

Preliminary Geothermal Analyses of the Area at the Historic Old Faithful Pub, Yellowstone National Park



Figure 1. Panoramic view of the historic Old Faithful Pub located near the Old Faithful Inn. Notice the geyser its cone on the left of the photograph and the sloping land surface extending from the geyser cone towards the pub. The sloping land surface is the siliceous sinter apron produced by flowing hydrothermal water. On 22 July 2009, the temperature at 20 inches (51 cm) depth in the geyser cone was 186 °F (85.5 °C). Photograph taken on 26 June 2009, view to the north.



Figure 2. Aerial view of the historic Old Faithful pub taken on 20 August 2009. The complete removal of the building as part of the historic renovation allowed a detailed ground temperature survey. The outline of the former building can be seen in the center of the photograph. View is to the northeast.

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EXECUTIVE SUMMARY

A hydrothermal area is a contiguous geologic unit including one or more thermal features. The boundary marks the maximum spatial extent of hydrothermally altered soils, thermal deposits, geothermal gas emissions, or heated ground.

The historic Old Faithful pub is located within an active hydrothermal area. A significant portion of the area contains hydrothermally altered soils and hydrothermal deposits. At one location, hydrogen sulfide and carbon dioxide were measured in significant concentrations (>100 parts per million (ppm) hydrogen sulfide and 24.9% carbon dioxide). Boiling temperatures were found at two locations at 30 and 38 inches (76 and 96 cm) depth. Significantly elevated ground temperatures indicate an active hydrothermal area throughout the entire construction site.

INTRODUCTION

Herb Dawson and Mary Murphy of Yellowstone's Concessions Management Division provided Yellowstone National Park Geology Program personnel with final plans for preservation of the historic Old Faithful Pub during June 2009. The plans described the excavation of the entire area under the pub structure (about 6,000 square ft or 560 square m) from 1 to 4 ft depth (0.3 to 1.2 m), and excavations for curbing as well as water lines, and sewer lines.

Because construction is occurring within an active hydrothermal area, YNP Geology Program personnel undertook a reconnaissance of subsurface temperatures on 22 July 2009. A report on the reconnaissance entitled "*Temperature Measurements at the Historic Old Faithful Pub*" was completed on 27 July 2009. On 17 August 2009, Chris Lehnertz, Deputy Superintendent, Yellowstone National Park, and Tom Olliff, Division Chief, Yellowstone Center for Resources, requested a more complete geothermal analysis of the building site. The purpose of the more detailed study was to gather data for the characterization of the hydrothermal activity at the construction site

LOCATION OF STUDY AREA AND GEOLOGY

The area of the historic Old Faithful Pub is approximately 400 ft (122 m) to the southwest of the Old Faithful Inn (see Figure 3). The historic pub was built on the thermal ground of the Myriad Group.

Previous geologic mapping (Christiansen and Blank, 1974; Waldrop, 1975; and Muffler and others, 1982) shows the geologic setting of the Upper Geyser Basin and the Old Faithful hydrothermal area. Christiansen and Blank's (1974) bedrock map shows sediments and silica-rich sinter between the lava flows of the Mallard Lake Dome (Mallard Lake rhyolite flow) and the Madison Plateau (Summit Lake rhyolite flow). Mapping by Christiansen and Blank (1974) and Muffler and Others (1982) shows the location of the historic pub within the sinter plain (Figure 4). Waldrop's (1975) geologic mapping emphasizes the various types of sediments in the Upper Geyser Basin and Old Faithful area. He describes (1) the obsidian-rich sands eroded from nearby lava flows, (2) the hydrothermally deposited silica-rich, white to light gray sinter, and (3) various glacial and late glacial sediments. Muffler and others (1982) provides a detailed geologic map of the Upper Geyser Basin. Their detailed map clearly shows the location of the historic Old Faithful pub on silica-rich, white to light-gray sinter of the Myriad Group.

In the Upper Geyser Basin, a red-clay layer exists in the Old Faithful developed area. Red clay forms when hydrothermal waters interact with obsidian-rich sands. This red clay layer forms a barrier to boiling temperature steam and water flow. Excavation into this red clay layer can result in the sudden release of boiling-temperature fluids. Due to the importance of the red-clay layer, Yellowstone Park personnel sited the new Old Faithful Visitor Center away from areas with a red-clay layer. Additionally, while assessing potential hydrocarbon plumes at the lower gas station, Wyoming Department of Environmental Quality personnel terminated drilling when they encountered the red-clay layer.

