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Characteristics of the Cove Fort-Dog Valley-Twin Peaks Thermal Anomaly, Utah

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ABSTRACT

There has been considerable geothermal exploration in the region of Cove Fort since the 1970s, culminating in the construction of ENEL Green Power North America's 25 MW (gross) binary power plant in late 2013 at Sulphurdale. This paper is a reassessment of more than 160 thermal gradient wells, eight oil and gas wells with depths between 500 m and 2.3 km, and over 20 wells with water level and temperature information from the Utah Division of Water Rights database. Contouring temperatures at 100 m depth indicates a 500 km^2 area of anomalously high temperatures (between 20 and 50 °C) extending 20 km northeast and west from near the Cove Fort power plant. Most of the thermal anomaly, including the reservoir beneath Sulphurdale, appears to coincide with high permeability fractured Paleozoic formations at relatively shallow depth. The typical mean annual ground temperature indicated by the thermal gradient wells is 13 ± 2°C, so 20°C at 100 m represents an average gradient of 70 °C/km. Assuming a thermal conductivity of 1.5 W/m°C for the uppermost 100 m of alluvium and volcanics, the 20°C isotherm corresponds to a conductive heat flow of about 100 mW/m^2, suggesting the anomalous conductive heat loss inside this contour is 110 MW with a 20% uncertainty. This implies a large thermal system at depth, and if generated by a 150°C cross-flow of water cooling conductively to 20°C, this amounts to a flow of about 200 kg/s. This flow rate is a minimum value and any additional cooling by mixing with cold groundwater would increase the total heat loss and the mass flow. In contrast, the conductive thermal loss from the Roosevelt geothermal system 25 km to the west is only 50 MW. The cooler temperatures (60–90°C) in the Paleozoic section encountered in the Hunt Energy well north of Dog Valley supports a cross-flow from the south (Sulphurdale) to the north and west. The highest recorded temperatures around Cove Fort are in the volcanics overlying the carbonate reservoir and in a monzonite intrusion beneath the carbonates (170–180°C.) This suggests the carbonates should be considered as a large outflow zone fed from an upflow zone, possibly south or southeast of Sulphurdale.

INTRODUCTION

Many geothermal exploration companies and contractors were interested in the Cove Fort region during the late 1970s and 1980s, including Amax, Union Oil Co., Hunt Energy Corp., Phillips Geothermal, and Mother Earth Industries. Exploration interest was stimulated by the discovery of anomalous temperatures at shallow depth over a large area, patches of hydrothermally altered ground 6 km to the north near Cove Fort, and weak, cool gas flow to the surface at Sulphurdale. Much of the exploration data has been preserved in databases (e.g. the Geothermal Data Repository; https://gdr.openei.org/). A review of publically available geologic and geophysical investigations at Cove Fort geothermal area up to the early 1980s was published by Ross and Moore (1985). More recent reviews of exploration drilling around Cove Fort-Sulphurdale were given by Huttrer (1992), Ross and Moore (1994). Rowley et al. (2013) contains the results of detailed geologic mapping along with an interpretation of the deeper hydrogeologic and structural regime beneath Cove Fort-Sulphurdale. Between 1985 and 2003, a geothermal power plant with a maximum capacity of 10 MWe was operating, and since late 2013 ENEL Green Power has been generating 25 MWe gross (about 19 MWe net) from a newly constructed plant.

The focus of this report is to examine the thermal regime using all available data, including non-geothermal data from nearby oil exploration wells (Utah Division of Oil, Gas and Mining; http://oilgas.ogm.utah.gov/Data_Center/LiveData_Search/files.htm), groundwater well information from the Utah Division of Water Rights (https://www.waterrights.utah.gov/wrinfo/query.asp), and previously confidential data from two deep wells that Hunt Energy Corp. donated to the Energy & Geoscience Institute (15-30 north of Dog Valley, and 22-2 west of the I-15 to I-70 interchange). Because of the very large, shallow thermal anomaly revealed by thermal gradient wells, the area of interest spans between the Mineral Mountains to the southwest, the Tushar Mountains to the southeast, Twin Peaks to the northwest, and Meadow hot springs (sometimes called Meadow-Hatton) to the northeast (Figure 1). This covers an area of about 2000 km^2. This report also reviews static water level and pressure data and integrates this with the thermal regime to assess likely flow directions and the possible location of the main geothermal upflow.

SHALLOW TEMPERATURES

This study compiled temperature profiles from 169 wells which were judged reliable for inferring the temperature at 100 m depth. An additional 14 wells were considered to have unreliable or unusable temperature data, mainly because of inadequate depth or excessively variable gradients with depth. Most wells show uniform thermal gradients with depth, allowing extrapolation of temperatures if the total depth of the well was less than 100 m. Examples of the thermal gradients from wells in the Cove Fort-Sulphurdale area and from near Dog Valley 10 km to the north are plotted in Figures 2a and 2b, with a detailed location map shown in Figure 3.

There were no data on how soon after drilling the temperature measurements occurred, so all temperatures represent minimums. However, the average zero-depth temperature intercept for all profiles was 13°C with a standard deviation of 2°C, which is close to the mean annual ground temperature for the region and suggests thermal profiles were close to equilibrium. The ground elevation at the sites varied between 1400 and 2200 m above sea level (m asl), and although there is some evidence of the adiabatic lapse rate affecting temperatures at three sites on the eastern flanks of the central Mineral Mountains, in general the effect of ground elevation is secondary to underlying geothermal factors. Of the 169 wells, 140 wells were considered to yield high-confidence temperatures at 100 m depth (depth greater than 100 m or less than 30 m of extrapolation to 100 m depth), and 29 wells were considered to yield low-confidence data (30–50 m of extrapolation or variable gradients with depth). The map showing 100 m depth temperatures with two levels of confidence is shown on Figure 4.

