

Analyses of Ground Temperatures and Geothermal Gases in the Laurel Dormitory Area at Old Faithful, Yellowstone National Park

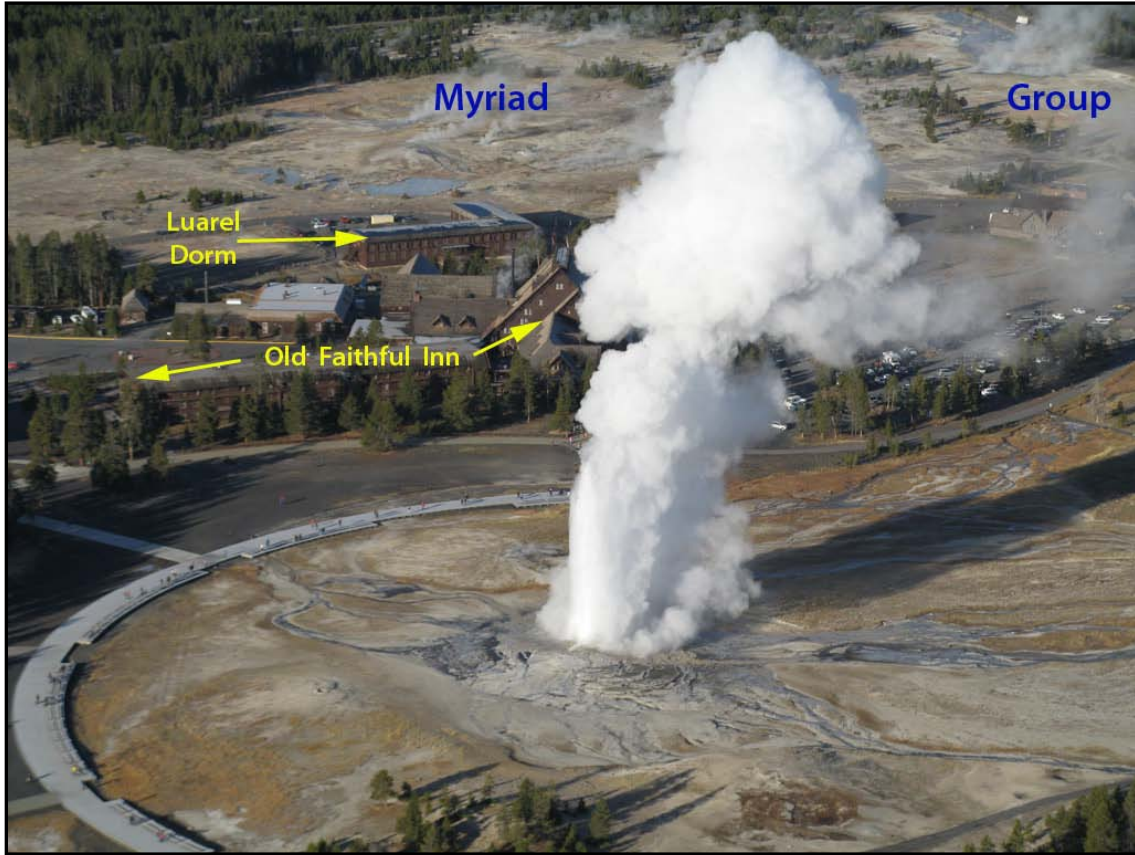


Figure 1. Oblique, aerial photograph showing Laurel Dormitory and its relationship to Old Faithful Geyser, the Old Faithful Inn, and the Myriad Hydrothermal Group. Photograph taken on 12 October 2010, view to the west.

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EXECUTIVE SUMMARY

A hydrothermal area is a spatially contiguous area that usually includes one or more thermal features. The surficial boundary of a hydrothermal area marks the maximum spatial extent of hydrothermally altered ground, thermal deposits, geothermal gas emissions, or heated ground.

The Laurel Dormitory at Old Faithful is located within an active hydrothermal area. Significantly elevated subsurface temperatures were found throughout the study area. Maximum temperatures were 110.0 °F (43.9 °C) at 10-inches (25 cm) depth, 123.1 °F (50.6 °C) at 20-inches (51 cm) depth, and 134.1 °F (56.7 °C) at 30-inches (76 cm) depth. Maximum subsurface carbon dioxide concentrations exceeded OSHA values: 19.6 % at 10-inches (25 cm) depth, 42.2% at 20-inches (51 cm) depth, and 17.4% at 30-inches (76 cm) depth. Hydrogen sulfide was detected at three locations, varying between 24.1 to 70 ppm. A significant portion of the area contains hydrothermally altered clays. Hot spring deposits were encountered at 10-and 20-inch (25 to 51 cm) depths at a variety of locations. Significantly elevated ground temperatures, the presence of geothermal gases, hydrothermally altered ground and hot spring deposits indicate an active hydrothermal area surrounding and beneath Laurel Dormitory.