Location Map of the Old Faithful Historic Pub

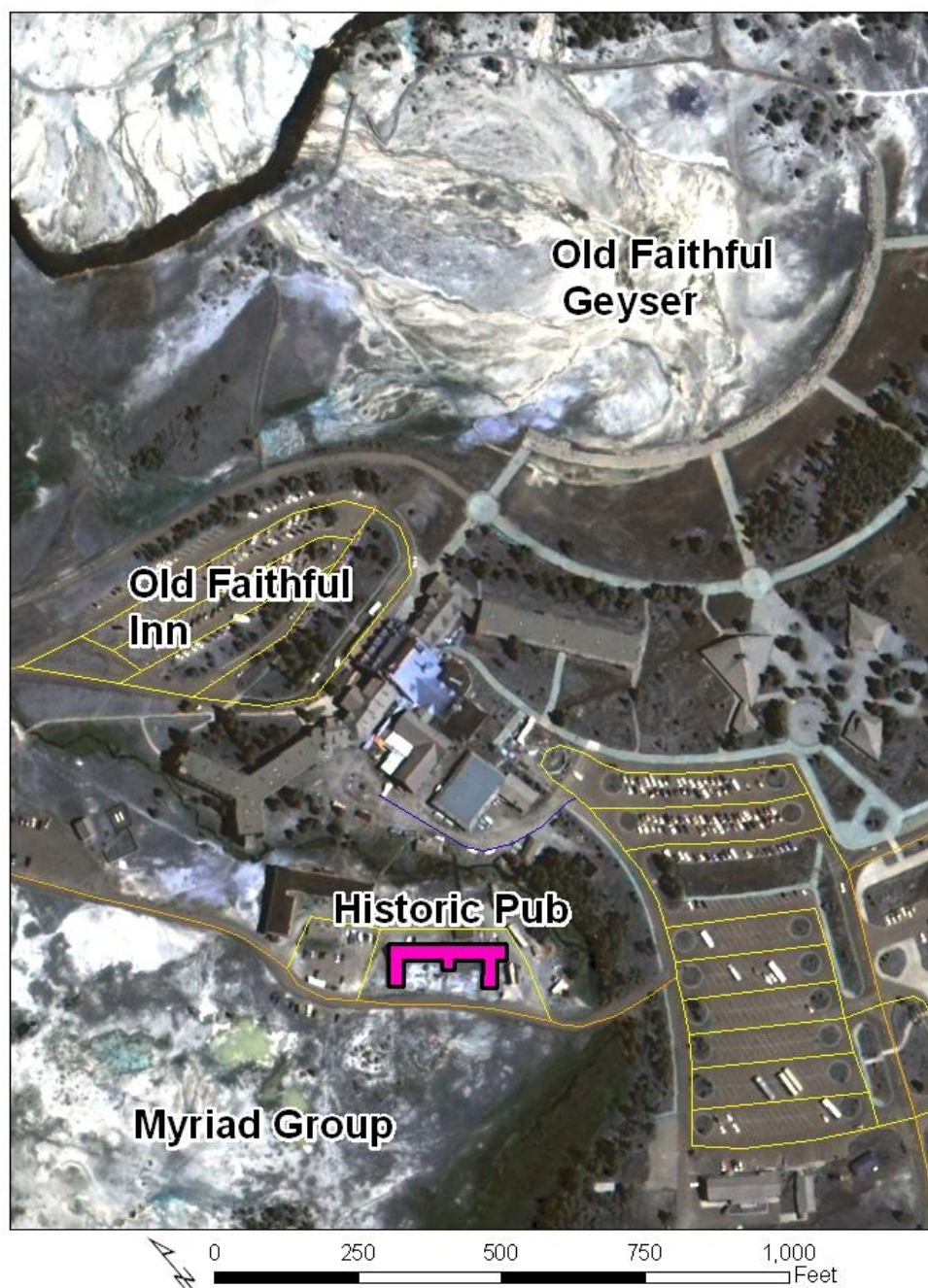


Figure 3. Map showing location of the historic Old Faithful Pub (hot pink) and roads (yellow). The Pub is southwest of the Old Faithful Inn along a service road that connects the lower gas station and Delaware North store with a parking lot northeast of the Old Faithful Ranger Station. Base map is a Quickbird satellite image taken 11 August 2006. Road layer (connector and special purpose roads) from the Yellowstone Spatial Analysis Center.

Bedrock Geology of the Old Faithful Area

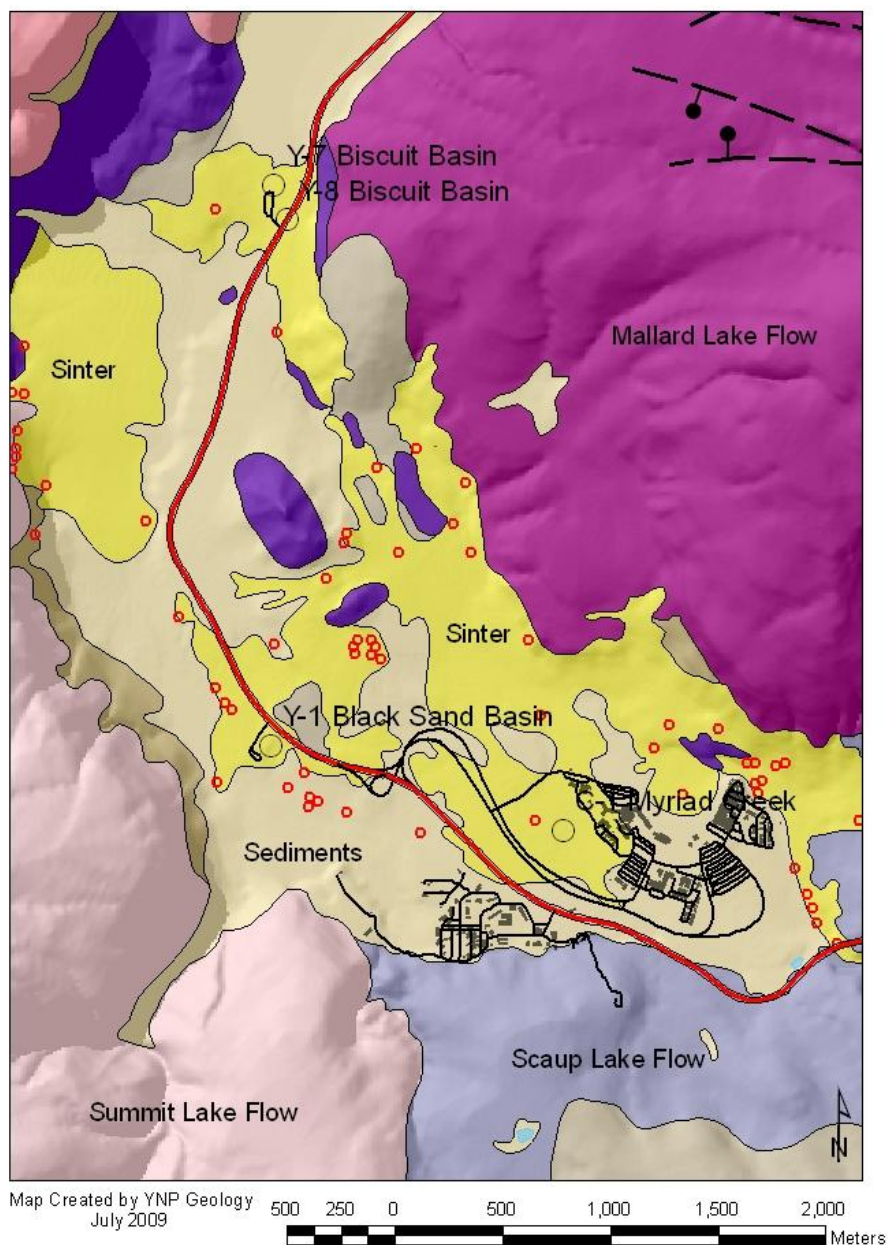


Figure 4. Map showing the bedrock geology of the Old Faithful area draped over topography (modified from Christiansen and Blank, 1974). Notice the lava flows (Mallard Lake (hot pink), Summit Lake (light pink) and Scaup Lake (lilac)) surrounding the Upper Geyser Basin. Sediments (tan) and sinter (yellow) are between the lava flows. An old lava flow (purple) crops out in the Upper Geyser Basin. The thick red line is the main road and the black lines are other roads in the Old Faithful area. Red circles are hydrothermal features from Christiansen and Blank, 1974.