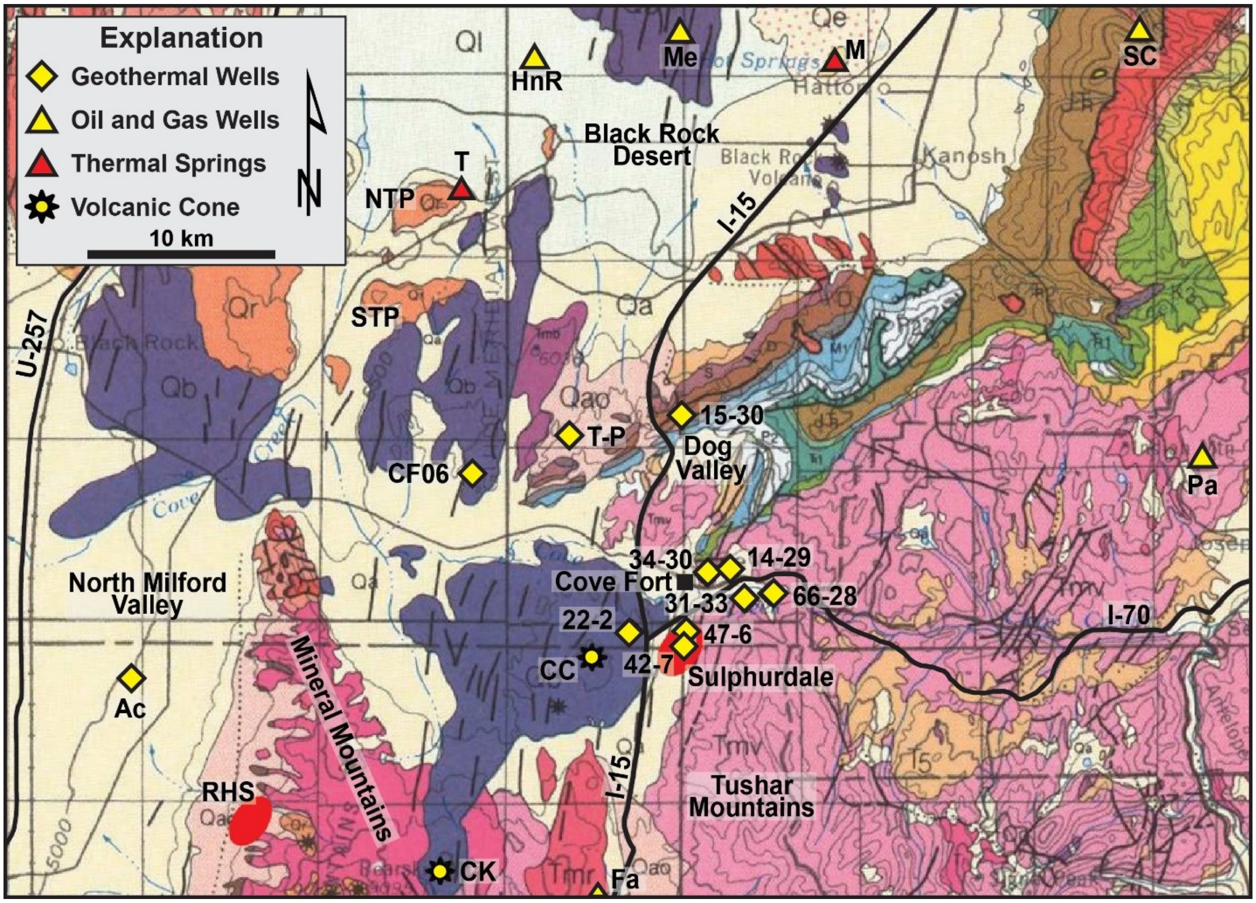

Figure 1. Geological map from Utah Geological Survey interactive website with overlay of deep wells and features referred to in the text (http://geology.utah.gov/apps/intgeomap/). Locations: CC - Cinder Crater, CK - Crater Knoll, STP - South Twin Peak, NTP - North Twin Peak. Thermal springs: RHS - Roosevelt Hot Springs, T - Twin Peak, M - Meadow-Hatton. Wells: HnR - Hole-n-Rock, Me - Meadow, Ac - Acord, T-P - Taft-Paxton, SC - Sunset Canyon, Pa - Paxton, Fa - Falcon. Selected geologic units: Qa - Quaternary alluvium, Qb - Quaternary basalt, Qr - Quaternary rhyolite, Ql - Quaternary lake sediments, Tmv - Tertiary volcanics, TR - Triassic, M - Mississippian, D - Devonian, S - Silurian, C - Cambrian. Background grid is township and range layout.

Given the various sources of uncertainty potentially affecting shallow temperatures (especially elevation), a contour of 20 °C at 100 m depth has been chosen as the minimum temperature indicating anomalous geothermal conditions. Compared to the local average zero-depth temperature intercept of 13 °C, this contour implies an average gradient of 7°C/100 m, or 70°C/km. If the upper 100 m of rock is assumed to be alluvium or weathered volcanics with a thermal conductivity of 1.3–1.5 W/m°C (with variable saturation having a significant effect on conductivity), the 20 °C contour implies a threshold shallow heat flow of about 90–100 mW/m^2. This thermal gradient (or equivalent conductive heat flow) cannot be used to extrapolate deeper temperatures. In Dog Valley, the temperature profiles become isothermal below about 300 m depth (Figure 2b). This is confirmed in a deep well at Dog Valley (discussed later), with the temperature at greater depth actually decreasing. A similar pattern of temperature profiles becoming isothermal or reversing below about 500–800 m depth is also seen in deep wells at Cove Fort and Sulphurdale. The thermal anomalies depicted in Figure 4 (and Figure 5 discussed below) represent a thermally conductive "cap" over warm- to hot-water aquifers at greater depth.

