The Geology, Geochemistry, and Geohydrology of the FORGE Deep Well Site, Milford, Utah

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Keywords: EGS, geology, geochemistry, mineralogy, faulting, hydrology, Basin and Range

ABSTRACT

The Milford FORGE deep well site is located 5 km west of the Roosevelt Hot Springs, on alluvial fan deposits (200-600 m thick) that overlie a large volume of hot crystalline basement rock. The site occurs within a region that is geologically complex and characterized by extensional faulting, sporadic magmatism, and zones of anomalously high heat flow, inside the southeast margin of the Great Basin.

The basement rocks at the FORGE deep well site are made up of Precambrian gneiss and Tertiary plutons. These crystalline units are exposed across the eastern part of the Milford Valley basin, from the Mineral Mountains in the east to the Acord-1 well in the west, and they are separated by intrusive and fault contacts. Gneiss contains biotite, hornblende, K-feldspar, plagioclase, quartz, and sillimanite, and isotopic dating indicates Proterozoic metamorphism ~1720 Ma. Plutonic rocks comprise diorite, granodiorite, quartz monzanite, syenite, and granite, containing variable amounts of biotite, clinopyroxene, hornblende, K-feldspar, magnetite-ilmentite, plagioclase, and quartz. The oldest intrusion was emplaced ~25 Ma followed by younger intrusion events at ~18 Ma and 11 to 8 Ma.

Hydrothermal alteration is widespread, but weak, and it is made up of quartz, illite, chlorite, mixed-layered clays, epidote, leuxcoene, hematite, calcite, anhydrite, and K-feldspar, which partly replace precursor minerals or deposited into open spaces. Temperature-sensitive phases lack well-defined depth zonation, which suggest that most of the alteration formed during earlier periods of hydrothermal activity associated with Tertiary magmatism. Modern hydrothermal activity is responsible for steam-heated acid alteration in the vicinity of fumaroles and steaming ground north of the Negro Mag fault, and silica sinter deposition along the Opal Mound fault.

High angle normal faults formed from east-west Basin and Range extension, but listric sliding and block rotation also produced low angle structures characterized by narrow zones of cataclasis in crystalline rocks. The Opal Mound fault is a prominent high-angle fault that dips east and offsets surficial deposits of alluvium and silica sinter, forming a hydrological barrier to lateral fluid flow. Additional north-south trending normal faults, which are blind to the surface, are likely to occur in basement rocks to the west beneath the alluvial cover. The Negro Mag fault is high-angle too, but it trends east-west, cutting across the Mineral Mountains. Lineament analysis and field mapping show that the crystalline rocks exposed in the Mineral Mountains host a fault-fracture mesh, characterized by relatively dense joint spacing, with fractures oriented in many different directions. Such fractures could play an important role in stimulating new permeability beneath the FORGE deep well site.

The groundwater regime across the FORGE deep well site is controlled by the west sloping potentiometric surface and an unconfined aquifer hosted in alluvial gravels. Geochemical data trace shallow hydrothermal outflow to the northwest and west, consistent with temperature profiles in gradient wells. The groundwater is chemically benign, non-potable, and suitable for EGS heat transfer experiments.

1. INTRODUCTION

The Milford FORGE deep well site (Fig. 1) is located 350 km south of Salt Lake City and 16 km north northeast of Milford, Utah, in an unpopulated area that is predominantly used for renewable energy (wind, solar, geothermal). It is situated on a west sloping alluvial fan in the North Milford valley, about halfway between the crest of the Mineral Mountains to the east and the Beaver River to the west. The deep well site covers about 1.5 km^2 and lies 5 km west-northwest of the Blundell geothermal power plant, which produces 35 MWe from flash and binary units.

This paper represents a review of geoscientific data pertaining to the geology, geochemistry, and hydrology of the FORGE site, which has been acquired over a period spanning 40 years. Much of this is the product of exploration and development of the Roosevelt Hot Springs KGRA. However, Roosevelt Hot Springs represents only a small part of a large area associated with anomalous heat flow, and the area to the west of the Opal Mound fault has long attracted interest in terms of EGS research and development (e.g. East, 1981; Goff and Decker, 1983). As a result, data are available from numerous field surveys and the drilling of many shallow and deep wells, including Acord-1, a 3.8 km deep well. These form the foundation for a 3D understanding the rock types, fault-fracture patterns, thermal structure, hydrology, and fluid types that make up the reservoir of the proposed FORGE laboratory. Companion papers by Allis et al (2016) and Hardwick et al (2016) summarize the physical attributes, including temperature and pressure regime and the basin structure based on gravity data.
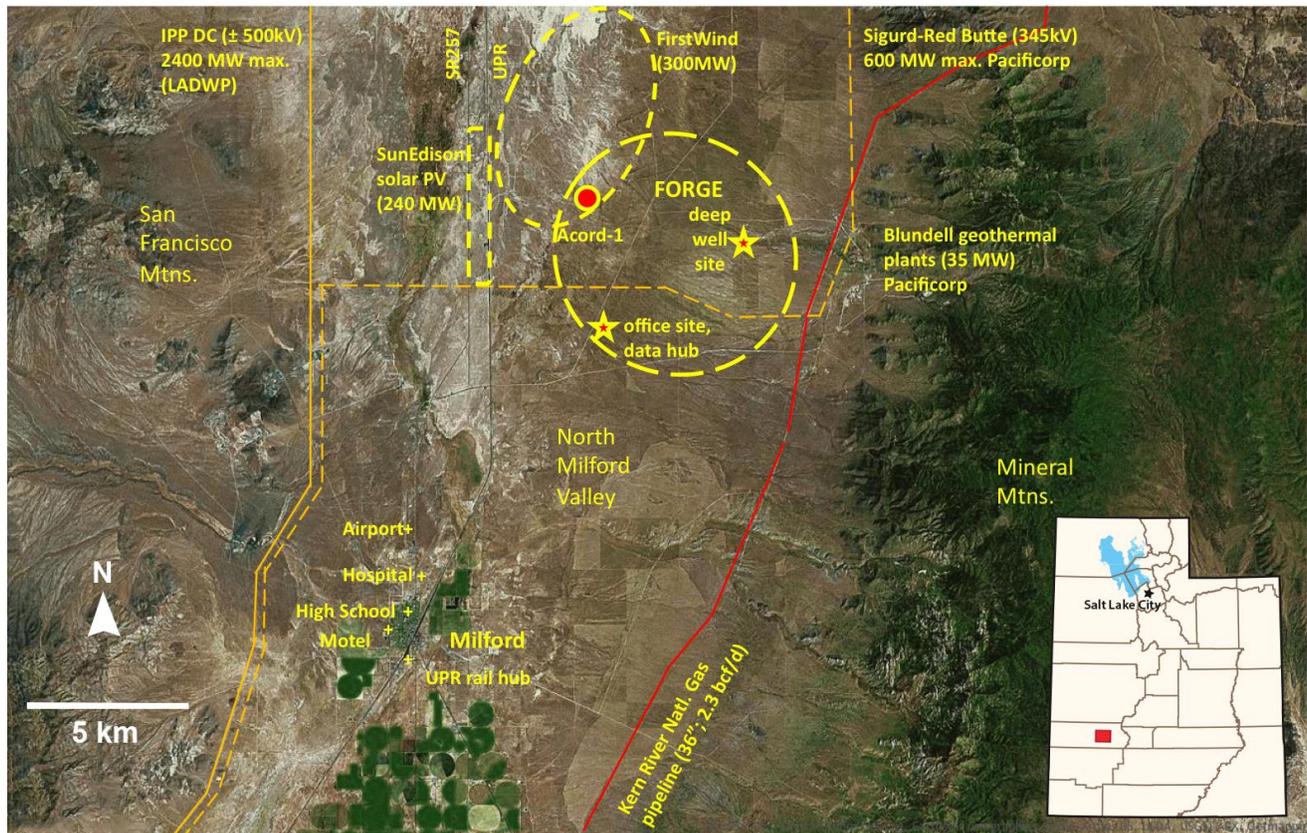
Figure 1: Location of the FORGE deep well site near Milford, Utah, showing infrastructure and physiography (Allis et al., 2016).