INTRODUCTION

In April 2010, Chris Lehnertz, Deputy Superintendent of Yellowstone National Park, requested a geothermal assessment of the area surrounding Laurel dormitory. Mary Murphy of Yellowstone's Concessions Management Division requested Xanterra Parks and Resort contract for gathering temperature and geothermal gas data for the study. Mark Siedlaczek of Xanterra received a proposal on 12 May 2010 from Tetra Tech in Billings Montana, to conduct soil gas monitoring at the Laurel Dormitory. Tetra Tech was on site at the Laurel Dormitory from 7 to 22 June 2010 to measure temperature, carbon dioxide, and hydrogen sulfide gases. Tetra Tech sent their completed report to Mary Murphy on 30 July 2010.

The Yellowstone National Park Geology Program received a copy of the Tetra Tech report on 13 August 2010. It was the responsibility of the Geology Program to scientifically analyze and interpret the data gathered by Tetra Tech. The interpretation focused on any potential geothermal activity near Laurel Dormitory.

LOCATION OF STUDY AREA AND GEOLOGY

The area of Laurel Dormitory is approximately 410 ft (125 m) the southwest of the main portion of the Old Faithful Inn (see Figures 1 and 2). The dormitory is approximately 80 ft (24 m) south of the west wing of the Old Faithful Inn. The dormitory was built on hydrothermal clays and hot spring deposits associated with 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 (UGB) and the Old Faithful (OF) 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 Laurel Dormitory within the sinter plain (Figure 3). Waldrop's (1975) geologic mapping emphasizes the various types of sediments in the UGB and OF 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 Laurel Dormitory on silica-rich, white to light-gray sinter of the Myriad Group.

In the UGB, hydrothermal clays that are pink, peach, white, tan and red occur in the study area. A red-clay layer exists in the OF developed area and it is important not to penetrate the red clay. 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 OF Visitor Center away from areas with red-clay. Additionally, while assessing potential hydrocarbon plumes at the lower gas station, Wyoming Department of Environmental Quality personnel terminated drilling when they encountered red-clay.

Location Map of Laurel Dormitory



Figure 2. Map showing location of the Laurel Dormitory (hot pink). The dormitory 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.