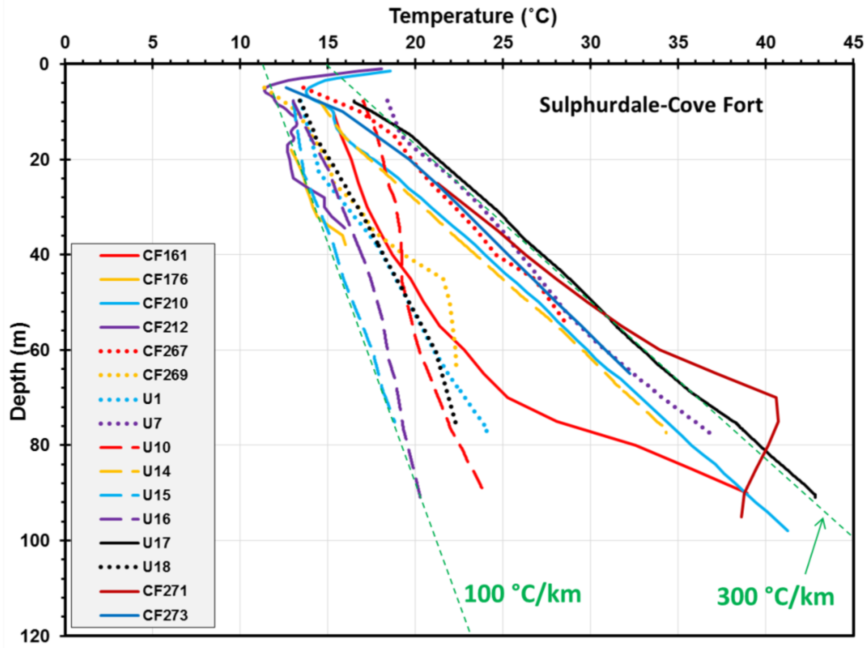

Figure 2. (a) Examples of temperature profiles in thermal gradient wells in Cove Fort-Sulphurdale area.

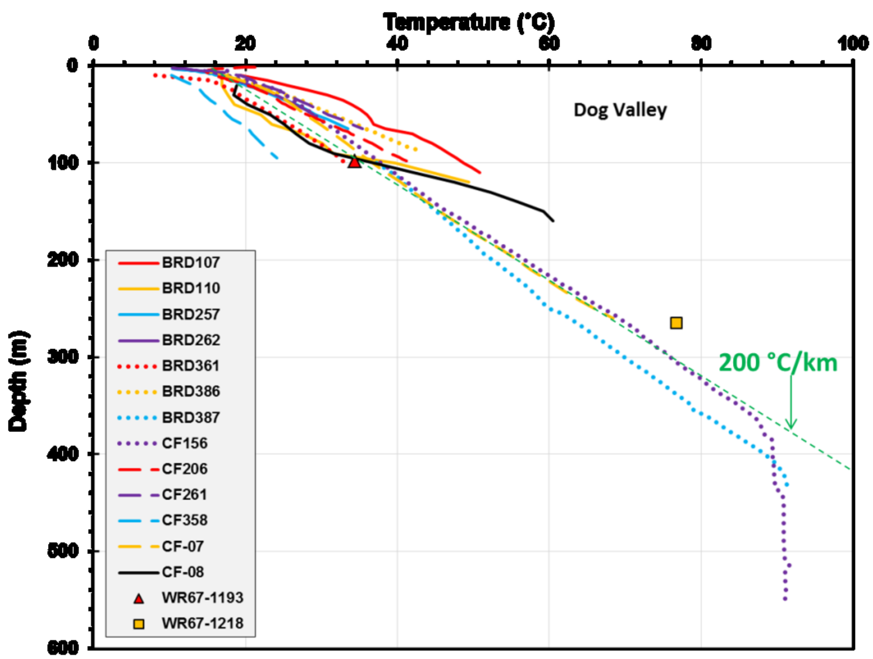

Figure 2 (b). Examples of temperature profiles in thermal gradient wells near Dog Valley. The locations of these wells are shown in Figure 3.

The largest thermal anomaly on Figure 4 includes what is called here the Cove Fort-Dog Valley area and covers close to 500 km^2 inside the 20°C contour. Apparently separate, smaller thermal anomalies occur to the northwest around Twin Peaks, and due north around the Meadow hot springs. The separation of the Twin Peaks anomaly from the Cove Fort-Dog Valley anomaly is in doubt because of uncertainties in the choice of temperature outlining the area showing a clear geothermal signature. The uncertainty is realistically ± 2°C, and in view of the higher topography near South Twin Peak the thermal gradient wells here may not have penetrated deep enough to sense the underlying hot water aquifer. Similarly, the three areas inside the Cove Fort-Dog Valley anomaly with temperatures of more than 40°C at 100 m depth may also be linked when topography is considered. There could be just one 40 °C anomaly with the two eastern areas linked forming a relatively narrow (2–3 km wide) north-south arm, which in turn is linked to the western area in the form of a southwest-trending arm. This southwest trending arm coincides with the trend of steeply-dipping Paleozoic formations here (see Figure 1, between Dog Valley and Twin Peaks).