METHODOLOGY

YNP Geology Program personnel measured subsurface temperatures in the construction area on 18 and 19 August 2009. With helicopter support, Yellowstone National Park geologists gathered oblique aerial photographs and airborne thermal infrared data of the construction site on 20 August 2009.

Field techniques included the measurement of ground temperatures at depths of 10 inches (25 cm), 20 inches (51 cm), 30 inches (76 cm), and 35 to 40 inches (89 to 102 cm). One team member drove a ½ inch (1.3 cm) diameter, 4-foot (1.2 m) long steel rod into the ground to allow temperature measurements. Geology personnel recorded temperatures, depth of measurements, red clay on the temperature probe, and ease of penetration into sediments or sinter in a field notebook.

A mobile mapping unit recorded accurate digital locations of the temperature sites. The mobile mapping system consists of a Trimble ProXH global positioning system (GPS) receiver with a Zephyr antenna and Allegro CX handheld field computer. After collecting temperature data, geology staff corrected the field locations using Trimble's GPS Pathfinder Office software and the Slough Creek Plate Boundary Observatory (PBO 720) precision GPS station. The horizontal accuracy of the corrected points generally varies from ±5.9 inches to 7.9 inches (±15 cm to 20 cm).

A FLIR Systems ThermoCAM SC640 imaged temperatures both on the ground and from a helicopter. An Oakton Acorn thermocouple-thermometer using a type K thermocouple measured ground temperatures to an estimated accuracy of ± 2.7 °F (± 1.5 °C) at a variety of depths.

A Bacharach 2825 gas meter measured concentrations of carbon dioxide and oxygen gases while a RKI GX-2003 gas meter measured the concentrations of hydrogen sulfide, carbon monoxide, and methane gases. Fresh-air calibrations of both gas sensors occurred on 18 and 19 August 2009 approximately 65 feet (20 m) northwest of the construction site.

Geology personnel also measured the pH of steam from an active steam vent. **ColorpHast** pH indicator strips measured the acidity of steam condensate in a condensation chamber of the Bacharach 2825 gas meter.

RESULTS AND DISCUSSION

SECTION 1: Subsurface Temperatures

Temperature measurements at the historic pub site are consistent with an active thermal area. Figures 5, 6, 7 and 8 show the results of the temperature survey. All temperatures (Figures 5 through 8) are significantly greater than temperatures in a non-geothermal area. Two sites clearly indicate boiling temperatures at 30 and 38 inches (76 and 96 cm) depth (Figures 7 and 8). At the elevation of the Old Faithful area, (about 7,300 feet (2,225 m)), the boiling temperature is 198 °F (92 °C). The pattern of high temperatures extends over the entire survey area, with highest temperatures measured in the northern and northwestern construction area.

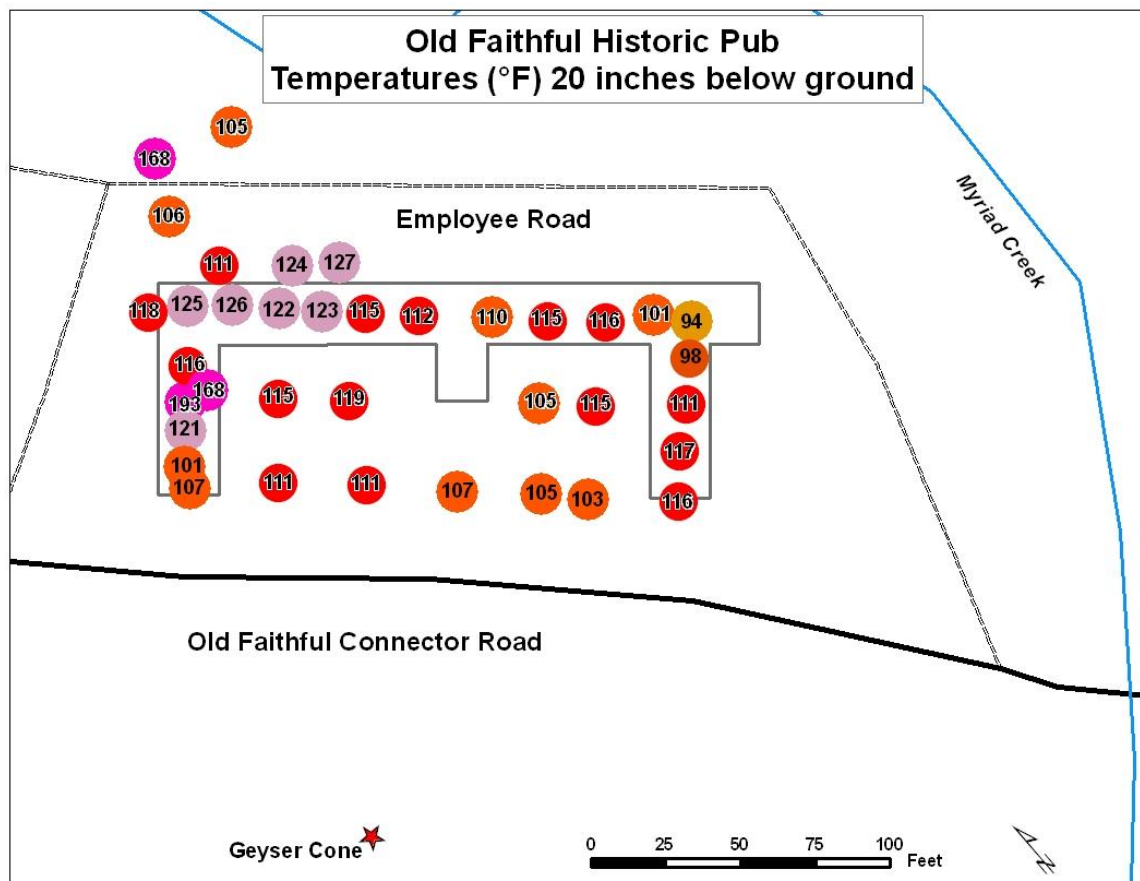


Figure 6. Map of the historic pub showing temperature measurements (in degrees Fahrenheit) at 20 inches (51 cm) depth. Temperatures measured 18 and 19 August 2009.

