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Geothermal Play Fairway Analysis, Phase 3: A Provisional Conceptual Model of the Camas Prairie, Snake River Plain, Idaho

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Geothermal Play Fairway Analysis, Phase 3: A Provisional Conceptual Model of the Camas Prairie, Snake River Plain, Idaho

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Keywords

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ABSTRACT

The Snake River Plain (SRP) Geothermal Play Fairway Analysis team identified two regions of interest during Phase 2 studies: the western SRP near Mountain Home, Idaho and Camas Prairie, Idaho. New geological, geochemical, and geophysical (gravity, magnetic, MT, seismic) studies of both areas led to a focus on Camas Prairie for validation during Phase 3. Camas Prairie is an EW-trending half-graben bounded on the north by the Idaho Batholith and on the south by the Mount Bennett Hills. Camas Prairie is bisected by a major NW-trending fault system (The Pothole fault) that separates NW-trending faults to east from ENE-trending faults to the west. The Camas Prairie geothermal system is indicated by warm springs and wells, geophysical evidence of buried faults and basins, mapped faults, elevated $^3He/^4He$ ratios, moderate calculated reservoir temperatures, and the occurrence of young basalt vents and lava flows along the range front. High permeability is suggested by the confluence of intersecting faults, including the range front system and the Pothole fault system, the presence of springs along mapped structural features, and dilational stress along major NW-trending fault systems. Basaltic vents as young as 692 ka along the range front are offset by late Pleistocene faults, indicating relatively recent magmatic flux and tectonic activity. Prolonged heat flux is inferred to result from mid- to shallow crustal sills, similar to those observed farther south. Magnetotelluric studies suggest the presence of a clay seal over the prospective target area that may result in part from hydrothermal alteration. Our model is similar to that proposed for the western SRP but is less energetic due to the smaller volume of magma inferred. It is also similar to Basin-and-Range geothermal systems, but differs by including a distinct magmatic heat component.

1. Introduction

The Camas Prairie is an EW-trending valley located in central Idaho, between the Idaho Batholith and the Mount Bennett Hills (Figure 1). It is bounded on the north by granitoids of the Idaho Batholith, and on the south by the Mount Bennett Hills, a south-dipping horst block with range front faults along its northern margin (Cluer and Cluer, 1986). The Mount Bennett Hills comprise basalt flows overlying rhyolite basement (Wood and Gardner, 1984). Camas Prairie itself is a half-graben, with basin-bounding faults on its southern margin and a gently dipping non-conformity to the north, where sediments overlie granitoids. The basin is filled with poorly sorted Pliocene to Holocene age sediments derived mainly from the Idaho Batholith to the north, interbedded with young volcanic units that flowed northward from eruptive centers in the Mount Bennett Hills, and overlain by clay-rich lacustrine sediments.

Camas Prairie resembles basin-and-range-style extensional systems, with fault-controlled deep crustal hydrothermal circulation, but displays limited direct evidence for major basin-bounding or intra-basin structures. It has elevated heat flow (Blackwell, 1989) and the presence of Quaternary volcanism in the southern part of the basin suggests a magmatic heat source. These data suggest a geothermal system with a mafic heat source similar to that proposed for the Snake River Plain to the south (Nielson and Shervais, 2014).