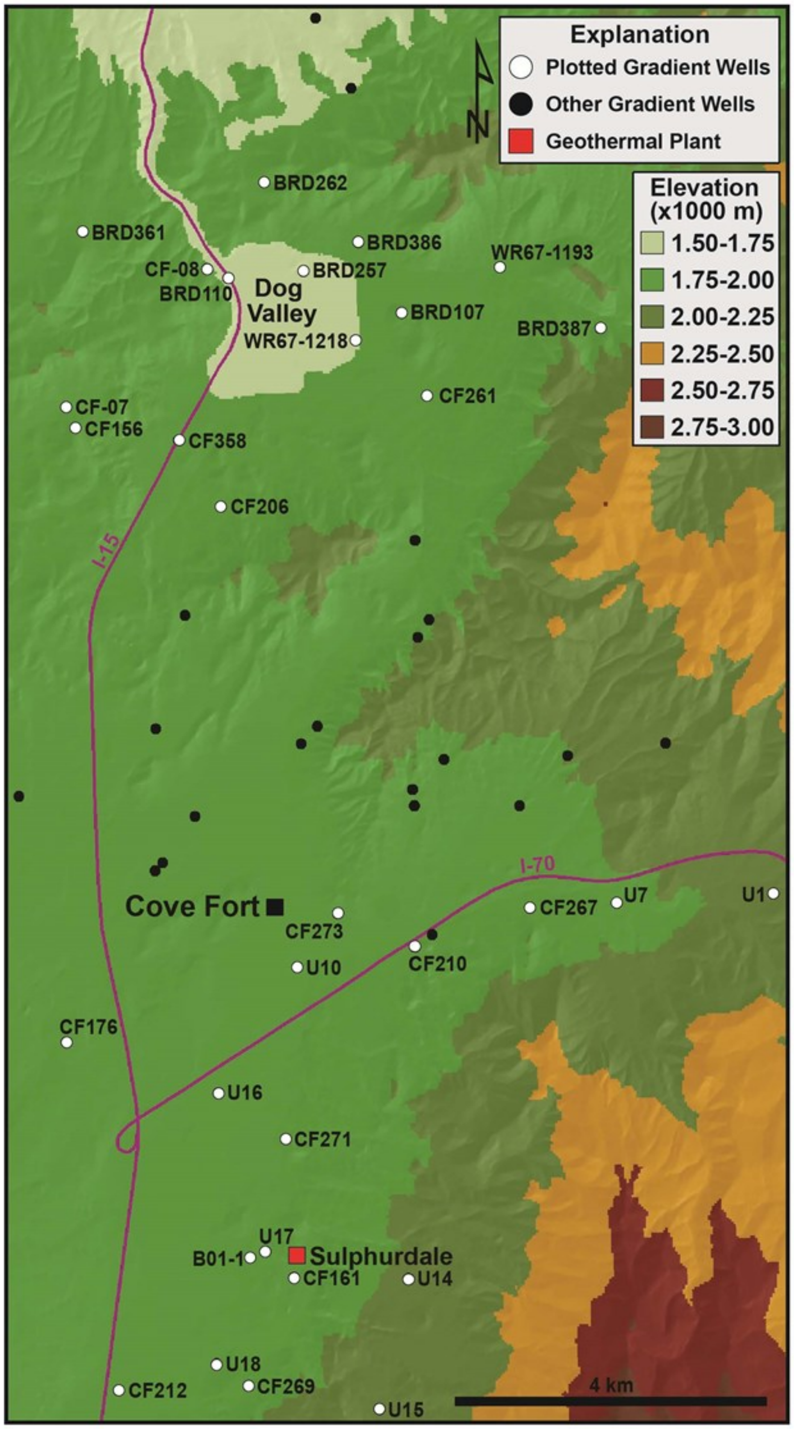

Figure 3. Location of thermal wells plotted in Figure 2. The profile for B01 is on Figure 6.

The Roosevelt Hot Springs (RHS) thermal anomaly is also shown on Figure 4. Data from the thermal gradient wells were compiled as part of the Milford FORGE project (Allis et al., 2016), and more recently have been reanalyzed by Gwynn et al. (2016). The 200 m depth temperature field presented in those two papers has been converted to the same 100 m depth datum, with the same 20°C, 40°C contours used in this report for the Cove Fort area. At RHS, the area within the 20°C contour at 100 m depth is about 150 km^2 and the area within the 40°C contour is 35 km^2. This contrasts with the 500 km^2 anomaly near Cove Fort-Dog Valley-Twin Springs (> 20°C at 100 m depth), with its three central anomalies (more than 40°C at 100 m depth) having a total area of about 70 km^2.

There is one important difference between the shallow thermal regime within the Cove Fort-Dog Valley anomaly and the RHS anomaly. At RHS the pre-development heat flow was centered on the boiling spring and adjacent steaming ground on the Opal Mound Fault (Ward et al., 1978; Allis et al., 2015). A shallow outflow plume of hot water moving towards the northwest had chemical characteristics indicating it was derived from the underlying 270°C geothermal reservoir. At Cove Fort there is no thermal ground, although there are areas of active gas outflow (especially CO_2 and H_2S) and extensive hydrothermal alteration that was a focus of sulfur mining between the late 1800s and 1952 (Callaghan, 1973; Ross and Moore, 1994; Klusman et al., 2000). It will be shown below that in contrast to hydrostatic pressure regime at RHS intersecting the ground surface, the pressure regime in the underlying geothermal reservoir at Cove Fort has its potentiometric head about 300 to 400 m below the ground surface. The near-surface signatures of the geothermal fluid at Cove Fort are obscured by a perched groundwater aquifer.