2. GEOLOGIC SETTING

The Milford FORGE site (Fig. 1) is located within a geologically complex zone that lies inside the southeast margin of the Great Basin and abuts the western edge of the Colorado Plateau (e.g., Wannamaker et al., 2001). Regional features include folded and imbricated Paleozoic-Mesozoic strata of the late Jurassic through Eocene Sevier orogeny, volcanic and intrusive centers resulting from Tertiary arc magmatism, detachment faulting associated with regional extension, tilting and exhumation of core complexes, and north-south trending normal faults resulting from Basin and Range extension (e.g., Dickinson, 2006; Anders et al., 2012). The zone also includes three producing geothermal fields, Cove Fort-Sulphurdale, Roosevelt Hot Springs, and Thermo Hot Springs, which are associated with young extensional faults, centers of Quaternary basalt-rhyolite magmatism, and large areas of anomalous heat flow covering >100 km^2 (e.g., Mabey and Budding, 1987; Blackett, 2007; Kirby, 2012; Simmons et al., 2015; Wannamaker et al., 2015). The FORGE deep well site lies within an area of anomalous conductive heat flow that extends west from the Opal Mound fault, outside the western boundary of the Roosevelt hydrothermal system (Allis et al., 2016).

3. LITHOLOGY AND MINERALOGY

The main rock types associated with the FORGE deep well site are crystalline basement rocks made up of Precambrian gneiss and Tertiary plutons, Tertiary basin-fill composed of volcanic strata, and Quaternary basin fill made of fluvial-lacustrine sedimentary deposits. The occurrence and distribution of these units is known from field mapping and petrographic studies of cuttings and cores mainly from four wells, 14-2, 52-2, 9-1, and Acord-1 (Figs. 2, 3 and 4; Glen and Hulen, 1978; Glenn et al., 1980; Sweeny, 1980; Welsh, 1980; Nielson et al., 1986; Coleman and Walker, 1992; Coleman et al., 1997; Hintze and Davis, 2003). Gravity data constrain the west sloping contact that separates underlying crystalline rocks, gneiss and granite, from overlying volcanic deposits and fluvial-lacustrine basin fill (Fig. 3; Hardwick et al., 2016). There is no evidence of any Paleozoic-Mesozoic strata in the vicinity of the deep well site, despite being a major component of the regional stratigraphy and exposed in the southern and northern parts of the Mineral Mountains (Nielson et al., 1986).