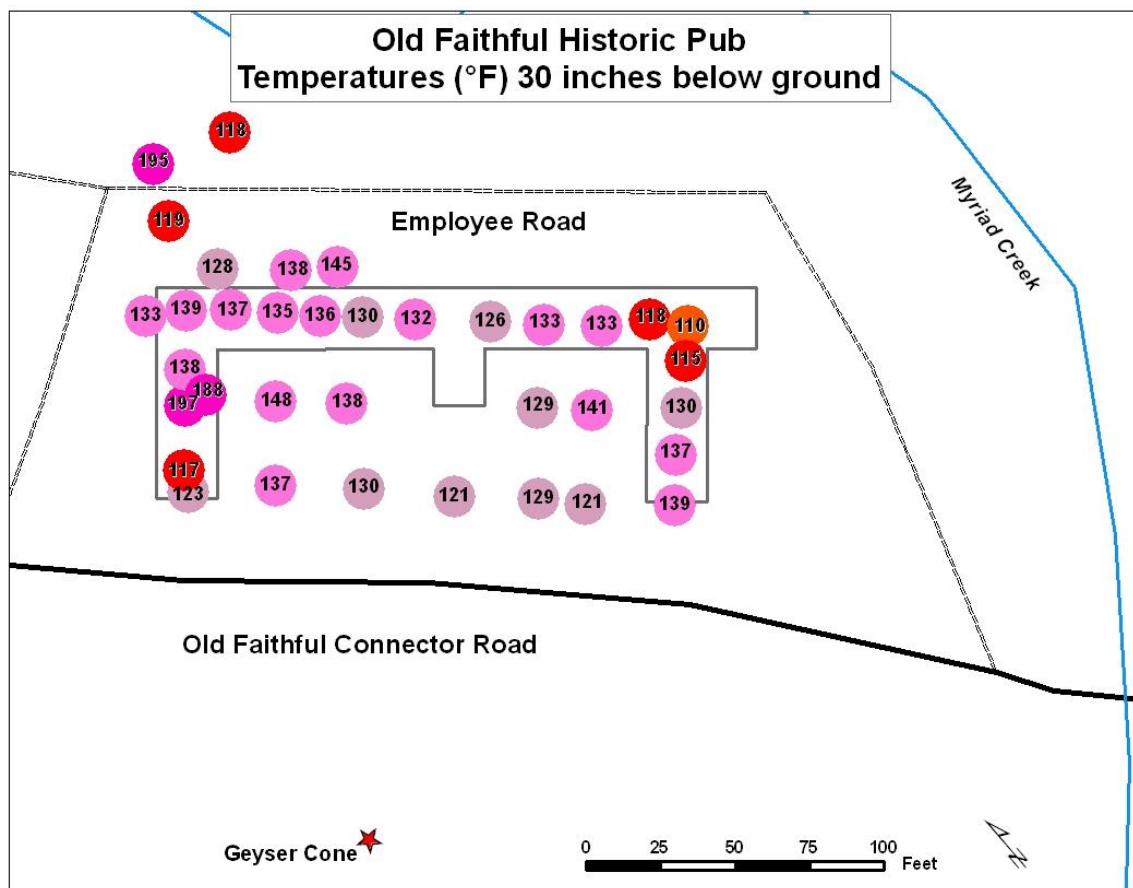


Figure 7. Map of the historic pub showing temperature measurements (degrees Fahrenheit) at 30 inches (76 cm) depth. Note the 197 °F (91.7 °C) temperature in the former northwest wing of the historic pub. Temperatures measured 18 and 19 August 2009.