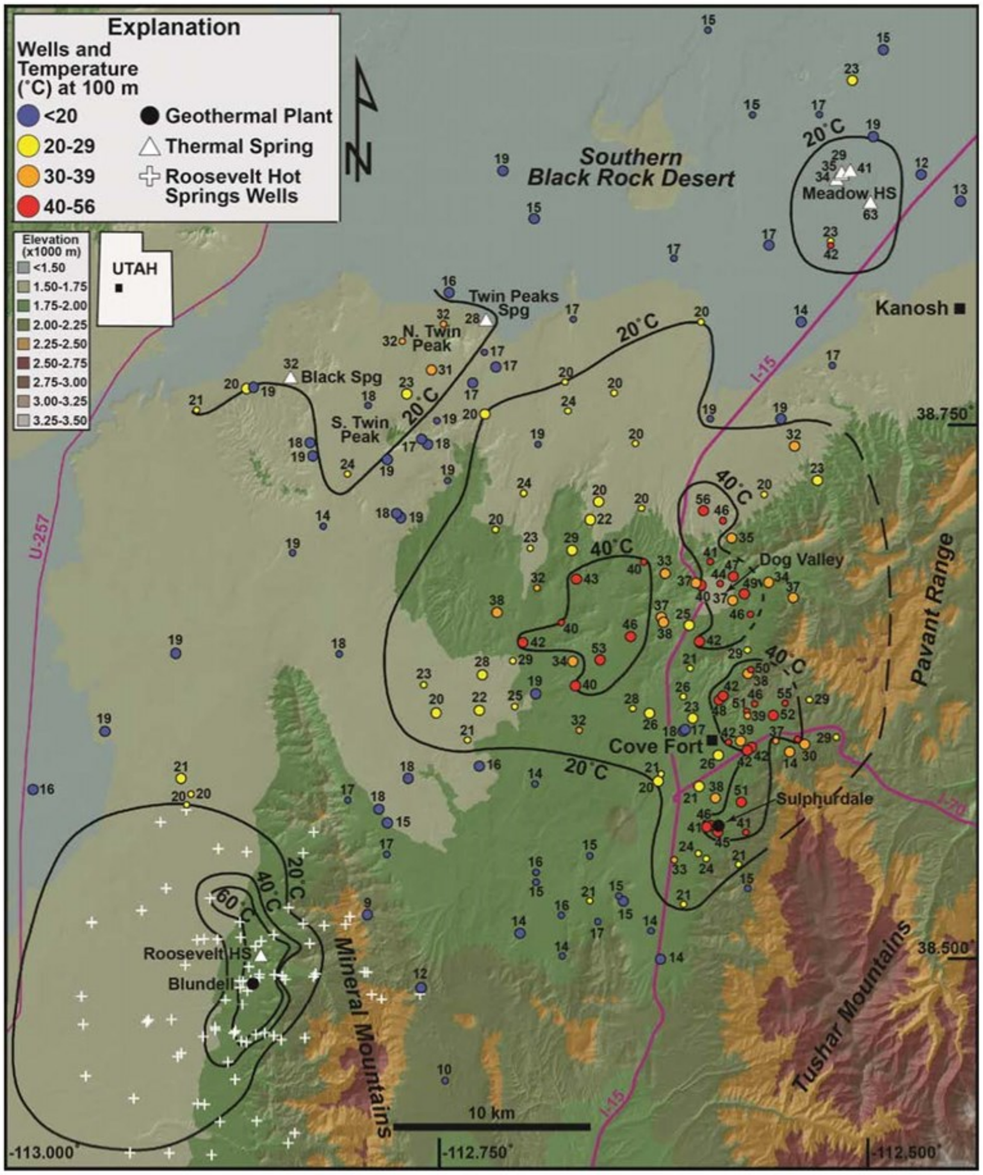

Figure 4. Temperatures at 100 m depth derived from thermal gradient wells and deeper geothermal wells on shaded topographic relief. The white crosses at Roosevelt Hot Springs are where the 100 m depth contours are derived from thermal gradient data presented in Allis et al. (2016). Temperatures of greater than 20°C indicate anomalous geothermal conditions.

SHALLOW HEAT FLOW

The thermal gradients discussed above can be converted to a heat flow map by assuming a thermal conductivity for the upper 100 m of rock. We initially considered trying to identify gradient holes that could have been predominantly in bedrock where the thermal conductivity could be significantly higher than those holes inferred to be in predominantly alluvium or tertiary volcanics. Because of possible location uncertainties of up to several hundred meters in the gradient wells, and doubt over factors such as porosity, saturation, and degree of weathering, a uniform thermal conductivity of 1.5 W/m°C was chosen as the best way handle the conversion from temperature gradient to heat flow. Uncertainties in basin fill or alluvium may contribute to a 20% uncertainty in thermal conductivity and heat flow. If the well was predominantly in carbonate, or quartzite/sandstone, the heat flow could be underestimated by as much as a factor of two. Given the high permeability found in deeper wells penetrating these formations and the occurrence of near-isothermal profiles due to flow (discussed in next section), the pattern of consistent thermal gradients in shallow wells across the region suggests almost all wells were in low permeability/low thermal conductivity rock.

The pattern of heat flow at 100 m depth assuming uniform thermal conductivity is shown in Figure 5. It is a scaled version of the temperature map, although with a different, non-linear contour interval (100, 200, 400, 800 mW/m^2), which causes the contours to have a slightly different shape. The heat flow contours for RHS are from Gwynn et al. (2016). The heat flow varies from large areas with less than 100 mW/m^2 to values in excess of 1000 mW/m^2 at RHS, and to peak values close to 600 mW/m^2 in the Cove Fort–Dog Valley anomaly. The area of the Cove Fort–Dog Valley anomaly (heat flow more than 100 mW/m^2) is 500 km^2, and that of RHS is 140 km^2. Integrating the heat flow within these two anomalies yields a total heat output of 110 MW for Cove Fort–Dog Valley and 50 MW for RHS. This value for RHS is slightly less than the 60–70 MW estimated by Wilson (1980). They used an average thermal conductivity of 1.64 W/m°C compared to our 1.5 W/m°C value for alluvium, and approximately half their total heat output was from the area inside a 1000 mW/m^2 contour. Although the uncertainties in total heat output are estimated to be at least ± 20%, it is clear that the total heat from the Cove Fort-Dog Valley anomaly is about twice that from the Roosevelt Hot Springs system.

DEEP TEMPERATURES: COVE FORT-DOG VALLEY

A comparison of selected shallow temperature profiles from thermal gradient wells (typically less than 300 m depth), and deep wells near Cove Fort show the presence of isothermal conditions and temperature inversions at depth (Figure 6). When the temperature in these wells is plotted against elevation rather than depth, the transition from a nice pattern of shallow thermal gradients to the varying effects of lateral and vertical convection occurs at about 1500 m asl. This is also close to the elevation of the deep water table across this area, and to springs in the southern Black Rock Desert. At Cove Fort-Sulphurdale, the hot wells have static water levels at 1550 to 1600 m asl (about 300 to 350 m depth; Barker et al. 2002 show the water table elevation in deep well B01 to be at 1580 m asl; located on Figure 3), whereas well 15-30 north of Dog Valley had a water level at 1500 m asl (about 300 m depth). These wells encounter permeable Paleozoic carbonates at 500 to 1500 m depth, the main geothermal reservoir at Cove Fort–Sulphurdale (Huttrer, 1992; Ross and Moore 1994; Rowley, 2013). Presumably relatively low permeability Tertiary volcanics at elevations of about 1500 m asl minimize the effects of water movement and record a thermally conductive cap overlying the hot aquifer(s) at greater depth. A perched, cool, groundwater aquifer between 1600 and 1800 m depth is locally tapped by shallow wells in the Cove Fort-Sulphurdale area. This aquifer flows towards the northwest and appears geochemicaly and thermally separate from any underlying geothermal outflow across much of the Cove Creek area (Kirby, 2012).