Precambrian gneiss is the oldest rock type, and outcrops occur sporadically at lowest elevations in the western Mineral Mountains, and it was penetrated in wells (Figs. 2 and 4). Both banded and massive varieties of gneiss exist. Segregations of quartz-K-feldspar form the light bands, whereas biotite-plagioclase-quartz-hornblende-K-feldspar form the dark bands (Glenn et al., 1980). Sillimanite occurs in outcrops. These minerals form an interlocking texture, and planes or zones of weakness, appear to be absent. U-Pb dating of accessory zircons gives an age of 1720 Ma, consistent with a model Rb/Sr whole-rock isochron of 1750 Ma, indicating early Proterozoic metamorphism (Aleinikoff et al., 1987).
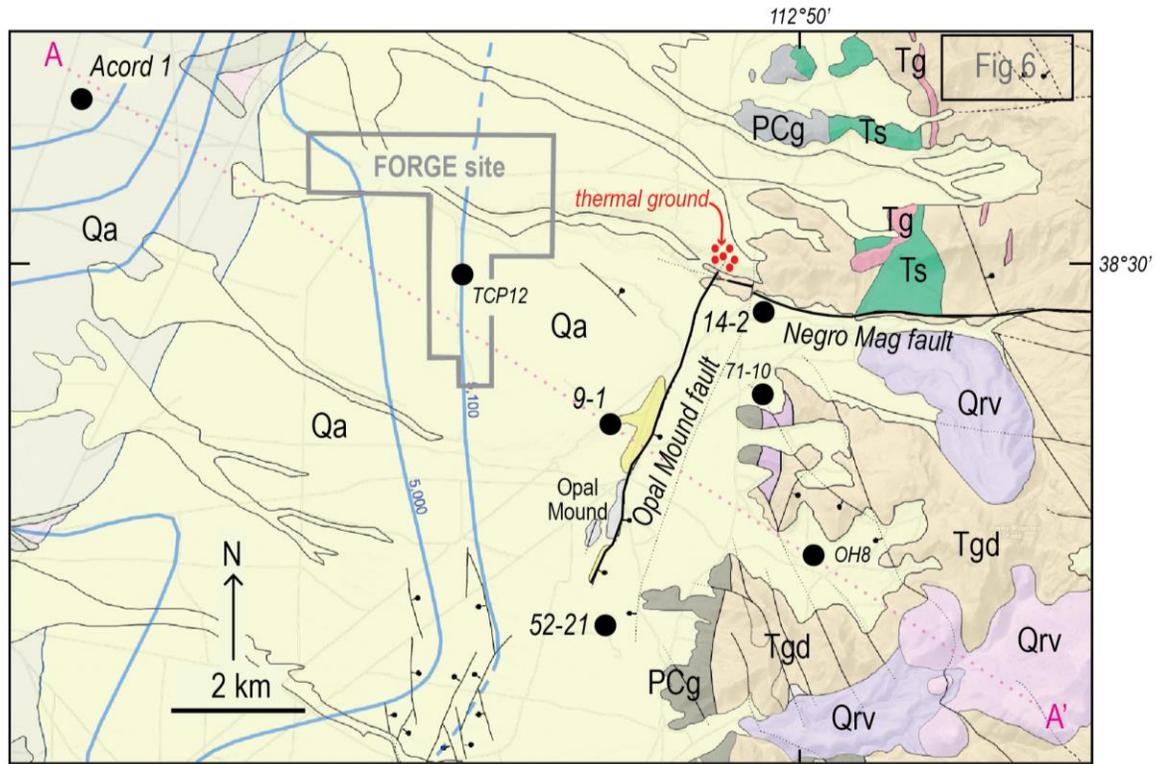
Figure 2: Geologic map of the FORGE deep well site, Milford, Utah (Hintze et al., 2003; Rowley et al., 2005; Kirby, 2012). For clarity, only a few of the many wells are shown. Blue lines represent the elevation (feet above sea level) of the groundwater potentiometric surface. Abbreviations for map units: Qa=Quaternary alluvium and claystone; Qrv=Quaternary rhyolite volcanic rock; Tgd=Tertiary granodiorite; Tg=Tertiary granite dike; Ts=Tertiary syenite; PCg=Precambrian gneiss. Inset outline in upper right corner shows the area represented in Figure 6.
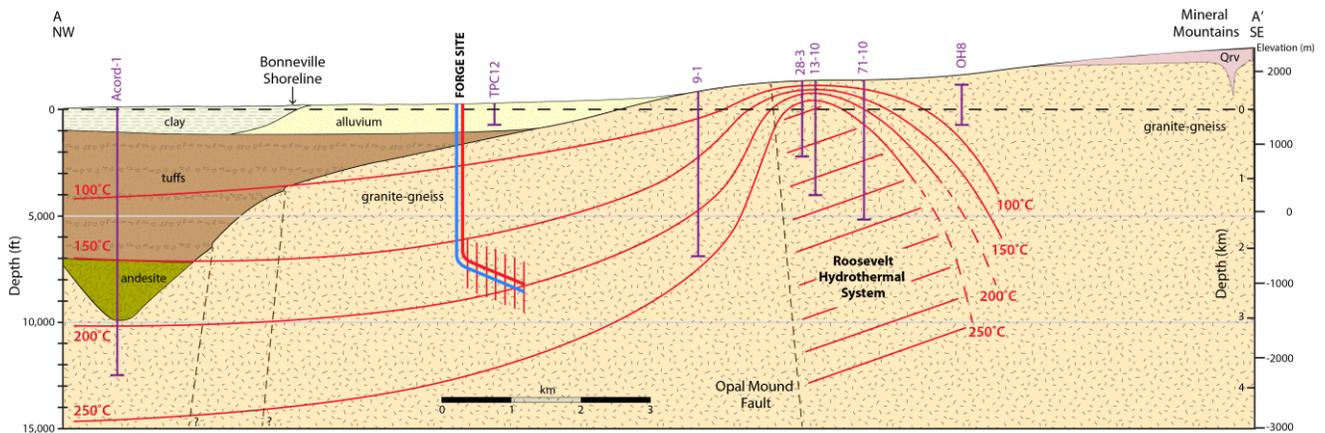