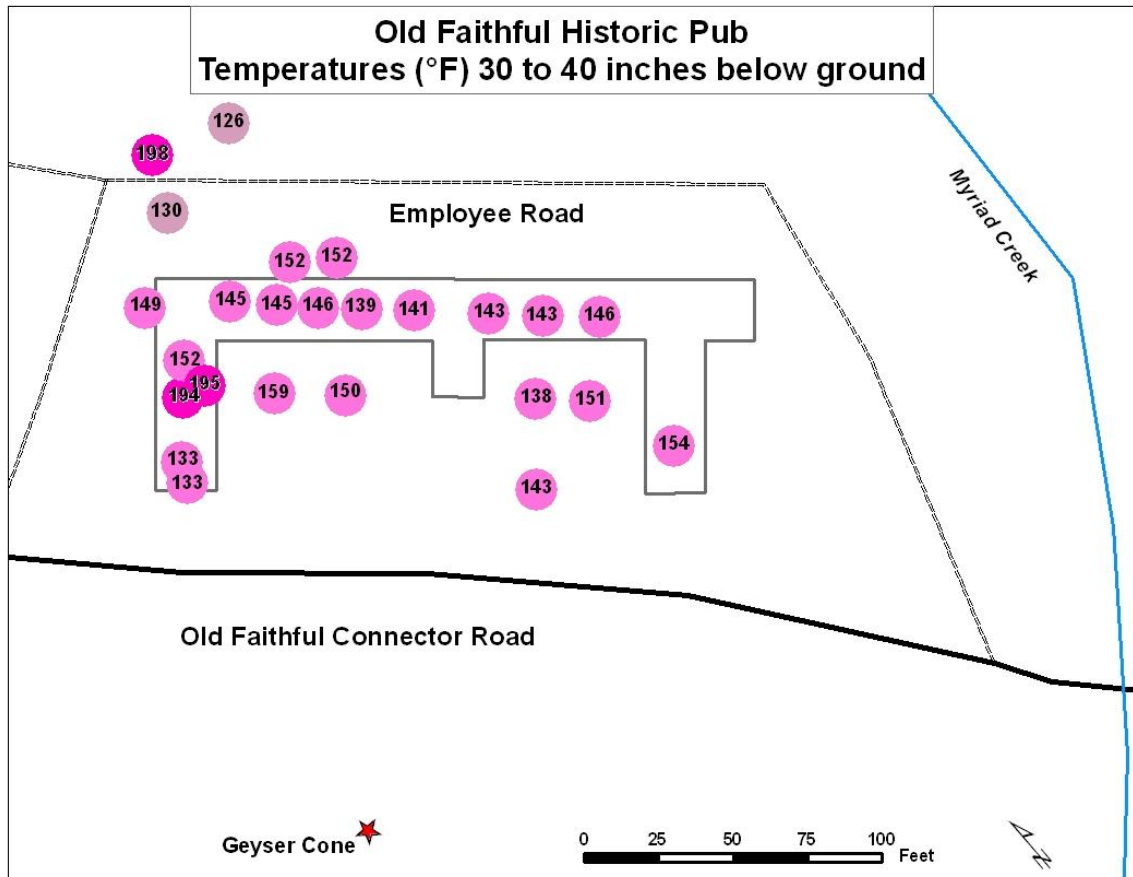
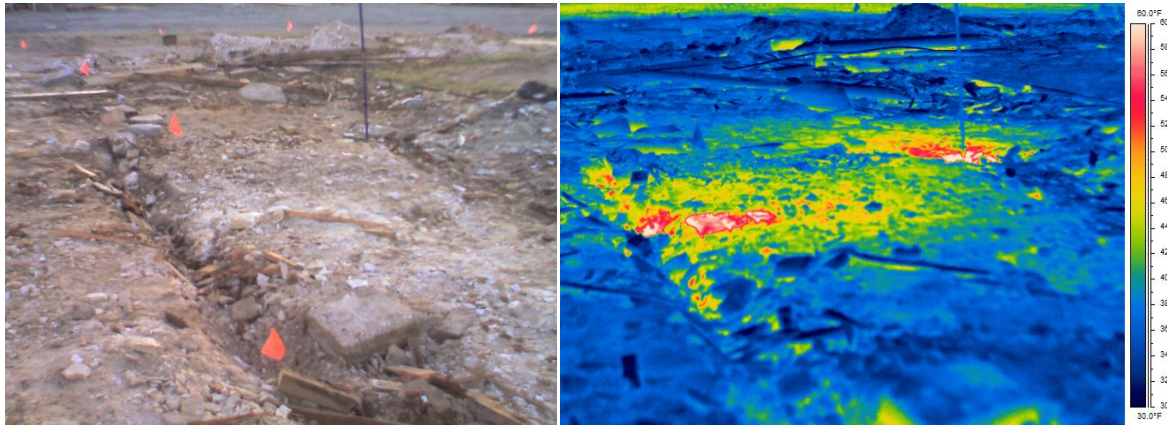
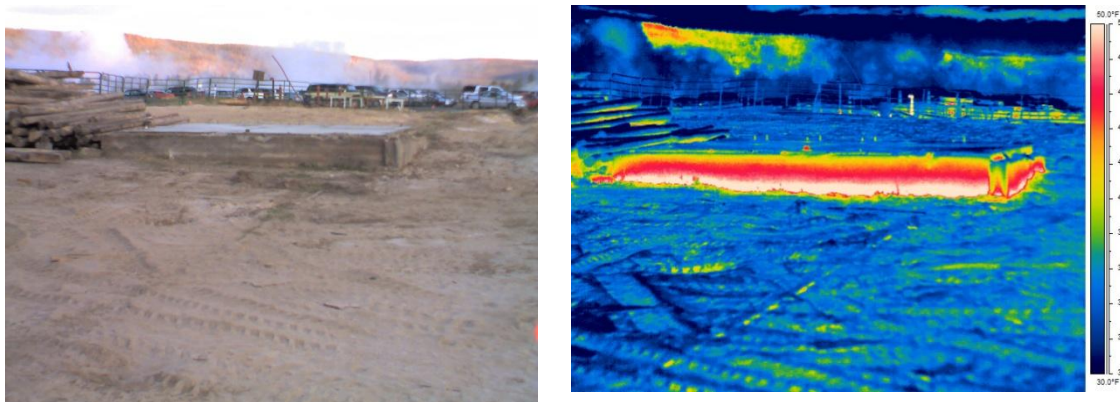


Figure 8. Map of the historic pub showing temperature measurements (degrees Fahrenheit) at depths 35 to 40 inches (89 to 102 cm). Note the 198 °F (92.2 °C) temperature in the northern portion of the map. Temperatures measured 18 and 19 August 2009.

The unusually high temperatures in the area also can be seen using a forward-looking thermal infrared (FLIR) camera that images heat and converts the heat to temperature. Figure 9a and 9b are images of the former northwestern extension of the historic pub where two high temperature areas were viewed. These two areas were probed with the thermocouple and are shown on Figures 5 through 8. In Figure 8, the 194 °F (90.0 °C) and 195 195 °F (90.6 °C) temperatures in the former northwestern wing were taken at 35 to 40 inches depth in the hot areas (shown in Figure 9). Figure 10 shows a concrete slab that formed the floor in the middle of the building and extends to the southeast. The FLIR image clearly shows the effect of heat being transferred from the ground into the concrete footer.



Figures 9 a & b. Visible (left) and forward looking thermal infrared image (right) showing hot areas along the former wooden floor and northwest corner of the historic pub. The temperature probe was pushed into these hot areas (See Figure 8 temperatures 194 °F (90.0 °C) and 195 °F (90.6 °C). Photograph taken 19 August 2009, 6:50 a.m. MDT. View is to the northeast.



Figures 10 a & b. Visible (left) and forward looking thermal infrared image (right) showing heat being conducted from the ground through the concrete footer. The footer existed in the middle of the building and extended to the southeast. View is to the southeast. The steam in the background of the photograph is from the Myriad Group. Photograph taken 19 August 2009, 6:53 a.m. MDT.

SECTION 2: Field Observations

One effect of high temperatures is the alteration and subsequent softening of the ground. This can be clearly seen in Figure 12. Figure 12 shows locations where the thermocouple probe could be hand-pushed below 30 inches (76 cm) depth. Because the 41 inch (104 cm) length thermocouple probe (Figure 11) is relatively flexible, any penetration of the probe into undisturbed ground means the ground is relatively soft. Thus, Figure 12 maps the area of soft ground resulting from both hydrothermal alteration and the deposition of soft, thermal deposits.



Figure 11. The Oakton Acorn thermocouple-thermometer using a type K thermocouple probe that is a hollow ¼ inch (6.4 mm) diameter, stainless-steel tube, 41 inches (104 cm) in length. Photograph was taken in the construction area on 18 August 2009. Chelsea Feeney, Geological Society of America Geocorps volunteer, is measuring temperatures at 10 inches (25 cm) depth.

The structural stability of a hydrothermally altered area may be assessed by how well the area supports people and equipment. A breakthrough of equipment at the construction site occurred in two locations on 12 August 2009.