The locations of the deep wells show a pattern of cooler hot water at depth towards the north and west from Cove Fort-Sulphurdale. Although the shallow temperature gradient at Dog Valley often exceeds 200 °C/km (Figure 2b), the deeper wells show a maximum temperature of about 90°C occurs at 300 to 400 m depth, and temperatures at greater depth, according to well 15-30 north of Dog Valley, are less than this to at least 1500 m depth.

West of Cove Fort–Sulphurdale, well 22-2 was drilled to 1.2 km depth (located on Figure 1). This well was spudded into Quaternary basalt and then entered Tertiary volcanics. Difficult drilling conditions were encountered and there is little data preserved from this well. A non-equilibrium temperature profile recorded 10 hours after drilling ceased, and a corrected bottom-hole temperature of 98°C at 1200 m depth, suggest a conductive thermal regime (~ 70°C /km) from near-surface to total depth (Figure 6). When extrapolated to between 2 and 2.5 km depth, the temperature in 22-2 could be in the range 150 to 190°C and close to that observed in the deepest (and hottest) well at Sulphurdale (42-7; 178°C at 2227 m depth). The temperature profile in 42-7 shows a strong correlation with the local stratigraphy. The high temperature gradient zone of 200–300°C/km at less than 500 m depth is predominantly in Tertiary volcanics. The maximum temperature at 800 m depth (167°C) occurs in Paleozoic sandstone (Queantoweap sandstone, Hintze and Davis, 2003) with the temperature inversion and isothermal section coinciding with the underlying Paleozoic carbonate section (900–1860 m depth). At greater depth, Tertiary quartz monzonite is encountered, and the deep temperature gradient is close to 30°C/km.

The simplest explanation for the thermal regime shown in Figure 6 is that the maximum temperature near the top of the Paleozoic section in 42-7 coincides with a cross-flow of hot water from an upflow zone to the south or southeast of this well. North-trending faults which cut the west flank of a large monzonite intrusion beneath the Tushar Mountains (Cook et al., 1980) may provide the permeability for the upflow zone. This same cross-flow is likely also occurring within the underlying, very permeable and laterally extensive carbonate units, and mixing with cold water, from the east and northeast, resulting in cooler temperatures in these units. The carbonates also provide the pressure control at Cove Fort-Sulphurdale, with the relatively low hydrostatic pressures here similar to shallow groundwater head around the southern Black Rock Desert and the Twin Peaks. The intersection of the north-trending fault zone near Cove Fort-Suphurdale and the steeply dipping thrust package of Paleozoic rocks that extends from south of Kanosh, southwest towards the Mineral Mountains is may control the 500 km^2 extent of hot water at depth. A more detailed analysis of the local and regional pressure trends will be presented elsewhere (Allis et al., in preparation).

REGIONAL THERMAL REGIME

The high heat flow thermal regime near Cove Fort–Sulphurdale is surrounded by relatively low heat flow. Several oil exploration wells have been drilled within about 30 km of Cove Fort (identified in Figure 1 as yellow triangles). Standard corrections to bottom-hole temperatures recorded on the headers of the wireline logs enable an estimate of the undisturbed temperature (Hendricksen and Chapman, 2002; Gwynn et al., 2013; 2014). Uncertainties are at least ± 10°C. Figure 7 compares these corrected bottom-hole temperatures with profiles from well 15-30 from north of Dog Valley, well 34-30 east of the town of Cove Fort, and well 42-7 near Sulphurdale. A profile from the Acord-1 geothermal exploration well in central North Milford Valley is also shown (yellow diamond symbol in Figure 1), as well as the convective upflow profile of wells in the RHS (Allis et al., 2016). The temperature gradient in granite below 3.1 km depth in Acord-1 is 41°C/km and the geotherm implies a conductive heat flow of 120 ± 20 mW/m^2.