Figure 3: Geologic cross section A-A' from Figure 2, showing the stratigraphy, structure, and the FORGE deep well site. The zero datum for the depth axes is at 1524 m asl (5000 ft asl). Precambrian gneiss and Tertiary plutonic rocks are undifferentiated. The Roosevelt Hot Springs hydrothermal system lies east of the Opal Mound fault. Isotherms are interpreted from well measurements, and the contact between granite-gneiss and overlying basin fill is interpreted from gravity measurements (Allis et al., 2016; Hardwick et al., 2016).
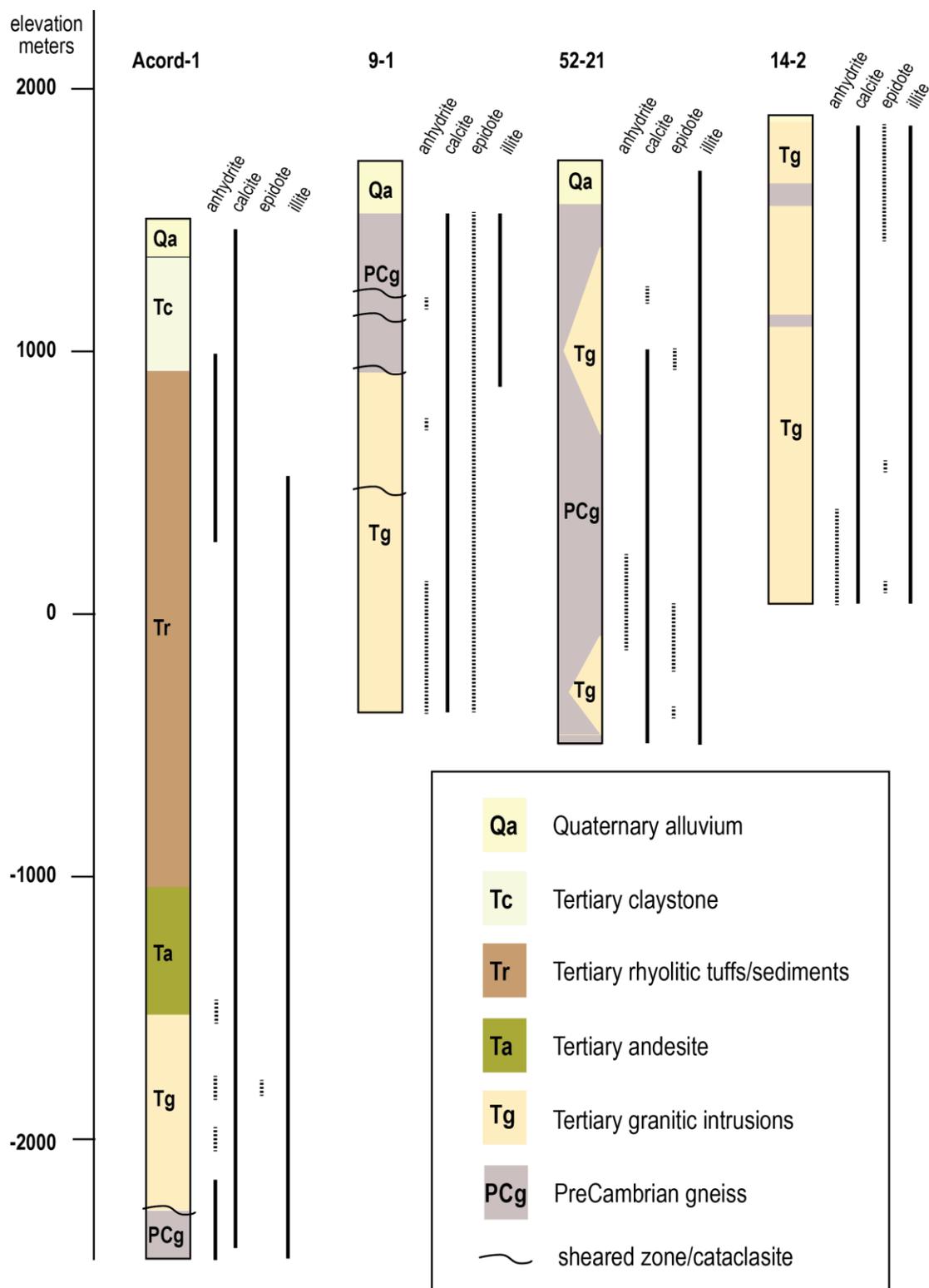
Figure 4: Stratigraphic logs for four deep wells in the study area surrounding the FORGE deep well site, Milford, Utah. Vertical intervals of hydrothermal anhydrite, calcite, epidote and illite (sericite) are based on petrography and XRD analyses. Sources of data: Acord-1 (Sweeney, 1980; Welch, 1980; Hintze and Davis, 2003); 9-1 (Glenn et al., 1980; Capuano and Cole 1982); 52-21 and 14-2 (Glenn and Hulen, 1979; Capuano and Cole 1982). Precambrian gneiss and Tertiary plutons are separated by contacts resulting from magmatic intrusion and faulting. All of the other major breaks in rock types are marked by unconformities.

Plutonic rocks of Oligocene-Miocene age form the core of the Mineral Mountains and the reservoir host rock in the Roosevelt Hot Springs system (Nielson et al., 1986), and these rocks extend to the west beneath the basin fill to the Acord-1 well (Figs. 2 and 4). The intrusions range from intermediate to felsic composition, but the outcrops east of the Roosevelt Hot Springs area mainly expose medium to coarse-grained hornblende granodiorite (Nielson et al., 1986; Coleman and Walker, 1992). Drill cuttings from well 9-1 confirm a spectrum of intrusive-types, including diorite, granodiorite, quartz monzanite, syenite, and granite; these phases are made up of variable amounts of plagioclase, hornblende, biotite, clinopyroxene, quartz, K-feldspar, magnetite-ilmentite, and accessory titanite, rutile, apatite, and zircon (Glenn et al., 1980). The oldest intrusion is associated with crystallization and emplacement of the hornblende diorite, and it has a U-Pb zircon date of 25±4 Ma (Aleinikoff et al., 1987); younger intrusion events followed at ~18 Ma and 11 to 8 Ma (Nielson et al., 1986; Coleman and Walker, 1992; Walker et al., 1997).

Tertiary volcanic rocks crop out sporadically through the Mineral Mountains, and cover large areas in the adjacent ranges, including the Tushar Mountains to the east and the Star Range to the west (e.g., Nielson et al., 1986; Coleman et al., 1997; Hintze and Davis, 2003). The thick sequence of volcanic strata (~1500 m) penetrated by the Acord-1 well (Fig. 4) is divided into a thick upper group made of felsic tuffs and flows, and a lower group made of andesite lavas (Sweeney, 1980; Welch, 1980). Quaternary volcanic rocks occur in the central part of the Mineral Mountains, representing small volume eruptions, obsidian flows and pyroclastic deposits (0.8-0.5 Ma), including the prominent Bailey Ridge flow (~6 km^2) near Roosevelt Hot Springs (Lipman et al., 1978).