On 18 August 2009, Brent Cotton, Site Superintendent for Swank Enterprises described the equipment breakthrough (Figure 13) on 12 August 2009 at two sites:

Tire Site 1:

“Gradall forklift 534D-9 pulled into existing building location and the rear tire sank into a mud pit, like squeezing, wet, saturated mud. Color of mud was red. And it was hot. Gradall also was empty. Gradall forklift had to be pushed out with an excavator.”

Tire Site 2:

“About 15 to 20 feet to the west, operator was pulling into site with Gradall 534D-9 (empty) and as he was driving in, the ground started to make a wave or move under the tires. The rear tires sank into the mud hole. The mud hole was hot, red, and squishy.”

On 17 August 2009, Brent Cotton and a laborer dug test pits with a shovel along the northern edge of the building and found two more sites with red clay. Brent estimated that the shovel pits were 1 foot deep.

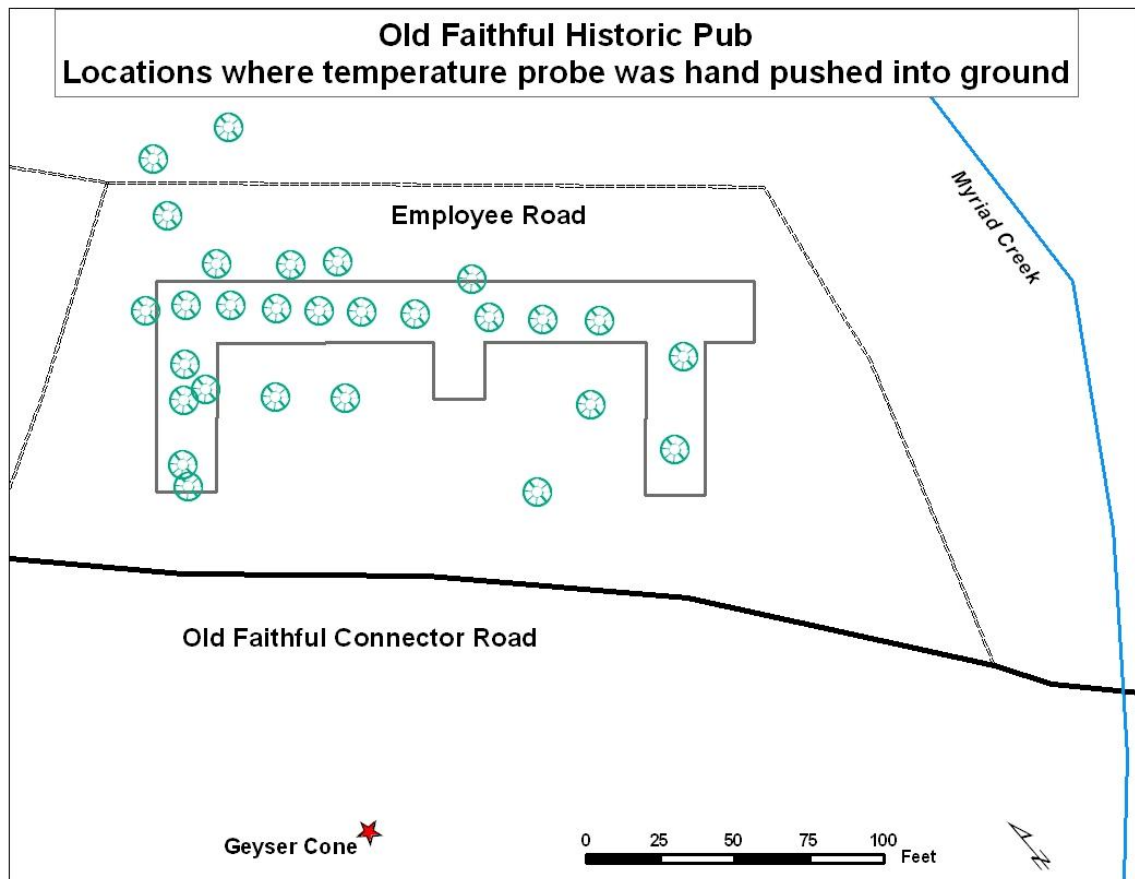


Figure 12. Map of locations where the thermocouple probe could be hand-pushed below 30 inches (76 cm) depth

Another independent assessment of ground stability was observed on 18 August 2009. At the construction site, the tracked excavator was crushing lumber taken from the historic pub. This was accomplished by dropping the excavator's bucket onto the pile of removed lumber. On the northeastern portion of the construction site, the impact of the excavator's bucket could be felt through the ground as sharp impacts. These sharp impacts reverberated through the ground as if the ground was hollow. On the eastern portion of the construction site, the impact of the excavator's bucket felt as if the ground was rolling, similar to gelatin shaking in a bowl. These observations were made by Henry Heasler and Cheryl Jaworowski, Geologists for Yellowstone National Park, Brent Cotton, Site Superintendent for Swank, and Herb Dawson, Project Manager for Concessions Management Division, Yellowstone National Park.



Figure 13. Photograph of fork lift that twice broke the ground surface into active thermal ground on 12 August 2009 between 3 to 3:30 p.m. MDT. Photograph taken 18 August 2009. Location of the two breakthroughs are shown in Figure 8 noted by the 152 °F (67 °C) temperatures outside the northeastern edge of the building.

Examination of excavated rocks and trenches show the following sequence of rocks from top to bottom (0 to 40 inches (0 to 102 cm) or less): (1) a soft, lightweight, layered rock, (2) silica-rich sinter of variable hardness and open spaces and (3) a red-clay layer underneath hard sinter. The top layer (Figure 14) easily can be broken by hand. Construction crushed this layer and spread a fine, light tan or grey powder over the site. This fine powdered sediment limits the maximum surface temperatures recorded by the FLIR camera. The silica-rich sinter (Figure 15) can be made of fragments of sinter cemented together or can be a solid and very hard layer. The hardest layer of sinter occurs just above the red-clay layer (Figure 16). In order to measure a temperature with the flexible temperature probe, this very hard layer had to be penetrated with a steel rod. After penetration of this layer with a rod, the temperature probe could be pushed by hand into the red-clay layer (Figure 17). This same sequence of rocks occurs throughout the entire area of the historic pub.

Previous construction of a water line along the Old Faithful Connector Road (Refer to Figure 5) also provides evidence of this active hydrothermal area. The construction of this water line resulted in the demise of Round Geyser either immediately or soon after construction around 1980 (Personal Communication, Jennifer Whipple, 2009). A fire hydrant associated with this water line ejected steam when opened.