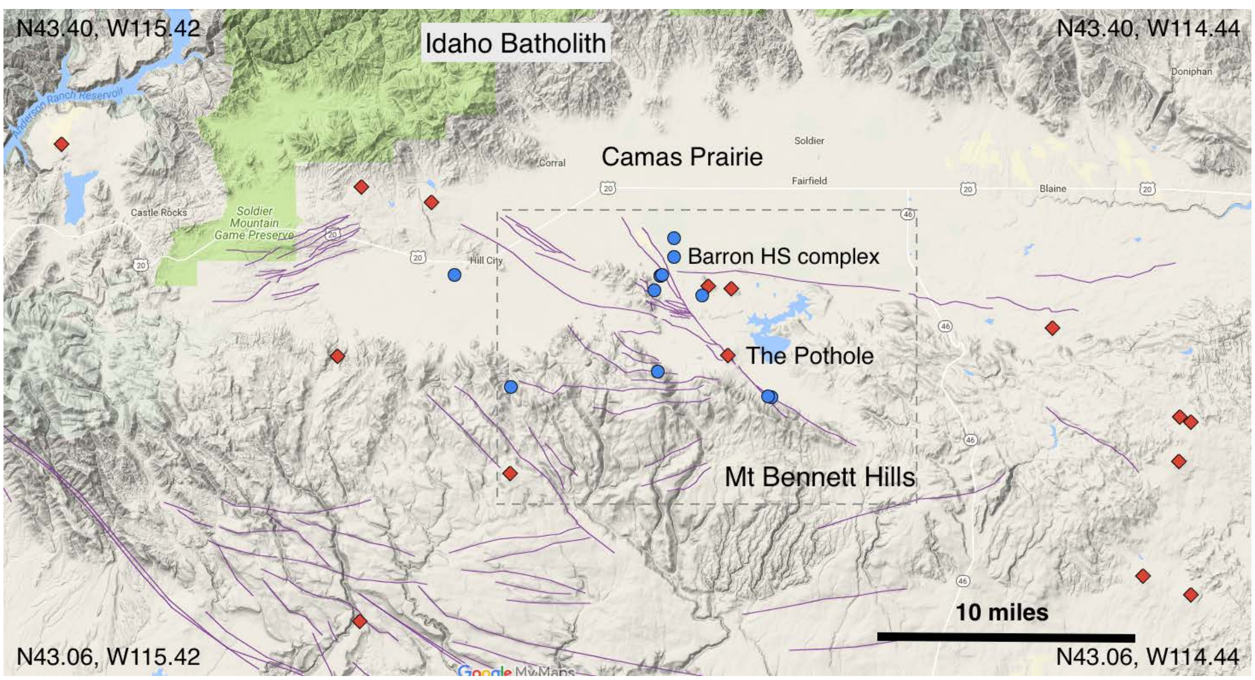

Figure 1. Camas Prairie location map. Red diamonds are basaltic vents, blue dots are springs or wells with geochemical data, purple lines are young faults. Mount Bennett Hills lies to the south and Idaho Batholith to the north. Dashed box shows location of Figure 4.

The Snake River Plain Geothermal Play Fairway Analysis project identified Camas Prairie as a region with a potential commercial resource. This assessment is based on the presence of hot springs and thermal wells, active faults that appear to control the upflow of thermal fluids, and a seal of clay-rich lacustrine sediments (Shervais et al., 2017). We present here a preliminary conceptual model for the Camas Prairie geothermal system based on structural, geochemical, geophysical, and petrologic evidence.

2. Geological Controls

2.1 Structure: Mapped Faults

Camas Prairie and the adjacent Mount Bennett Hills are characterized by four major structural domains: (1) the basin-bounding range front fault system along the northern margin of the Mount Bennett Hills that forms the southern margin of the graben-fill sediments, (2) ENE-trending fault systems in the western Mount Bennett Hills, (3) NW-trending faults of the eastern Mount Bennett Hills, and (4) the Pothole fault system, a major NW-trending fault that separates domains (2) and (3), and has surface expression across much of Camas Prairie. Where the Pothole fault crosses the Prairie, multiple EW-trending splays emanate to the west of the main fault trace. This fault offsets a volcanic feature (The Pothole) that has been dated at 692 ka (Shervais et al., 2018).

Structural mapping of faults and fault intersections along the Pothole fault system included topographically expressed faults along with orientation of polished and striated surfaces that document slip directions. Fault intersections are abundant along the Pothole fault system, e.g., where the NW-trending dextral dip-slip Pothole fault intersects the EW-trending range front faults, creating a series of releasing bends near Barron Hot Springs (Figure 1). Regional stress field data indicate that these NW-trending faults have high dilation tendencies, whereas ENE-trending faults of domain (2) have high slip tendencies.

2.2 Structure: Seismic Reflection Profiles

Active source seismic data were acquired using the Boise State University (BSU) seismic land streamer and accelerated weight drop system that allowed survey rates of 5-km per day at 4-m source spacing. Data were processed and interpreted with industry-standard seismic processing software. Reflectors on cross lines were utilized to map key stratigraphic and structural boundaries. The focus of the seismic profiling effort was to characterize the sedimentary cover, and to identify faults that offset basement *and faults without surface expression*. Seismic results show that sedimentary cover thickens from north to south, with a depocenter about 3 km north of the Mount Bennett Hills. Sediments thin again to the south of the depocenter, with crystalline basement at depths of <1.0 km beneath the southern margin of Camas Prairie. The seismic data also define a complex network of active faults, which progressively offset basin sediment layers, corresponding to locations of elevated groundwater temperatures. These faults offset basement (inferred to be older volcanic and granitic rocks), as well as overlying sedimentary cover. Multiple, basin-wide unconformities are identified with late Quaternary sediment fill of less than 0.2 km along the basin margins.