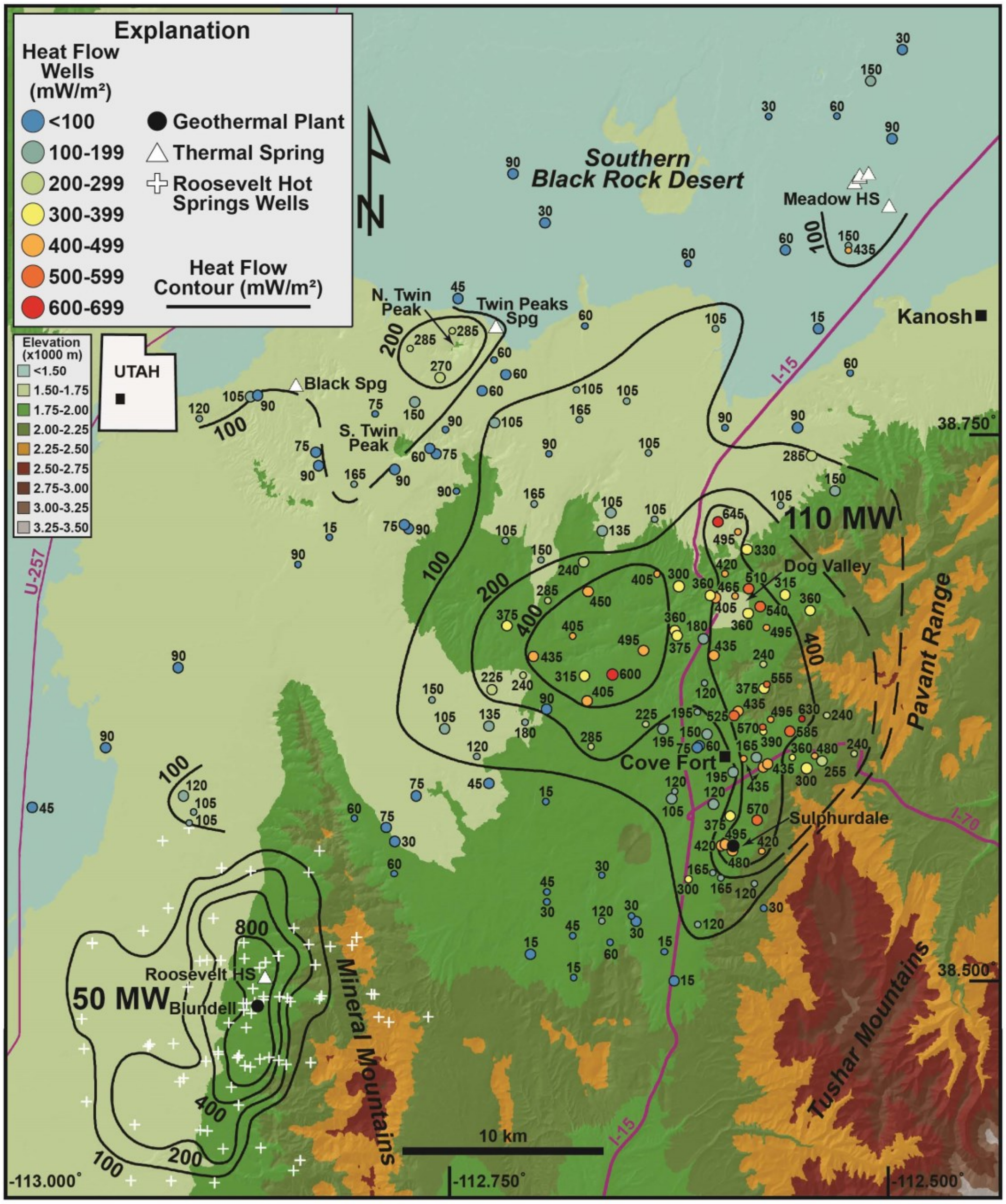

Figure 5. Conductive heat flow at shallow depth (~ 100 m; units are mW/m^2) superimposed on shaded topography. The contours around Roosevelt Hot Springs (RHS) are derived from thermal gradient data at the white crosses (Allis et al., 2016). The total heat output from inside the 100 mW/m^2 contour around Cove Fort is 110 MW, and from the RHS area is 50 MW.

The corrected bottom-hole temperatures from the oil exploration wells surrounding Cove Fort form a linear trend with a gradient of 23 ± 2°C/km between 1 and 5 km. Assuming an average thermal conductivity of 2.7 ± 0.2 W/m°C for the predominantly Paleozoic carbonate occurring in most wells in this depth range, the regional heat flow is 60 ± 10 mW/m^2. The zero-depth intercept of the trend line for this regional gradient is 17°C, which is reasonable, because the lower thermal conductivity of less consolidated sediments near surface would cause the geotherm to curve towards the 13°C temperature intercept discussed earlier. The regional heat flow of 60 ± 10 mW/m^2 is also consistent with heat flow estimates of Gwynn et al. (2013) for wells Hole-n-Rock and Meadow in the southern Black Rock Desert. This heat flow is significantly lower than the average Basin and Range heat flow (85 ± 10 mW/m^2; Blackwell, 1983; Blackwell et al., 2011) and lower than the heat flow of 70–90 mW/m2 of the transitional zone on the central Utah plateaus east of the Basin and Range on the west side of the Colorado Plateau (Henrikson and Chapman, 2002; Edwards, 2013; Wannamaker et al. 2001, 2008). A disturbed thermal and fluid flow history over the last 25 million years may be the explanation. The large batholithic-scale intrusions forming the Mineral Mountains and the Tushar Mountains during the mid-Tertiary have been followed by the rhyolite and basaltic eruptions from the Twin Peaks 2 million years ago, and more recently by the rhyolitic and basaltic activity in the Mineral Mountains and to the east towards Cove Fort. Perhaps large-scale fluid flushing of the upper crust, facilitated by fluid movement in laterally extensive, permeable Paleozoic carbonate formations, are still affecting the regional thermal regime today. The "Ely heat flow low" anomaly (~ 60 mW/m^2) in east-central Nevada and western Utah is also attributed to large-scale lateral movement of water in underlying Paleozoic carbonate units (Sass et al., 1971; Heilweil and Brooks, 2011; Masbruch et al., 2012).

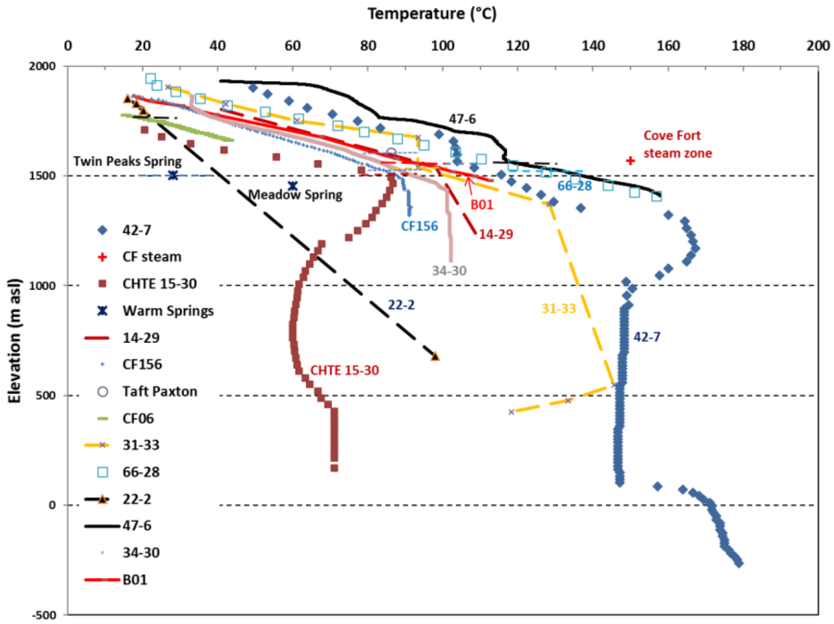

Figure 6. Compilation of thermal data from deep wells in Sulphurdale-Cove Fort-Dog Valley area. Wells are located on Figures 1 or 3. The wells are plotted against elevation rather than depth because of the apparent influence of the deep geothermal aquifer with a head at between 1500 and 1600 m above sea level (asl). A conductive thermal gradient exists in most wells at higher elevations.