Young unconsolidated basin fill covers the floor of Milford Valley. These deposits consist of alluvial and lacustrine deposits that contain interbedded sand, silt, gravel, and clay (Hintze and Davis, 2003). In Acord-1, unconsolidated basin fill has a thickness of >1000 m and spans from Recent to late Tertiary in age. Within the vicinity of the FORGE deep well site, these deposits are 200 to 600 m thick, poorly consolidated, and made up of quartzo-feldspathic alluvial fans shed off the Mineral Mountains. Point bar deposits to the west lap on to the fan deposits and mark the high-stand of Lake Bonneville 18,000 years ago .

Petrographic and XRD analysis of drill cutting indicate widespread occurrences of minor amounts of hydrothermal minerals (Fig. 4), comprising quartz, illite, chlorite, mixed-layered clays, epidote, leuxcoene, hematite, calcite, anhydrite, and K-feldspar (Glenn and Hulen, 1978; Glenn et al., 1980; Sweeney, 1980; Nielson et al., 1986,; this study). Locally, hydrothermal alteration is concentrated around narrow zones of cataclasis, characterized by comminuted rock flour, streaky foliation, and micro-veining (e.g., well 9-1; Glenn et al., 1980). Quartz, chlorite, illite, calcite, epidote and anhydrite, replace precursor phases and fill open spaces, but they lack well-defined depth zonation (Fig. 4; Capuano and Cole, 1982). A number of small prospect pits expose weakly developed hydrothermal Cu-Mo-W mineralization in granitic rocks of the central Mineral Mountains (Nielson et al., 1986). These occurrences suggest that most of the alteration formed during ancient periods of hydrothermal activity that date back to the Miocene and episodes of Tertiary magmatism.

Mineralogical products of modern hydrothermal activity occur along and east of the Opal Mound fault. In the northern part of the Roosevelt Hot Springs area, quartz, alunite, kaolinite, and hematite are products of steam-heated acid alteration in the vicinity of fumaroles and steaming ground (Parry et al., 1980). In the south, a thick deposit (>3 m) of colloform banded sinter makes up the Opal Mound. A subvertical north-south trending fissure (~0.5 m wide) filled with banded silica forms the main vent and marks the Opal Mound fault. Two radiocarbon dates indicate the sinter deposited between 1600 and 1900 years BP (Lynne et al., 2005). Although the site is no longer thermally active, a significant volume of hot near neutral pH chloride water discharged here, similar in composition to modern produced reservoir waters that feed the Blundell-Roosevelt geothermal plant. The hot water flow to the surface likely ceased due to silica deposition in combination with lowering of the water table. Today the Opal Mound Fault represents the western edge of the hydrothermal system and mineral sealing may have played a role in creating a barrier to flow.

4. FAULTS & LINEAMENTS

Three separate types of faults have been identified in the study area, and they are products of two distinct tectonic events that include late Mesozoic-early Cenozoic compression during the Sevier orogeny and middle Tertiary to Recent extension. The Sevier orogeny produced large-scale horizontal displacements and low angle thrust faults (e.g., Hintze and Davis, 2003). Examples of these are exposed in the northern and eastern part of the Mineral Mountains. The original dip of these structures may have been steepened through rotation associated with uplift and exhumation of the Miocene plutonic complex (Nielson et al., 1986).