Figure 14. Photograph of top layer exposed in a trench. This layered sediment easily breaks by hand.

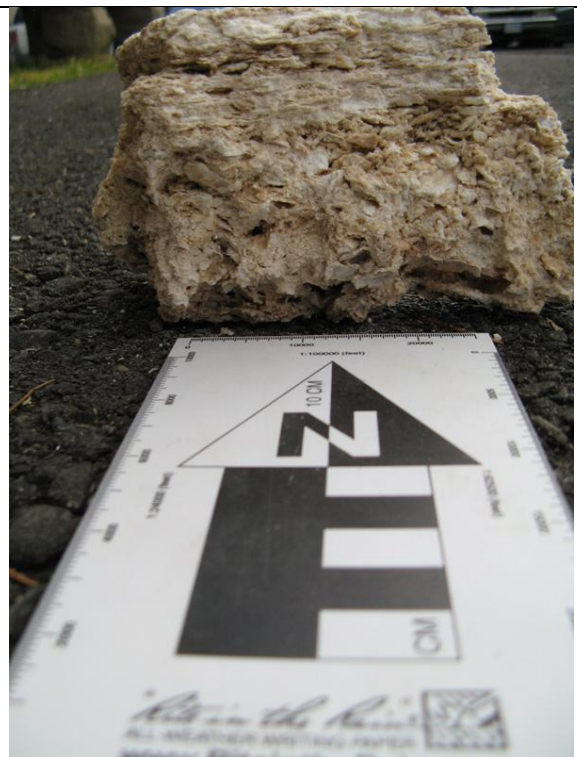


Figure 15. Photograph of layered and porous, fragmental sinter below soft top layer.



Figure 16. Photograph of hard sinter and red-clay layer.

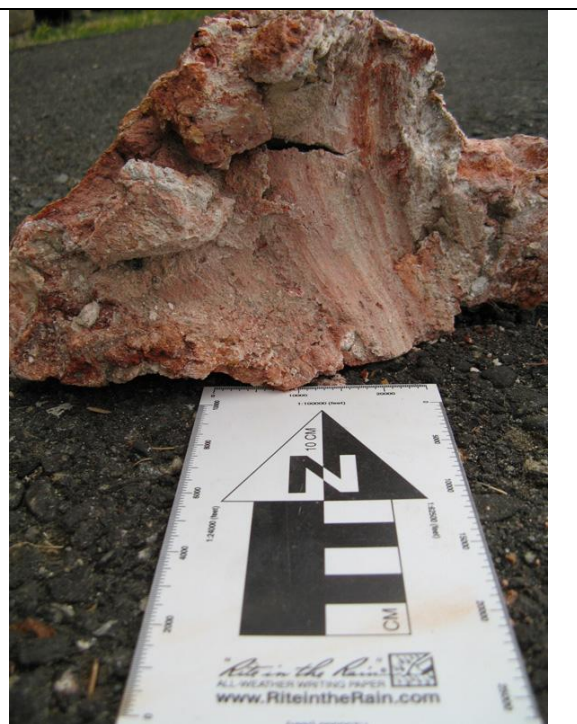


Figure 17. Photograph of red-clay layer. According to Brent Cotton, this was soft, wet, and hot when the forklift's tires broke through the ground.

SECTION 3: Geothermal Gases

Yellowstone National Park's active geothermal system produces toxic gases such as hydrogen sulfide (H₂S) and carbon dioxide (CO₂). Historically, people observed animals killed by natural, toxic emissions of gases. But, few of Yellowstone's hydrothermal areas occur in topographic depressions and thus toxic gases generally do not reach fatal concentrations. Because of factors such as wind, the likelihood of a fatal exposure is remote in most areas.

The death of animals by toxic geothermal gases is not unusual in Yellowstone National Park. In the upper Lamar River valley, Weed (1889), noted the death of six bears, one elk, and "several squirrels, rock hares, and other small mammals, besides numerous dead butterflies and insects" in an area now called Death Gulch. In the late 1800's, Jagger (1899) also wrote of naturally occurring toxic gases in the northeast corner of Yellowstone and noted 7 dead bears in Dead Gulch. Ravines or topographically low areas can accumulate the dense, toxic gases during times of still air. A cursory survey of holdings at the Yellowstone Research Library indicates that many other people have recognized the dangers of toxic gases within Yellowstone (Ash, 1939; Frisbee, 1960, Fournier, 1959; Love and Good, 1970; Traphagen, 1904, Heasler and Jaworowski, 2004, Heasler and others, 2008). Only one human death has been attributed to toxic gases (Ash, 1939, Love and Good, 1970).

Hydrogen sulfides's effect upon humans varies with concentration. The odor of H₂S increases up to 30 ppm (parts per million). At concentrations of 1-30 ppm, humans recognize its characteristic rotten-egg smell. From 30-100 ppm, humans recognize H₂S gas as "sickeningly sweet". Above 100 ppm, a human's ability to detect H₂S is impaired. Prolonged exposures can lead to bronchitis, pneumonia, headaches, irritations of eyes, nose or throat, dizziness, nausea, shock, convulsions, coma, or death.

Hydrogen sulfide (H₂S) is a **chemical asphyxiant**, similar to carbon monoxide and cyanide gas. It inhibits cellular respiration and the uptake of oxygen, causing biochemical suffocation. With a vapor density of 1.19, hydrogen sulfide is approximately 20 percent heavier than air, so this invisible gas may collect in depressions on the ground and within confined spaces.

Another toxic gas that occurs in geothermal areas is carbon dioxide (CO₂). At a concentration of 10%, carbon dioxide paralyzes the human respiratory system. The result is fatal with no evidence of an agonal struggle. The ratio of carbon dioxide to hydrogen sulfide in most geothermal areas ranges between 1,000 to 1 to 100 to 1 (Bill Evans, United States Geological Survey, Personal Communication, March, 2004).

The concentration of CO₂ in fresh outdoor air is around 330 ppm (0.033%). Carbon dioxide can become slightly elevated indoors where there is insufficient ventilation. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) currently recommends that indoor CO₂ levels not exceed the outdoor concentration by more than about 600 ppm (Western Area Power Administration, 2008). The Occupational Safety and Health Administration (OSHA) identifies 5000 ppm (0.5%) as

the permissible exposure limit of carbon dioxide contaminant in air, over an 8-hour time-weighted average (OSHA, 2006).