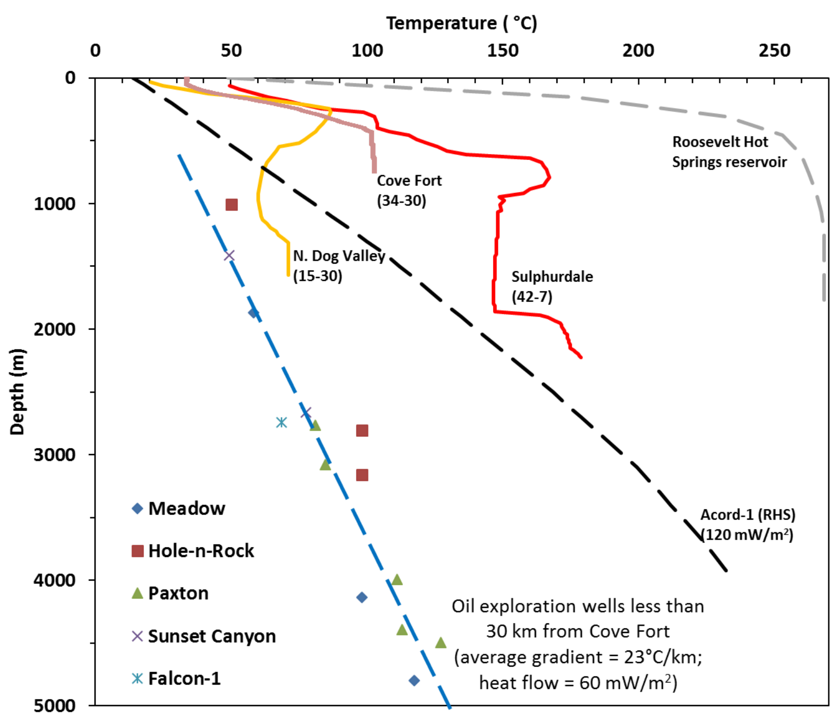

Figure 7. Comparison between the thermal regime in oil exploration wells within 30 km of Cove Fort, and three deep wells in the Sulphurdale-Cove Fort-North Dog Valley area. The composite profile for wells in the hydrothermal reservoir of the Roosevelt Hot Springs is also shown, as is the unproductive Acord-1 exploration well in the central North Milford Valley (located on Figure 1; details in Allis et al., 2016).

The hydrothermal upflow at RHS with its magmatic geochemical signatures (Simmons et al., 2015, 2016; Allis et al. 2016) points to very high temperatures under the west flank of the Mineral Mountains. It is unclear whether heat from this area is also the ultimate source of the heat outflow at Cove Fort–Sulphurdale, or whether deep circulation of water in faults in the monzonite intrusion beneath the Tushar Mountains is the source of the heat. If the latter, the regional gradient of 23°C/km in deep wells requires fluid circulation to 7–8 km depth for temperatures of 180-200°C in the inferred upflow zone for Cove Fort.

Union Oil Company's review (1979) of their exploration drilling at Cove Fort commented that the geochemical characteristics of the reservoir fluids were complex and variable despite the relatively high permeability. Silica geothermometers were considered the most reliable, indicating a temperature in 31-33 of 178°C, which is the same as the maximum temperature measured at the total depth of 42-7. The most reliable Na-K-Ca deep temperature estimate collected from Cove Fort wells was considered by Union Oil Company (1979) to be 257°C . Later analyses from two production wells at Sulphurdale yielded Na-K-Ca geothermometer estimates of close to 250°C (Moore et al., 2000). If this is representative of a hydrothermal upflow temperature at Cove Fort, then the fluids are unlikely to be circulating in the thermal regime depicted by the deep oil exploration wells in Figure 7.

CONCLUSIONS

Thermal gradient wells delineate a temperature and heat flow anomaly at 100 m depth that covers about 500 km^2 between Cove Fort-Dog Valley, the northern Mineral Mountains, and Twin Peaks at the southern end of the Black Rock Desert. The total heat output from this anomaly is 110 MW, which is twice the shallow heat flow from the RHS. The highest temperatures in deep wells at Cove Fort-Sulphurdale are between 170 and 180°C, but the thermal gradient in intrusive rocks below 2 km depth is only 30°C/km. Cooler, near-isothermal temperatures in a thick sequence of Paleozoic carbonates beneath this area suggest the geothermal water is mixing with cooler water in these very permeable rocks and that the large thermal anomaly is the result of lateral flow towards the north and west. Conductive heat loss at shallow depth is the dominant cause of cooling. Assuming a 150 °C cross-flow of water cooling conductively to 20 °C, this amounts to a flow of about 200 kg/s. This flow rate is a minimum value and any additional cooling by mixing with cold groundwater would increase the total heat loss and the mass flow. The high permeability in these carbonate units may be controlling the geothermal potentiometric surface, and causing the head at Cove Fort-Sulphurdale to be 300–400 m below the ground surface. Five deep oil exploration wells less than 30 km from Cove Fort-Sulphurdale show a regional thermal gradient of 23°C/km between 1 and 5 km depth. If the upflow zone at Cove Fort-Sulphurdale is deeply circulating water on the north-trending fault zone on the west side of the monzonite intrusion beneath the Tushars, then the water circulation has to penetrate to at least 7–8 km. If geochemical signatures in the Cove Fort-Sulphurdale water indicate temperatures of more than 200°C, then the source of the water is probably from deep beneath the central Mineral Mountains.

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