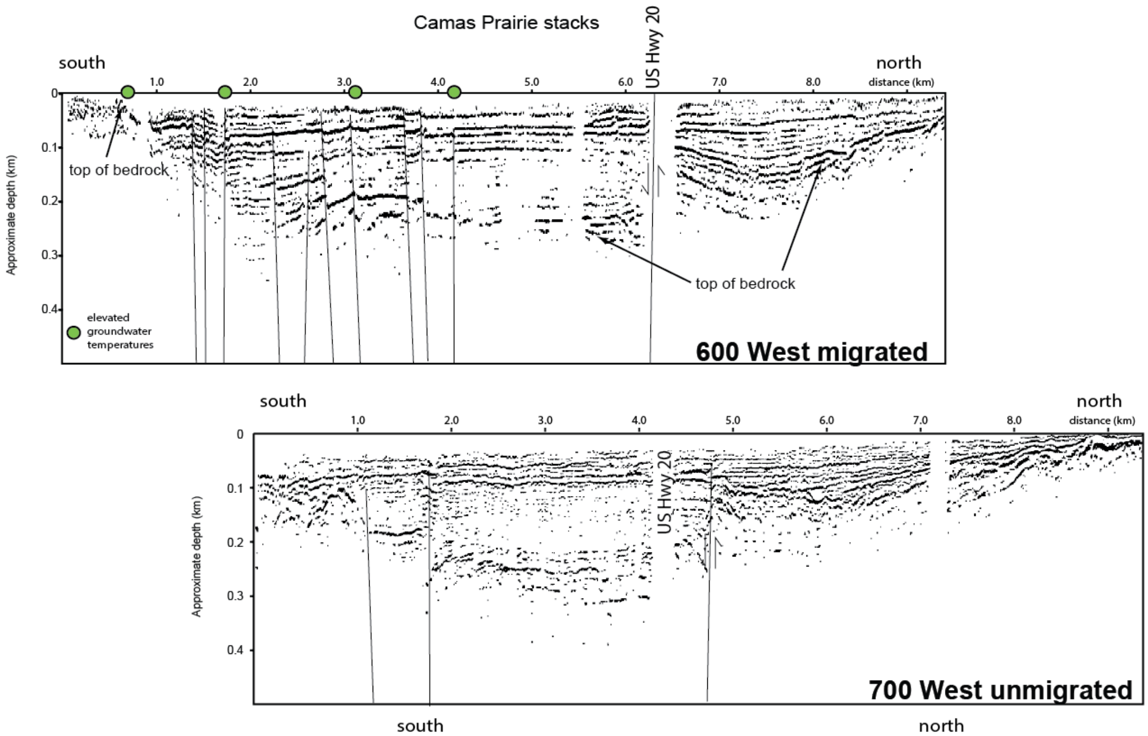

Figure 2. Two active source seismic profiles with south to north orientation that identify depth to basement, offset sediment reflectors, and fault locations. Numerous faults in basement are evident as offsets in highly reflective markers. A major buried EW-trending fault lies under US HW20. The 600W profile shows location of thermal springs and wells (green dots) relative to seismically identified faults. These faults correlate with offsets in gravity and magnetic potential fields, and are being integrated into the overall structural models.

2.3 Structure: Gravity and Magnetic Maximum Gradients

Residual isostatic gravity maps document gravity lows that define several NW-trending sub-basins (Figure 3). The deepest of these inferred sub-basins is located north of Barron's Hot Springs, in an area that is characterized by anomalously high groundwater temperatures. The steep gradient along the SW margin of the gravity low aligns with The Pothole fault system (*structural domain 4*) and appears to be the most structurally active part of the basin. Steep gradients that trend approximately EW to the south are subparallel to the range front fault system (*structural domain 1*). The intersection of these two fault systems may control the location of the hot springs.

Gravity and magnetic maps of the Camas Prairie and surrounding region were processed to identify maximum horizontal gradients that delineate the edges of buried sources such as geologic contacts and faults (Figure 3). There are two dominant trends: EW-trending structures that reflect the major basin-bounding faults, and NW-trending structures co-linear with structural domain 4 that control the major sub-basin geometries. These structures define a deep (500-1000 m), structurally controlled sedimentary basin that displays offset along numerous structures that also appear in the seismic profile. This basin is floored by crystalline basement partially capped with volcanic flows derived from the south. Interbedded volcanic flows are offset along the same structures identified in the seismic profiles, reinforcing the potential field results.

