Warner Mountain whereas outcrops of the Oligocene basalt flows, pyroclastic rocks, and related sedimentary rocks are exposed in the Warner Mountains (Walker, 1963). The youngest sequences include Pliocene-Pleistocene lava flows are mapped at higher elevation outcrops in the Warner Mountains. Quaternary sediments covers the valley areas (Brown et al., 1980).

The range forming faults that mostly extends N-S are the dominant structural features in the area (Brown et al., 1980). A series of SE-NW trending faults is also mapped in the Warner Mountains (Walker, 1963). These faults are shown to intersect or offset the N-S trending range forming fault west of the Warner Mountains. It is likely that these faults continue to the west underneath the quaternary valley fill sediments. The thermally anomalous area coincide with these fault intersections near the town of Lakeview.

**2.9. Mt. Home geothermal area**

This geothermal area is located in the western Snake River Plain in southwestern Idaho covering an area around the town of Mt. Home, Mt. Home Air Force Base, and an expanse of area to the east from Mt. Home. Although the eastern part of the area was a previously designated KGRA (Burkhardt et al., 1980), geothermal potential of western parts of this area (around Mt. Home Air Force Base) was identified by the HOTSPOT drilling project (Shervais et al., 2013). The Bostic-1A well drilled in the late 1970s within the previously designated Mt. Home KGRA indicated the presence of low-permeable but high temperature (~200 ºC) system at a depth of about 3 km (Arney 1982; Arney et al., 1982; 1984). The HOTSPOT MH-2B well at the Mt. Home Air Force Base indicated a permeable zone at a depth of about 1.8 km with a temperature of about 150 ºC. Similarly, multiple hot springs are located along the foot of the Mt. Bennett Hills, several kilometers north from this area.

The western Snake River Plain is a northwest trending fault-bound graben filled with basalt and sediments. The hotspot induced rhyolitic volcanic activities to the south from this area started ca. 11 Ma with extensive blanketing of the Idaho Batholith granodiorites (Shervais et al., 2002). The basaltic volcanic activities in the area began ca. 9 Ma with subsequent deposition of lacustrine sediments (Jenkes and Bonnichsen, 1989). Younger (<2 Ma) basalts cover the lacustrine sediments in the area and expose as surface flows and shield volcanos (Shervais et al., 2002).

**2.10. Neal Hot Springs geothermal area**

The Neal Hot Springs geothermal area is located near Vale in Oregon. Presence of hot (90° C) springs (IHRA) drew attention to the region as a potential site for geothermal development. Initial exploratory activities in the area were conducted by Chevron Minerals in 1979. The bottom-hole temperatures in several production wells are recorded in the Range from 135 to 145 °C (U.S. Geothermal, personal communication). Currently, U.S. Geothermal Inc. operates a net 22 MWe power plant at this site.

Geologically, this area consisted of volcanics and sediments that can be grouped into three units – the middle Miocene Columbia River Basalt Group, middle Miocene Oregon-Idaho graben fillings of silicic and basaltic lavas and volcanoclastic rocks, and the late Miocene-Pliocene western Snake River Plain calc-alkaline lavas, lacustrine, fluvial, and volcanoclastic rocks (Edwards, 2013).

The Neal Hot Springs geothermal area lies along a fault zone potentially developed by the intersection of the Oregon-Idaho graben (representing the northern extremity of the Basin and Range extensional faulting) to the south and the Vale fault zone (an extension of the western Snake River Plain) to the north-northeast (Edwards, 2013). Abundant crustal extension in the region has created anomalously thin continental crust with high heat flow (Colwell, 2013). The Neal Hot Springs geothermal reservoir is assumed to be fault-controlled. Specifically, the area is bound to the east and west by two west-dipping normal faults, Neal and Sugarloaf Butte faults, respectively.

Fluids ascend up Neal Fault and also travel laterally through the Cottonwood Creek Fault, a northwest-striking, concealed low-angle fault that links the Neal and Sugarloaf Butte faults. Production wells intersect the Neal fault or associated relay ramp and stepover faults between 680 and 1900 meters below the surface (Edwards, 2013). Well temperatures range from 135-145°C (U.S. Geothermal, personal communication). The hot springs issue from a north-plunging intersection between the Neal fault and the splay of the east-dipping Horse butte fault. All production wells terminate in the Basalt of Malheur Gorge, a basalt formation correlated with the Columbia River Basalt (Edwards, 2013).

**2.11. Preston geothermal area**

The Preston area (Cache Valley) is a northward trending valley located in southeastern Idaho. It is situated at the confluence of several geologic terrains on the northeastern terminus of the Basin and Range Province where it 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). Although this area was not an officially designated KGRA, it has a couple of IHRAs (Battle Creek Hot Springs and Squaw Hot Springs). Geothermal exploration of the area began in the 1970s with USGS hydrogeologic studies (McGreevy and Bjorklund, 1970; 1971).