Hydrogen sulfide and carbon dioxide can accumulate in topographically low areas on cold, calm nights because they are denser than air. Increased gas production may be associated with changes in thermal activity.

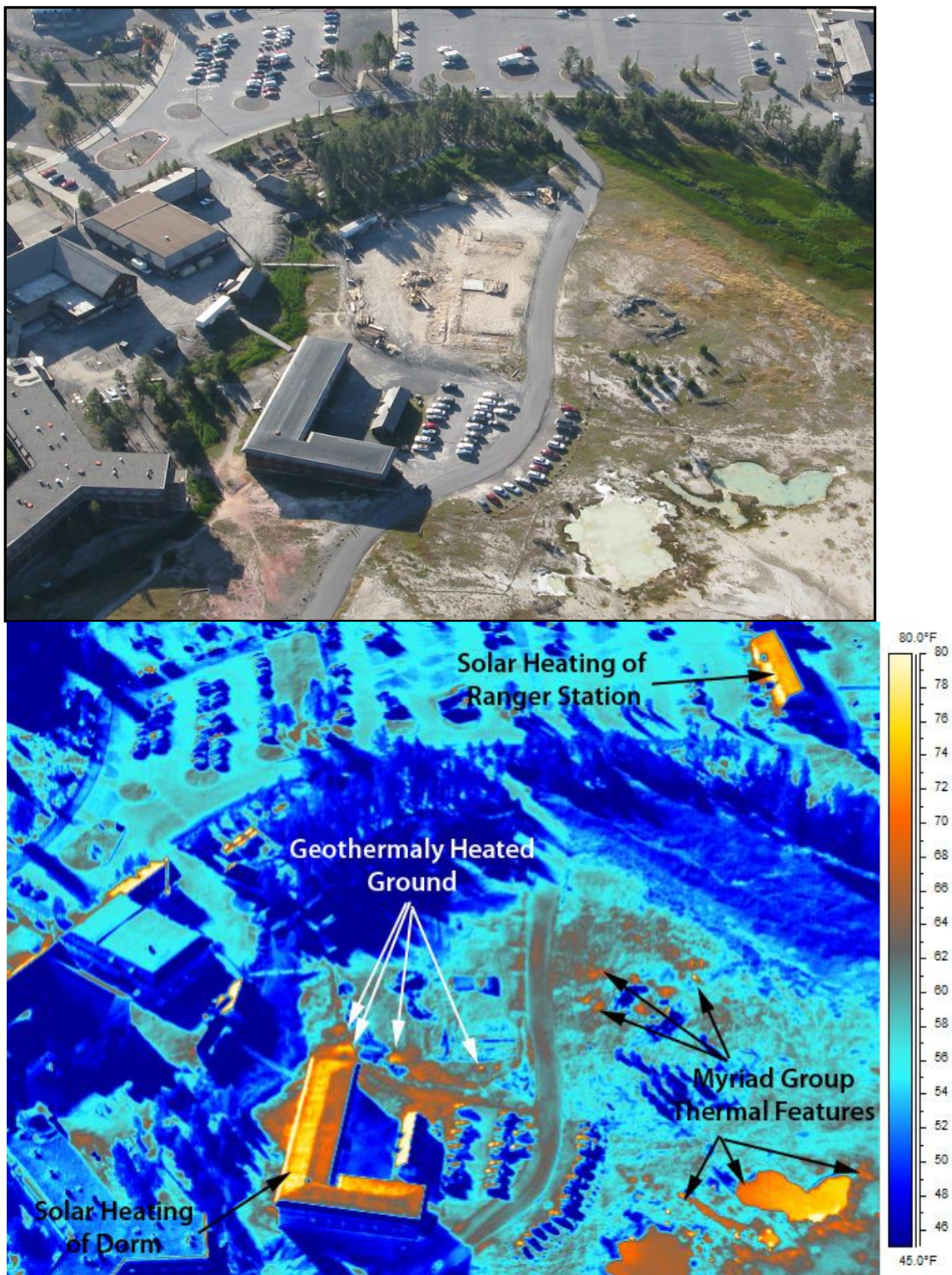
Geothermal gases were measured at the site of the 30 inch (75 cm) depth, 197 °F (91.7 °C) temperature (Figure 6). At this site, the temperature hole was emitting steam vigorously on 18 and 19 August 2009. Gas concentrations were measured at a depth of 3 inches (8 cm) in the hole on 18 August 2009 and 6 inches (15 cm) on 19 August 2009. The pH of the steam condensate from this hole was 5 using pH paper.

Date	Carbon Dioxide (%)	Hydrogen Sulfide (ppm)	Oxygen (%)	Carbon Monoxide (ppm)	Lower Explosive Limit (%)
18 August 2009	16.4	>100	20.5	0	0
19 August 2009	24.9	>100	19.9	0	10.0

SUMMARY

The historic Old Faithful pub is located within an active hydrothermal area. Evidence supporting this statement includes the widespread occurrence of hydrothermally altered soils and hydrothermal deposits at the site of the historic pub. Additional evidence includes a significant and singular measurement of hydrogen sulfide and carbon dioxide gas concentrations (>100 ppm hydrogen sulfide and 24.9% carbon dioxide). Boiling temperatures were found at two locations at depths of 30 and 38 inches (76 and 96 cm). Significantly elevated ground temperatures that indicate an active hydrothermal area are found throughout the site.

The extent of hydrothermal heating in the area of the historic pub can be seen on an aerial oblique thermal infrared image taken on 20 August 2009. Since the thermal image was acquired approximately one hour after sunrise, solar heating is obscuring some of the weak geothermal heating signals. Also, the movement of equipment at the site of the building masks the geothermal signature due to finely powdered dirt. However, hydrothermally heated ground (Figures 15 a & b) is visible at the construction site. The high temperatures in Figure 15b clearly show that the construction site is immediately adjacent to the Myriad Group and probably is part of this thermal group.



Figures 15 a & b. Airborne thermal IR taken 20 August 2009 at 8:48 a.m., MDT. Sunrise was approximately 6:30 a.m., MDT. Solar heating of the nearby dormitory and cars is evident. Solar heating is starting to mask the heat from the Myriad Group. Within the undisturbed Myriad Group, the small orange areas are thermal features.

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