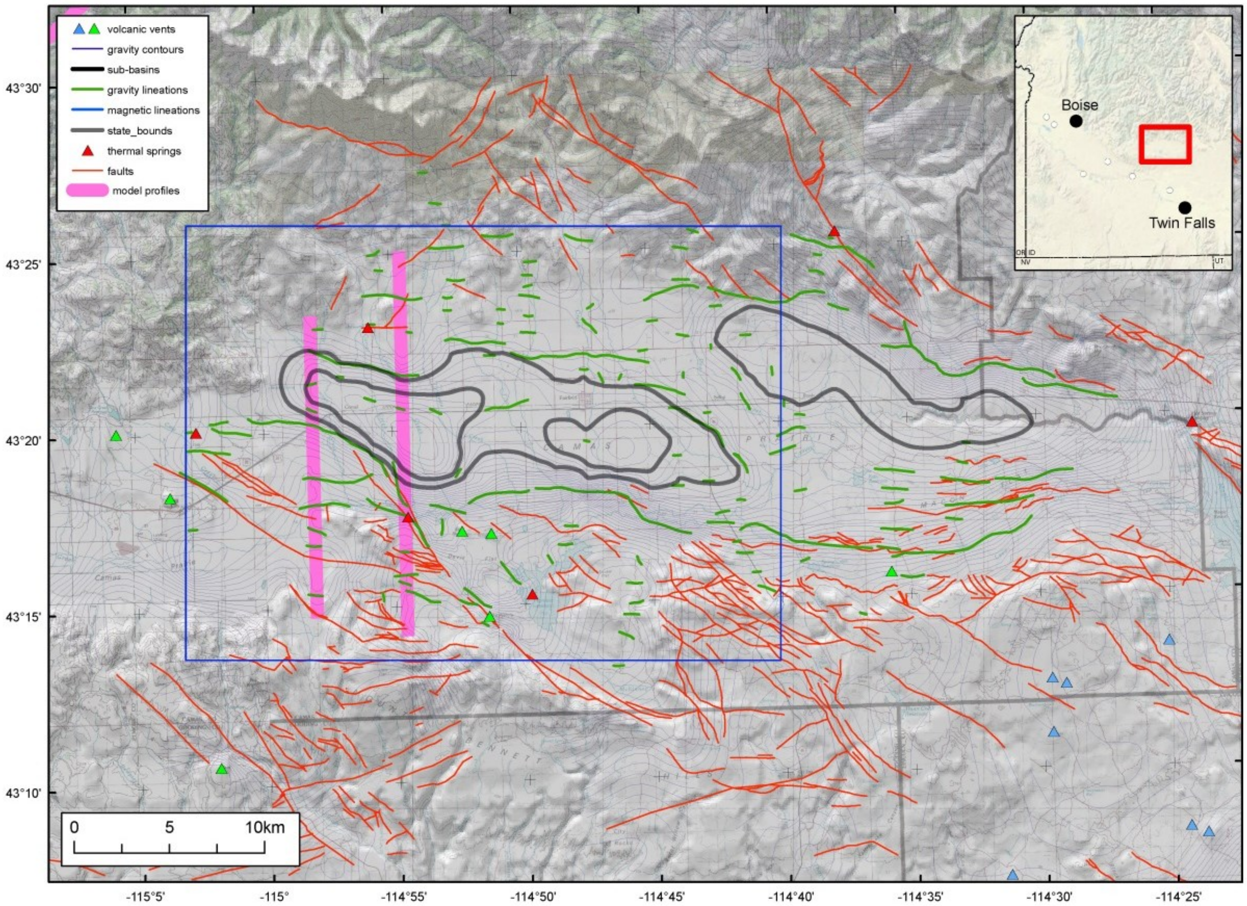

Figure 3. Topographic map of the Camas Prairie study area showing contours of the residual isostatic gravity, volcanic vents, thermal springs, deep drill holes, and profile model locations. Geophysically inferred structural features (gravity lineations) based on maximum horizontal gradients of residual isostatic gravity are shown in green. Faults (red) are derived from a number of sources including Garwood et al. (2014) and new mapping performed as part of this study. Also shown are outlines of sub-basins (thick grey lines) interpreted from the gravity data. Blue triangles indicate young volcanic vents, and magenta lines are seismic transects. (From Glen et al., 2017.)