The younger faulting episode is related to ongoing east-west Basin and Range extension, which dates back at least ~17 Ma, producing predominantly north-south trending fault zones that bound basins and range fronts (e.g., Hintze and Davis, 2003; Dickinson, 2006). In the region surrounding the FORGE deep well site and the Mineral Mountains, both older low-angle faults and younger high-angle faults exist (Nielson et al., 1986; Hintze and Davis, 2003). The Cave Creek fault in the southern part of the Mineral Mountains dips 20° west, and it is associated with a 200 m thick zone of cataclasite, which is developed mainly in the underlying 18 Ma pluton (Nielson et al., 1986; Coleman and Walker, 1994; Coleman et al., 1997; Anders et al., 2001). Evidence of early ductile deformation and foliation is crosscut by subvertical fractures and breccias that represent a transition to brittle deformation over time (Nielson et al., 1986). Another low-angle fault, dipping 15° west and named the Wildhorse Canyon fault, is identified in the western Mineral Mountains, directly east of Roosevelt Hot Springs (Nielson et al., 1986). This fault may extend to the west below the surface based on cataclasite intervals intersected in well 9-1 (Fig. 4). The presence of a continuous listric detachment surface, however, is difficult to verify since there are few drill holes with cored intervals to make stratigraphic correlations. Coleman et al (1997) suggest that rather than being the original dip of displacement, the low-angle structures started out as high angle normal faults, which were tilted as the fault zone evolved (e.g., Buck, 1988), consistent with the dip and north-south strike orientation of the youngest faults in the foothills of the Mineral Mountains (Nielson et al., 1986).
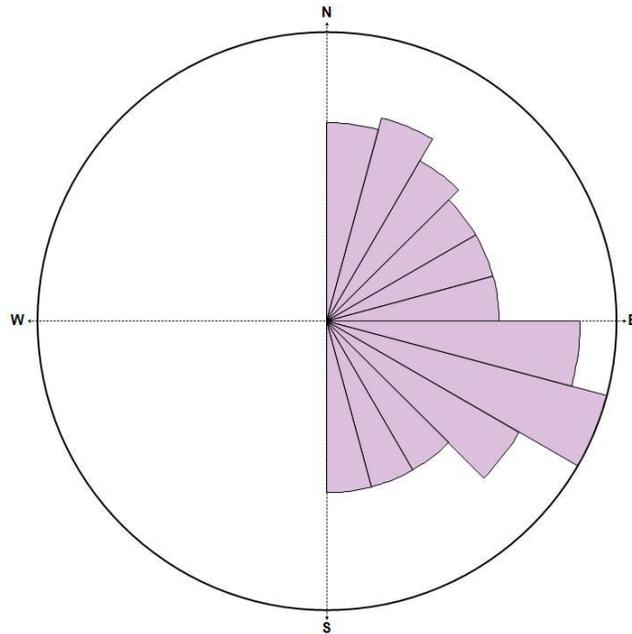
Figure 5: Summary of lineament orientations (n=4452) in granitic basement rock in the Mineral Mountains over a 9x9 km^2 area.
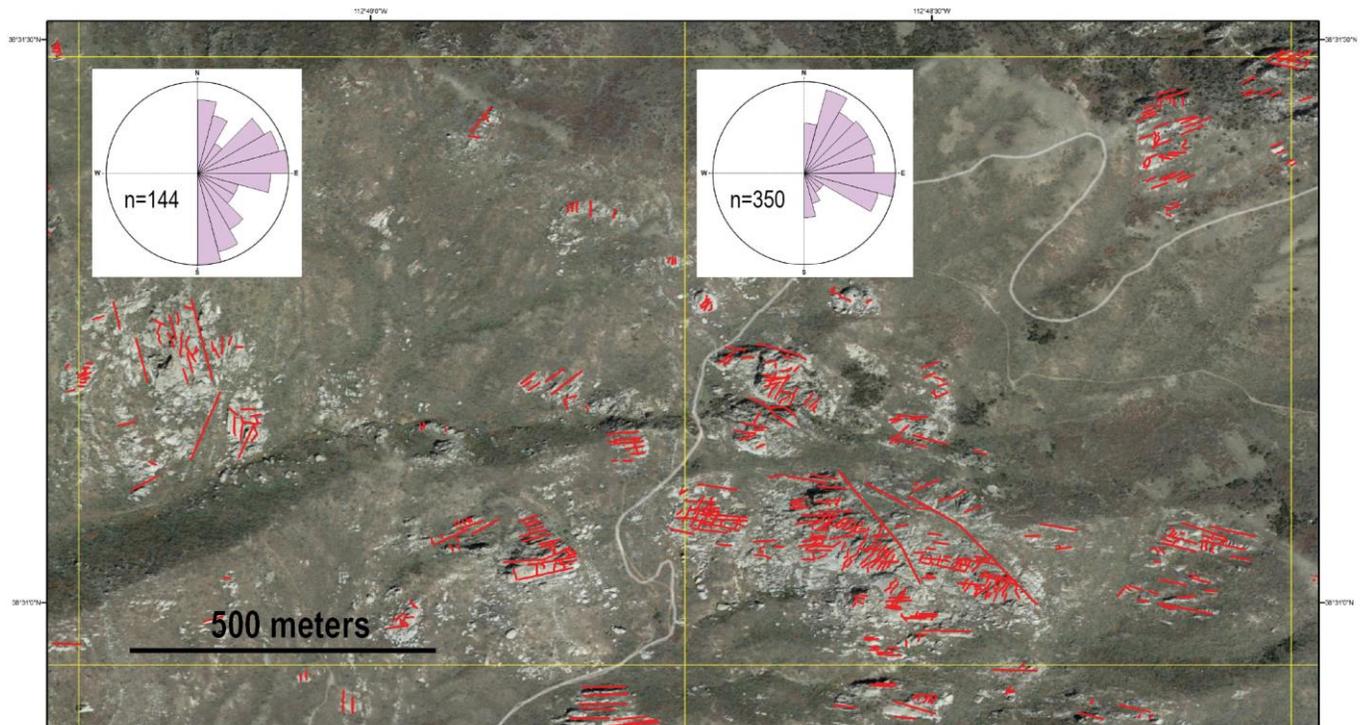

Figure 6: Illustration of lineaments in granitic basement rock in the Mineral Mountains, ~5 km northeast of Roosevelt Hot Springs. Rose diagrams show how azimuths vary within a 2 km^2 area. The location of the study area is shown in Figure 2.
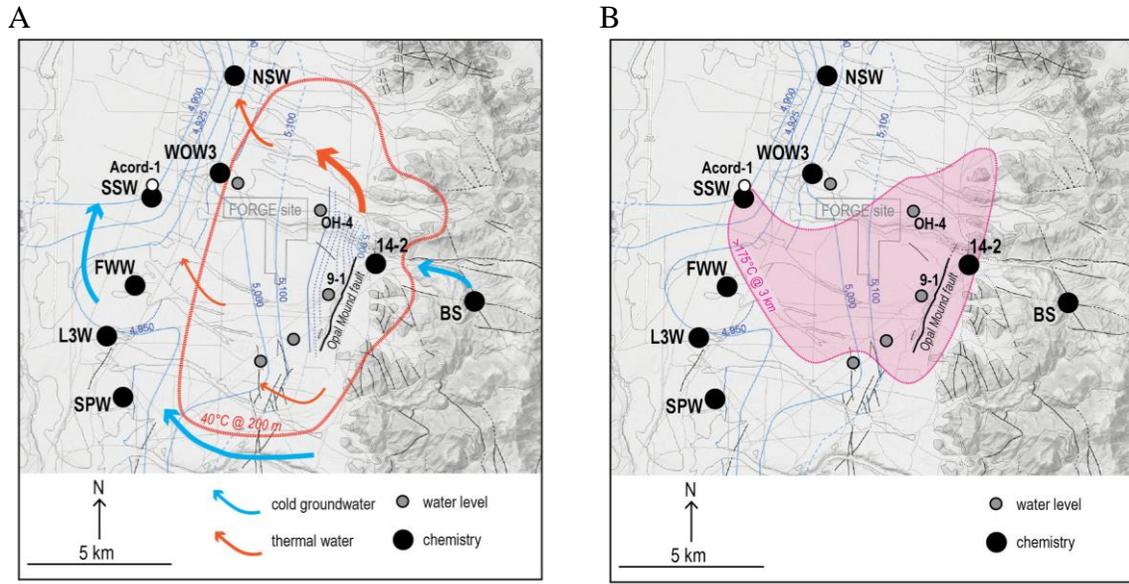
Figure 7: A) Groundwater map of the FORGE deep well site, Milford, Utah, showing some of the wells used to map the potentiometric surface (blue lines, elevation in feet above sea level) and water chemistry. BS is Bailey spring in the Mineral Mountains, and 14-2 is a deep well inside the Roosevelt Hot Springs system that initially produced fluid but is used for injection. Arrows indicate the approximate direction of shallow ground water (cold and thermal) flow. The red dotted line represents the 40°C isotherm at 200 m depth and the limit of the thermal anomaly in the shallow groundwater regime owing to thermal outflow from Roosevelt Hot Springs. B) Map showing the 175°C isotherm at 3 km depth in granite-gneiss country rock (Allis et al., 2016). Compared with A) these maps reflect two distinct thermal regimes, shallow and deep, that are disconnected across the FORGE site.