The valley is formed by horst complexes, with possible secondary faults flanking the primary high angle normal faults; the interaction of these faults is thought to provide much of the permeability (Wood et al., 2015). Heat is interpreted to be derived from fault-controlled advective flow from mantle-lower crust boundary, typical of geothermal systems in the Basin and Range Province (e.g., Kennedy and van Soest, 2007). Mitchell (1976b) brought attention to a potential geothermal resource in this area with reports of surface expression temperatures ranging from 33°C to 84°C and predicted reservoir temperatures of 85°C to 217°C. Commercial interest arrived in the late 1970’s with the drilling of temperature gradient wells and two deep test wells by Sunoco Energy Development (McIntyre and Koenig, 1978; 1980). The projects were abandoned in the early 1980s despite McIntyre and Koenig (1980) concluding that neither deep well adequately tested the prospect. Interest in the area waned until January 2014 when a 79 m deep well (Bosen Well) encountered a bottom hole temperature of 104°C (Wood et al., 2015). Multicomponent geothermometry suggests reservoir temperatures ranging from 170 to 180°C (Neupane et al., 2016a).

**2.12. Raft River geothermal area**

The Raft River geothermal field is located near Malta in Cassia County in southern Idaho. It is a designated KGRA with the highest measured bottom-hole temperature of 149 ºC (Dolenc et al., 1981). Extensive exploration and development activities conducted by the USGS and the US Department of Energy in the mid to late 1970s and early 1980s has proved the viability of this area to generate commercial electricity using geothermal energy (Dolenc et al., 1981; Ayling and Moore, 2013). Currently, U.S. Geothermal, Inc. operates a 13 MWe geothermal power plant at this site.

The Raft River geothermal system consists of two geologic units – Precambrian basement rocks and unconformably overlying mid-Tertiary to Quaternary sedimentary-volcanic rocks (Devine and Bonnichsen, 1980; Blackett and Kolesar, 1983). The basement rocks include metamorphosed adamellite, schist, and quartzite. The oldest unit in the area is gneissic in texture containing large phenocrysts of feldspars in the groundmass of quartz, biotite, and feldspars. Other basement units include lower and upper Narrows Schist of biotite-chlorite-muscovite with quartz and feldspars with muscovite bearing Elba Quartzite in between them. The Yost Quartzite comprising white quartzite with calcite veins is the youngest basement unit.

The younger rocks consist of a thick (up to 1600 m) Tertiary sequence of rhyolites, tuffs, and fluvial-lacustrine sedimentary rocks (Salt Lake Formation) and non-indurated Pleistocene deposits of quartz sand, silt, and gravels (Raft Formation) (Blackett and Kolesar, 1983). The Salt Lake Formation consists of three members: Upper Tuffaceous Member, Jim Sage Volcanic Member, and Lower Tuffaceous Member (Jones et al., 2011).

Structurally, two major fault systems, the Bridge Fault Zone and the Horse Wells Fault Zone, are identified in the area (Dolenc et al., 1981). These fault systems, most importantly, the Bridge Fault Zone, are presumed to be intersecting a basement shear zone called Narrows Structures and controlling the up flow of the geothermal water (Ayling and Moore, 2013). The reservoir is fracture-controlled; hydrothermal water circulates along fractures in the Precambrian basement and rises through northwest-striking normal faults (Dolenc et al. 1981). Water then permeates fractured Tertiary lacustrine sediments of the Salt Lake Formation and rises up through these fractures towards the surface (Dolenc et al. 1981).

**2.13. Sumer Lake geothermal area**

This geothermal area is located in Lake County in south-central Oregon. Geothermally active area extends from southern shore of Summer Lake to the east to the town of Paisley. A US DOE funded rural cooperative geothermal power plant (binary 2.7 MWe) taps the geothermal resource (at about 115 ºC) in the area with three geothermal wells (Culp et al., 2015).

Geographically, this area is located near the northern edge of the Basin and Range Province, which makes this area having significant geological interactions with the adjoining provinces (e.g, Cascades and High Lava Plains Provinces). Such convergences of geologic provinces has resulted in a high geothermal potential in the areas (Pezzopane and Weldon, 1993; Makovsky et al., 2013; Mink et al., 2015).

Local geology of the area includes mostly volcanic rocks ranging in age from Eocene (?) to Pleistocene (Muntzert, 1969; Makovsky et al., 2013). The oldest (Eocene?) reported unit of the rocks is the thick sequences of dacite flows which is unconformably overlain by Oligocene andesitic sedimentary and pyroclastic rocks. These two units are also intruded by younger plutonic complex. Overlying the Oligocene rocks are the Miocene andesite flows, late Miocence-Pliocene silic (rhyolite to dacite) flows, Pliocene basalt flows, and Pleistocene vesicular basalt flows (Muntzert, 1969). Lowlands east of Paisley also has young valley fill lacustrine and fluvial sediments.