2.4 Resistivity Anomalies

Magnetotelluric data interpretation documents a low-resistivity structure where the EW-trending basin-bounding faults (*structural domain 1*) intersect the NW-trending Pothole fault system (*structural domain 4*). This structure is interpreted to represent a clay-cap related to hydrothermal alteration of volcanic rock, but may also reflect clay-rich basin sediments (Glen et al., 2018).

3. Hydrologic Controls

3.1 Hot Springs, Cold Springs and Wells

The location of cold springs, hot springs, and former springs (currently dry) are shown in Figure 4. These springs tend to cluster along major structural features, and are especially common where different structures and structural domains intersect, *e.g.,* along the Pothole fault system (*structural domain 4*) where it intersects ENE-trending faults of *structural domain 2* and EW-trending structures of *structural domain 1* and its geophysically inferred cohorts.

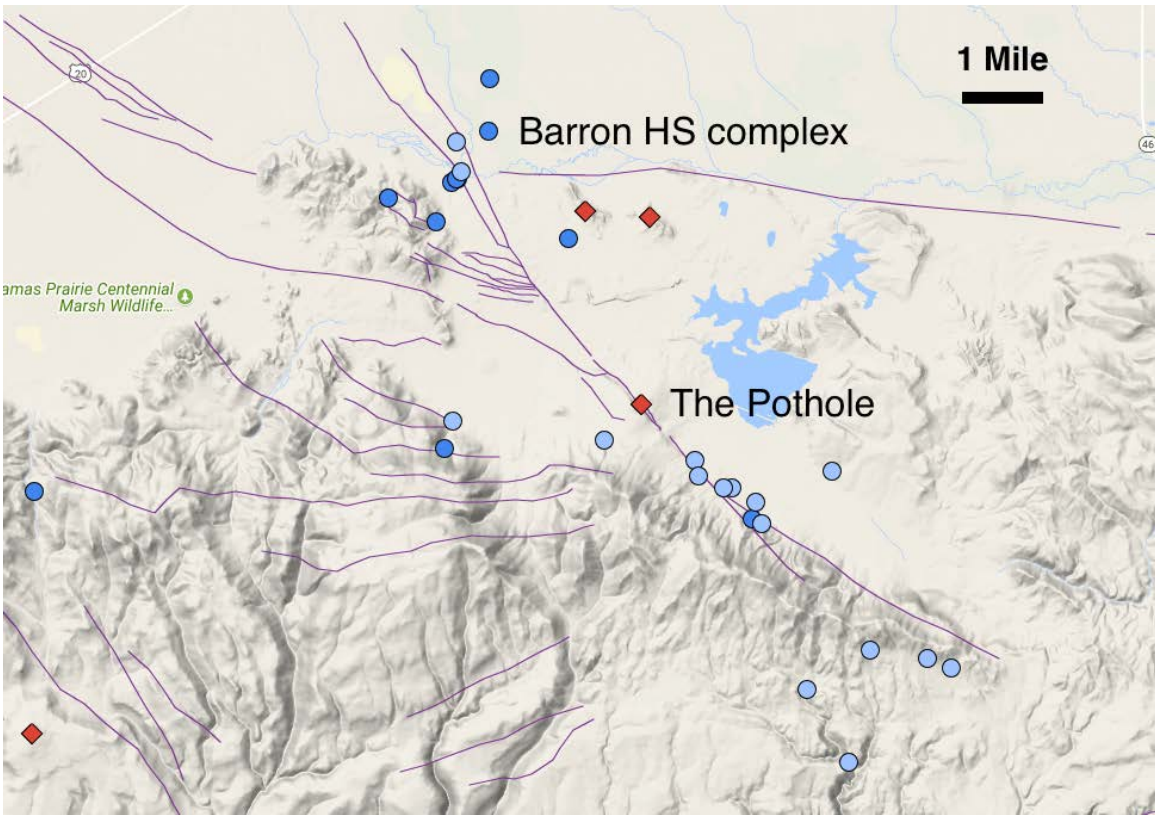

Figure 4. Location of hot springs, cold springs, and wells on southern margin of Camas Prairie. Dark blue dots: Sampled; light blue dots: Dry. Red diamonds are basalt vents, purple lines are faults. Barron HS complex lies at nexus of range front and Pothole fault systems. See Figure 1 for location.