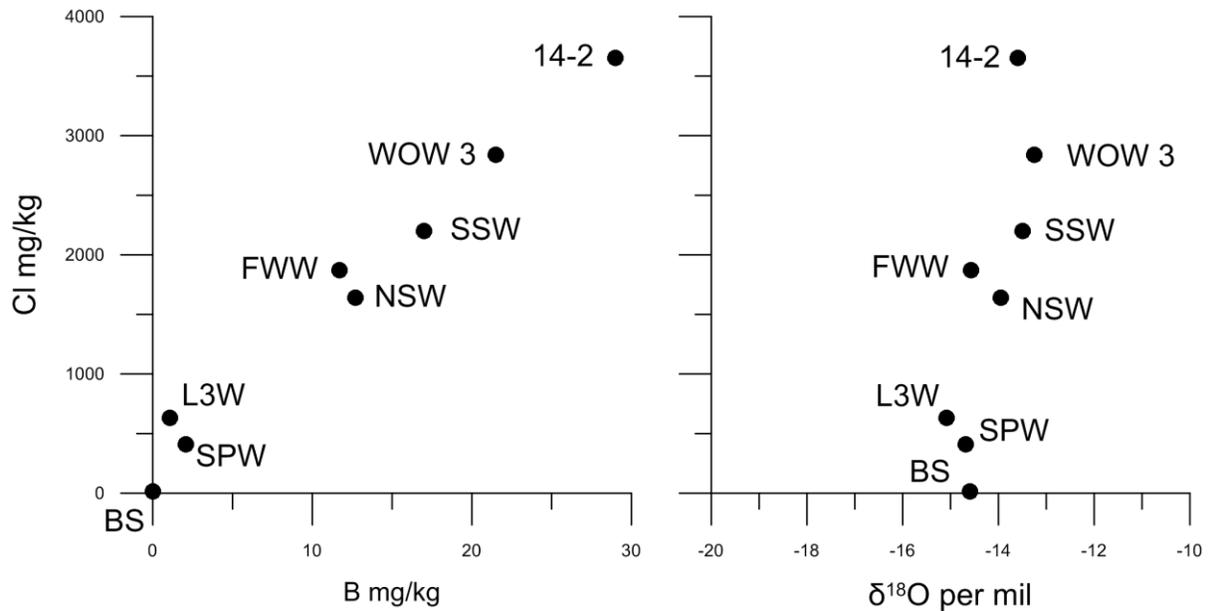**Figure 8: Geochemical trends in Cl versus B and Cl versus δ^{18}O for groundwaters, showing linear mixing-related trends. Sample localities are shown in Figure 6. Sources of data: Rohrs and Bowman (1980); Capuano and Cole (1982); Kirby (2012).**

The Opal Mound fault (Fig. 2) dips steeply to the east and offsets surficial deposits of alluvium and silica sinter, with a total down-dip displacement of at least 15 m (Nielson et al., 1986). Other young north-south trending faults form a narrow graben in the fan deposits 5 km south of the FORGE deep well site (Fig. 2). The offset on these faults is small and less than 3 m. We expect that there are additional north-south trending normal faults in the crystalline basement rocks, which are blind to the surface. Similar faults are inferred from the gravity profile and westward thickening basin fill (Fig. 3; Nielson, et al., 1986; Allis et al., 2016; Hardwick et al., 2016).

The Negro Mag fault is the other major steeply dipping fault, but it trends east-west (Fig. 2). The fault cuts across the Mineral Mountains for ~6 km, however the direction and amount of displacement are unknown due to the absence of markers within the plutonic rocks (Nielson et al., 1986). An east-west trending structure 2 km to the south of Negro Mag fault was the site of micro-seismicity ~35 years ago (Zandt et al., 1982; Nielson et al., 1986; Allis et al., 2016). East-west trending faults also occur at Cove Fort-Sulphurdale and Thermo Hot Springs. These faults may reflect arc-parallel structures, which formed during southward migrating magmatism in the Eocene-Oligocene, and, or Proterozoic structures in deep-seated basement (e.g., Dickinson, 2006; Wannamaker et al., 2015).

From mineralogical investigations, the crystalline basement rocks appear to be strong, even though they vary in rock composition and mineralogy (i.e., granitic to gneissic); they are massive and banded, and they are locally sheared due to cataclasis. Nonetheless, pre-existing fractures and joints are likely to play the most important role in stimulating new permeability beneath the FORGE deep well site. The range of fracture density and orientations in crystalline rocks beneath the FORGE drill well site were therefore studied by locating lineaments in the Mineral Mountains using high-resolution aerial images. A zone covering 9x9 km^2 directly east of Roosevelt Hot Springs was studied and gridded into 1x1 km^2 sections. Overall, more than over 4450 lineaments were mapped, ranging from 10s to 100s of meters in length and having orientations in all compass directions, with a predominant west northwest-east southeast trend (Fig. 5). A finer scale representation of the distributions and orientations of lineaments in two adjacent sections is shown in Figure 6. Three major joint sets were documented in earlier field mapping (Faulder, 1991), two having subvertical dips and azimuth bearings of north-south and east-west and a third having a low-angle dip to the west. These joints are spaced <1 to ~30 m apart (Faulder, 1991).