Structurally, the area is characterized by a fault transfer zone associated with the Winter Ridge Fault that begins western side of the area and extends along the western shore of Summer Lake to the north and Paisley Hill Fault that begins eastern side of the area near the town of Paisley and runs to the south. Makovsky et al. (2013) argues that the highly faulted transfer zone makes favorable permeable body of rocks for the geothermal systems in the area.

**2.14. Vale geothermal area**

The Vale geothermal area is located in Malheur County in southeastern Oregon. This geothermal area is characterized by the presence of hot springs (73 ºC) and wells. Wisian et al. (1996) report the maximum recorded subsurface temperature of 143 ºC. Also the area has a long history of direct use of geothermal energy.

This area lies near the western margins of western Snake River Plain that also borders with the Basin and Range and Columbia Plateau. Regionally extensive volcanic activities occurred in the area over the last 5-15 Ma. Specifically, the area was covered by rhyolitic super volcanic ash flows from the south-southeast and basaltic flows (Columbia River Group) from the north-northwest (Wisian et al., 1996). Idaho Group sediments are also present in the area.

Structurally, a swarm of SE-NW extending faults (Vale fault zone, Fern et al., 1993) define the geothermal activities and thermally anomalous area. The local thermal anomalous area coincides with a gravity high, potentially, indicating a buried horst block (Wisian et al., 1996). Audio-magnetotelluric studies (Long and Kaufmann, 1976) also indicated a local low resistivity zones around the Vale KGRAs.

**2.15. Vulcan Hot Springs geothermal area**

The Vulcan Hot Springs geothermal area is located in Valley County in western Idaho, about 30 km NE from Cascade. The geothermal area encompasses a mountainous area with elevation ranging from 1670 to 2120 m. The area is entirely lies within the Cretaceous Idaho Batholith granite/granodiorite unit. Young Quaternary alluvial/glacial deposits occur along the valley of the South Fork of Salmon River (Lewis et al., 2012).

The area is characterized by the presence of hot springs that issue near-boiling water (87 ºC). The hot springs activity in the area seems structurally controlled as such a set of intersecting faults is mapped or indicated by telluric profiles (Moore et al., 1979; Long and Lewis, 1979; Christopherson et al., 1980; Lewis et al., 2012). A north-south fault with an alteration zone is identified by Christopherson et al. (1980). This east dipping fault defines the western side of the South Fork of Salmon River and passes though the hot springs area. The eastern side of the river valley is also defined by a west-dipping fault (Christopherson et al., 1980; Lewis et al., 2012) which intersects with the east-dipping fault few kilometers south from the hot springs area. Moreover, the topographic breakage in the area may indicate a NW dipping fault that intersects the east-dipping fault in the northern vicinity of hot springs area.

**3. Data sources**

The compositions of water samples from numerous geothermal features such as hot springs and wells located in the KGRAs of southern Idaho and southeastern Oregon were assembled from various sources such as past reports of the USGS, states water resources management agencies, conference papers, and journal articles. Specifically, the water compositions for the geothermal features in the southeastern Oregon area were obtained from Mariner et al. (1974), Dellechaie, (1975); Benoit (1976), Nehring and Mariner (1979), Nehring et al. (1979); Brown et al. (1980); Mariner et al. (1980), Culp et al. (2015), and so on. Following data sources were used to assemble water composition data for several KGRAs in southern Idaho: Young and Mitchell (1973), Young et al. (1975); Young and Whitehead (1975), Mitchell (1976a,b), Crosthwaite (1976), Rightmire et al. (1976), Young (1977), Spencer and Russell (1979a,b), Mitchell et al. (1980), Dolenc et al. (1981), Young and Lewis (1982), Lewis and Stone (1988), Young et al. (1990), Freeman (2013), Dobson et al. (2015), Neupane et al. (2016b), Mattson et al. (2016), Neupane et al. (2017), and so on. The compositions of control group samples were obtained from Bartholomay and Twining (2010). Water compositions and other relevant data for thermal as well as non-thermal features used in Lindsey et al. (2017) are given in Table 2.

The structural data, especially, the types and interactions of faults as defined by Faulds et al. (2011), were obtained from various sources (Walker, 1963; Walker and Repenning 1965, Bond, 1978; Brown et al., 1980; Oriel and Platt, 1980; Ferns et al., 1993; Jenks et al., 1998; Bonnichsen and Godchaux, 2006; Lewis et al., 2012; Edwards and Faulds, 2012, Makovsky et al., 2013; Garwood et al., 2014; and various Idaho County-wise geologic maps prepared by Link et al. (2002). The weighting for various structural attributes are based on the percentage values for different fault-interactions that are controlling the geothermal systems in the Basin and Range Province (Faulds et al., 2011). The heat-flow values were obtained from different sources, such as Blackwell et al. (1978), Williams and DeAngelo (2011), Shervais et al. (2016); McClain and Dobson (2016).

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