3.2 Water Chemistry

Water samples collected from springs and water wells were analyzed for major and trace elements (Neupane et al., 2017). Hot spring and thermal well samples are largely Na-HCO_3-type waters, whereas cooler groundwater and spring waters are Ca, Mg-HCO_3-type. A mixing trend is observed between Ca, Mg-HCO_3 and Na-HCO_3 water types. In general, water chemistry and isotopic compositions indicate that hydrothermal waters in Camas Prairie area are dominantly meteoric in origin with some modification from water-rock interaction at elevated temperature (Neupane et al., 2017).

Equilibrium reservoir temperatures calculated using cation, silica, and multi-component geothermometry show that springs on the northern margin of Camas Prairie, associated with the Idaho Batholith, have an estimated reservoir temperature as high as 200ºC, whereas waters analyzed from the southern margin of Camas Prairie yield estimated reservoir temperatures of about 110ºC (Neupane et al., 2017).

3.3 He isotopes

Neupane et al. (2017) document elevated helium $^3He/^4He$ isotope ratios (~2 R_A) in geothermal fluids found along the Pothole fault system adjacent to the Mount Bennett Hills, indicating high flux of mantle-derived volatiles. These isotopic compositions suggest a system with magmatic input, and indicate high permeability on a crustal scale.

4.0 Preliminary Conceptual Model

4.1 Structural Model

Faulds et al. (2013) has shown that most geothermal prospects in the Basin-and-Range province are found in complex structural zones, e.g., fault intersections, step-overs, transfer zones, and splays. In the Camas Prairie, hot springs are most common along the Pothole fault system (*structural domain 4*), where it forms oblique intersections with numerous small faults to the south and west (*structural domain 2*), and with the EW-trending range-front fault system (*structural domain 1*), creating a series of releasing bends with enhanced permeability that may focus fluid upflow along the main Pothole fault structure (Figure 5). These surface structures are further reinforced by geophysically-inferred structures that offset basement and form a series of elongate sub-basins beneath the Prairie. Regional stress field data indicate that the NW-trending faults (*structural domain 4*) have high dilation tendencies, whereas NE-trending faults found SW of the Pothole system (*structural domain 2*) have high slip tendencies. The intersection of the Pothole fault system (*structural domain 4*) with the ~EW-trending range front fault system (*structural domain 1*) creates a high permeability zone marked by the location of Barron Hot Springs (Figure 5). The Pothole fault cuts the Pothole basalt flow that was dated at 692 ka, suggesting it is a young, potentially active fault.

4.2 Heat Model

We infer that the heat source for Camas Prairie is a sill or dike complex related to young volcanic activity, similar to that inferred for the Snake River Plain (Nielson and Shervais, 2014). In this model, intrusion of the basaltic sill complex is driven by a magma supply rate that exceeds the extension rate of crustal deformation, leading to a build-up of heat that drives geothermal circulation (Nielson and Shervais, 2014; Nielson et al., 2017). Volcanic vents are not common but they cluster along the southern margin of the Prairie. The youngest documented vent is the Pothole (692 ka) and the oldest is the Macon Flat basalt (1.45 Ma; Garwood et al., 2014).

Heat flow is >100 mW/m^2 throughout Camas Prairie, similar to heat flow beneath the Snake River Plain (Blackwell and Richards, 2004). Elevated helium isotope ratios in groundwater indicate a significant mantle-derived volatile flux that may be associated with young magmatism, as well as relatively high crustal permeability that must extend to depth (e.g., Kennedy and van Soest, 2007). The presence of mantle He, Pleistocene basalt, and a low resistivity clay cap distinguish this thermal system from potential outflow from the Idaho Batholith system to the north.