5. GEOHYDROLOGY AND FLUID CHEMISTRY

Semi-arid conditions, western sloping topography, alluvial basin fill, fractured basement rocks, steeply dipping faults, and the location of the Roosevelt Hot Springs hydrothermal system control the geohydrology of the FORGE deep well site. These are reflected in the water levels and the chemical compositions of waters from shallow and deep wells across the study area (Figs. 7 and 8). Boiling waters associated with steaming ground and fumarolic activity north of Negro Mag wash (Fig. 2) represent the only active thermal springs, but the discharge is feeble (<0.1 kg/sec) and outflow disappears below the surface into unconsolidated gravels. At higher elevation to the east, Bailey Spring represents cold groundwater that infiltrates the Mineral Mountains. All of the rest of the data pertaining to the geohydrology come from shallow groundwater, temperature gradient, and geothermal wells (Rohrs and Bowman, 1980; Capuano and Cole, 1982; Kirby, 2012; Allis et al., 2016; this study).

The potentiometric surface dips west away from the Opal Mound fault and the Mineral Mountains (Fig. 6). From the FORGE deep well site and to the west, the potentiometric surface forms a gentle slope that descends from 5100 to 4900 ft towards the center of the basin. Alluvial gravels host the groundwater aquifer, which is unconfined at higher elevations. Near SPW, L3W, FWW, and SSW (Fig. 6), however, the aquifer is confined beneath impermeable Quaternary claystone (Figs. 3 and 4). East of the FORGE deep well site, the potentiometric surface slopes upward forming a sharp step between OH-4 and Roosevelt Hot Springs (Fig. 6). Well measurements indicate two distinct pressure regimes across the Opal Mound fault, which acts as a horizontal barrier to shallow fluid flow (Allis et al., 2016).

Geochemical data trace the direction of shallow ground water flow. The most dilute water in the area comes from Bailey Spring; westward, however, the groundwater composition changes markedly. At Roosevelt Hot Springs, the groundwater is dominated by hot mineralized waters that rise nearly vertically from a reservoir >1000 m deep. Their compositions are known from surface seeps (50-85°C) and deep wells (feed points 250-265°C), which produce near neutral pH chloride waters that contain 3000-4500 ppm Cl (Capuano and Cole, 1982, unpublished data). From production well 14-2 to the groundwater wells WOW3, SSW, FWW, and NSW, aqueous chloride, boron, and δ^{18}O show a systematic decrease in values resulting from dilution with fresh ground waters, represented by L3W and SPW. This trend suggests that thermal water leaks into the groundwater aquifer from the intersection of the Opal Mound and Negro Mag faults, then flows downhill and to the northwest to form a large but shallow outflow that is evident in many gradient wells (Fig. 6; Allis et al., 2015; 2016). Another plume, probably smaller, flows west around the southern tip of the Opal Mound fault, contributing heat to the shallow thermal anomaly in the south (Allis et al., 2016).

The geochemical data also provide clues about the states of fluid-mineral equilibria, and the tendency for fluids to dissolve or precipitate minerals. Recent sampling of production wells at Roosevelt Hot Springs indicates that reservoir fluids are similar to the native state fluid compositions, but that they have been modified by varying degrees of boiling and mixing with injectate (Capuano and Cole, 1982; Simmons et al., 2015; unpublished data). Geochemical modeling indicates the deep thermal waters are close to saturation in calcite and anhydrite, and this result is consistent with the widespread occurrences of both minerals in hydrothermal alteration assemblages (Fig. 4). The regional occurrences of sulfate and carbonate minerals in the basin stratigraphy makes them available for remobilization by any hydrothermal activity, whether they be ancient events or modern. The deep waters are also very close to equilibrium with Na and K-bearing feldspars, quartz, chlorite, and illite (Capuano and Cole, 1982; Simmons et al., 2015).

The groundwaters around the FORGE deep well site are chemically benign, but non-potable (Vuataz and Goff, 1987; Allis et al., 2015; 2016), and they appear to be suitable for EGS heat transfer experiments. A recent pump test indicates shallow wells completed in the unconsolidated alluvium should be able to supply more than 100 gallons/minute.

6. SUMMARY

The Milford FORGE deep well site is located within a geologically complex region characterized by extensional faulting, sporadic magmatism, and zones of anomalously high heat flow inside the southeast margin of the Great Basin. The geological, geochemical, and geohydrological attributes of the site are favorably suited for development of the EGS laboratory.

Crystalline basement rocks, comprising Tertiary granitic intrusions and Precambrian gneiss, crop out in the Mineral Mountains and extend westward through the center of the Milford Valley basin, as revealed by deep wells in the Roosevelt Hot Springs, well 9-1 west of the Opal Mound fault, and the Acord-1 well. They form a large volume (>100 km^3) of low porosity rock that underlies the FORGE deep well site, buried beneath a veneer of alluvial fan deposits 200 to 600 m thick.

The crystalline basement rocks comprise alumino-silicate minerals and quartz, and interlocking grain textures seen in thin section indicates the rocks are relatively strong except where fractured. Hydrothermal alteration is widespread, but weakly developed, and outside Roosevelt Hot Springs, it appears to be the product of ancient hydrothermal activity.

The analysis of lineaments in the Mineral Mountains suggests that the crystalline rocks beneath the FORGE deep well site are faulted and fractured, having a wide range of orientations, striking north-south to east-west and dipping high to low angle. Such fractures could play an important role in stimulating new permeability beneath the FORGE deep well site.

Mineralized thermal waters from the Roosevelt Hot Springs flow outward from around the Opal Mound fault to the northwest and west, through a shallow unconfined aquifer. Dilution with cold groundwater produces a linear mixing trend. Across the east side of the Milford Valley basin and around the FORGE deep well site, groundwaters are non-potable, but chemically benign and unlikely to cause significant mineral dissolution or precipitation during fluid circulation and EGS testing.

7. ACKNOWLEDGMENTS

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