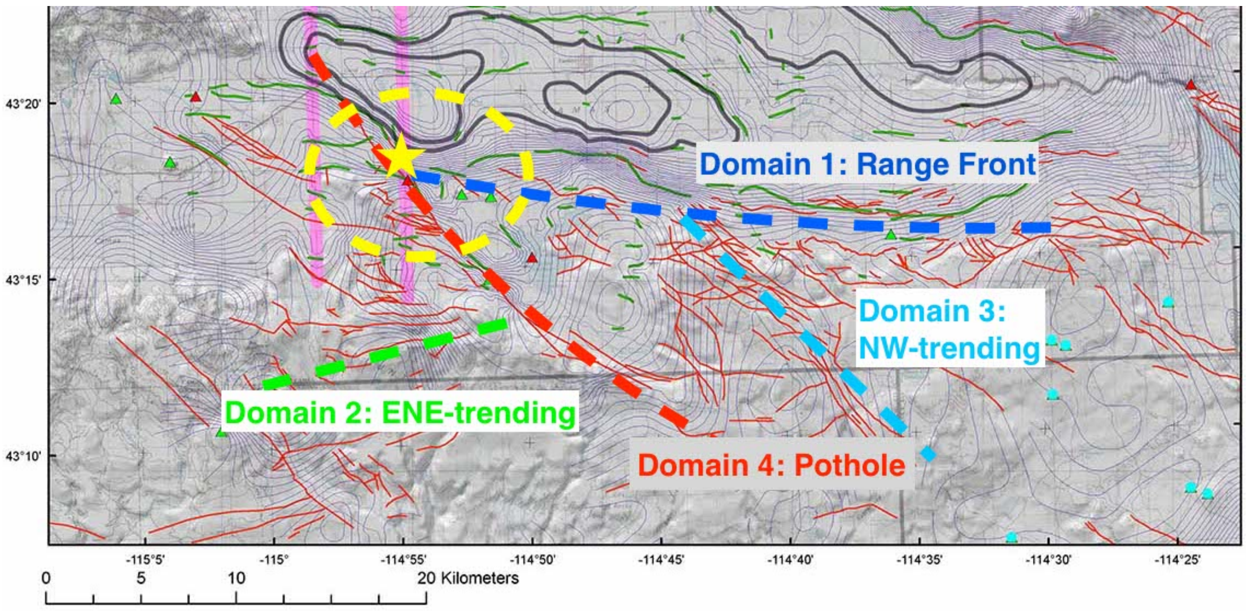

Figure 5. Structural domains superimposed on fault map. Domain 1 (dark blue) Range front faults; Domain 2 (green): ENE-trending faults in Mt Bennett Hills; Domain 3 (light blue): NW-trending faults in MBH; Domain 4 (red): The Pothole fault system. Yellow circle shows intersection of Domains 1, 2, and 4; yellow star is potential drill site. Base map is gravity contours on hillshade topography (from Glen et al., 2017).

4.3 Seal

Camas Prairie appears to have two seal types: (1) a 30 m thick clay layer (lacustrine sediments) seen in water well logs that underlies much of the southern part of the prairie; and (2) a clay cap seal that appears to be associated with hydrothermal alteration and inferred from the MT data, that centers around the Pothole fault system near its intersection with the range front fault system, and the cluster of WNW-trending faults that splay off from it (Glen et al., 2017).

5. Summary and Conclusions

The ultimate heat source for geothermal systems in the southern part of Camas Prairie is a mid- to upper-crustal basaltic sill complex similar to that thought to underlie the adjacent Snake River Plain (e.g., Shervais et al., 2006). Basaltic systems in which the rate of magma supply exceeds the rate of crustal extension may accumulate magma in crustal sills (rather than dikes, which lose heat rapidly to their wall rock, Nielson et al. (2017)). Heat accumulates over time and may be sufficient to support a geothermal system. Intersecting fault systems provide pathways for the deep circulation of meteoric water.

The most effective fault systems in Camas Prairie are The Pothole fault system (*structural domain 4*) and its intersections with the range front system (*structural domain 1*) along the northern edge of the Mount Bennett Hills, where WNW-trending faults are observed to splay off of the Pothole system north of the range front (Figure 5). NW-trending faults have high dilation tendencies, and the abundant intersections provide enhanced permeability for fluid flow. Fine-grained lacustrine sediments (regional in extent) and a hydrothermally-altered clay cap provide an effective seal to the Camas geothermal system.

Our plan is to drill a 700 m (~2000 ft) test well into a permeable structure, collecting core in the lower part of the well. If successful we will perform a suite of reservoir tests and down-hole geophysical logs to characterize the system and document reservoir characteristics. The location of this well will be along The Pothole fault system near the range front of the Mount Bennett Hills. Our goal is to confirm a low-temperature resource similar to other low-temperature systems that have proved to be economically viable, such as the Don A. Campbell (also known as the Deadhorse Wells or Wild Rose system) field in Nevada and the Paisley field in Oregon (e.g., Orenstein et al., 2015; Mink et al., 2015).

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