Bedrock Geology of the Old Faithful Area

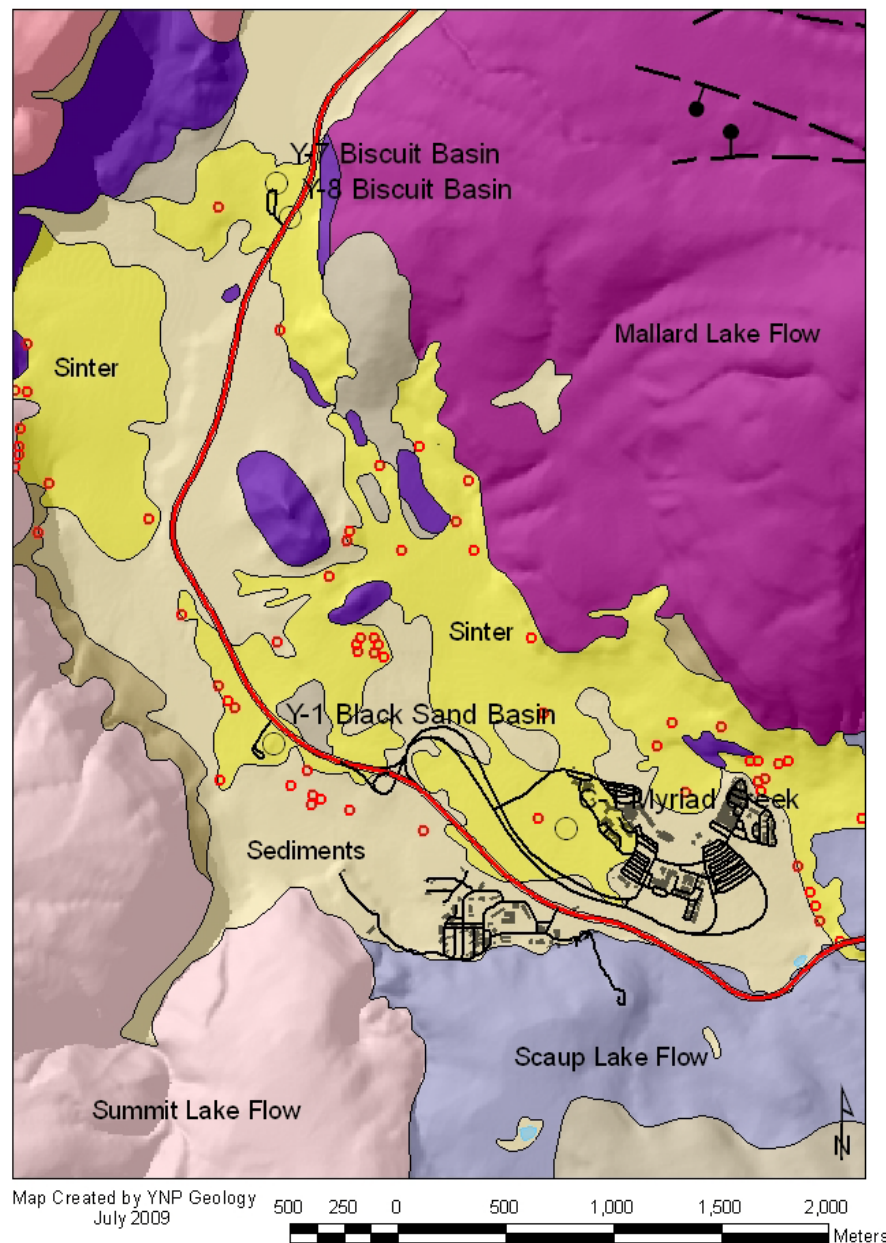


Figure 3. Map showing the bedrock geology of the Old Faithful area draped over topography (modified from Christiansen and Blank, 1974). Notice the lava flows (Mallard Lake (hot pink), Summit Lake (light pink) and Scaup Lake (lilac) surrounding the Upper Geyser Basin. Sediments (tan) and sinter (yellow) occur 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.

METHODS

Tetra Tech personnel measured subsurface temperatures, carbon dioxide, and hydrogen sulfide gases in the area of Laurel Dormitory from 7 to 22 June 2010. The following description of Tetra Tech methods is taken from “Summary Report – Soil Temperature & Gas Monitoring, Laurel Dormitory, Old Faithful, Yellowstone National Park, July 30 2010, Tetra Tech Project No. 550365.100:

“Tetra Tech personnel Mr. Shane Ewert and Mr. Shawn Reinhart conducted soil gas and temperature monitoring at the site during June 7-22, 2010. Prior to collection of the data, the investigation area was delineated into a grid with sample points defined on ten feet by ten feet centers. These drill points’ geoposition coordinates were recorded using a Topcon Model GR3E12-XT geographic positioning system (GPS) unit with a horizontal precision of 0.033 feet and the datum NAD 1983 Wyoming State Plane. Three-quarter inch diameter holes were drilled in each delineated test area using a rotary hammer drill with 36-inch drill bit. Each test area was drilled to ten-inch intervals with a final depth of thirty inches. Figure 2 shows the boring grid layout: and all sample locations are included in Table 1.

Measurements of CO₂ and H₂S concentrations and soil temperatures (degrees Fahrenheit) were collected at 10-inch, 20-inch, and 30-inch depth increments and recorded on a field sheet (Attachment B). The temperature data was converted to Celsius using a Microsoft Excel spreadsheet. CO₂ concentrations were measured using an RKI EAGLE 72-5401RK gas monitoring unit. H₂S concentrations were measured using a RAE QRAE2P. Temperature was measured using a TCI Velociacalc meter. The CO₂ and H₂S instruments were factory calibrated by TRS Environmental on June 2, 2010 (Attachment A) and rechecked daily to zero ambient air conditions.”

Yellowstone National Park geologists acquired oblique, aerial photographs, airborne thermal infrared images and ground thermal infrared images of the Laurel Dormitory area on 19 August 2009, and 12 October 2010. Both airborne and ground thermal infrared imagery allows the visualization of the pattern of heat being radiated from the ground, vegetation, buildings or other objects. A FLIR Systems ThermaCAM SC640 was used to capture the “skin-temperature” (the outermost few microns) of objects in thermal infrared images. The thermal infrared energy captured by the FLIR ThermaCAM SC640 was in the 8-12 micron range.

Subsurface temperature, geothermal gases, and other data gathered by Tetra Tech were mapped and displayed using ArcGIS software. The temperature maps show ground temperature at 10-inch, 20-inch and 30-inch depths (25, 51, or 76 cm). Subsurface temperatures generally are greater than the “skin-temperatures” in the FLIR thermal infrared imagery. An increase of subsurface temperature with depth is to be expected in an active hydrothermal area. Maps of geothermal gases and hydrothermal deposits are consistent with an active hydrothermal area.

RESULTS AND DISCUSSION

SECTION 1: Subsurface Temperatures

Temperature measurements at the Laurel Dormitory area are consistent with an active thermal area. Figures 4, 5 and 6 show the results of the temperature survey at depths of 10 inches (25 cm), 20 inches (51 cm) and 30 inches (76 cm). All temperatures (Figures 4 through 6) are significantly greater than temperatures in a non-geothermal area. The highest temperature, 134 °F (57 °C) at 30 inches (76 cm), exists under the southeast portion of the dormitory. This area under the dormitory contains consistently high temperature (Figures 4 though 6)

The pattern of high temperatures extends over the entire survey area, with highest temperatures measured under the dormitory, to the northwest of the dormitory, and to the southeast of the dormitory. No boiling temperatures were encountered. At the elevation of the Old Faithful area, (about 7,300 feet or 2,225 m), the boiling temperature is 198 °F (92 °C).

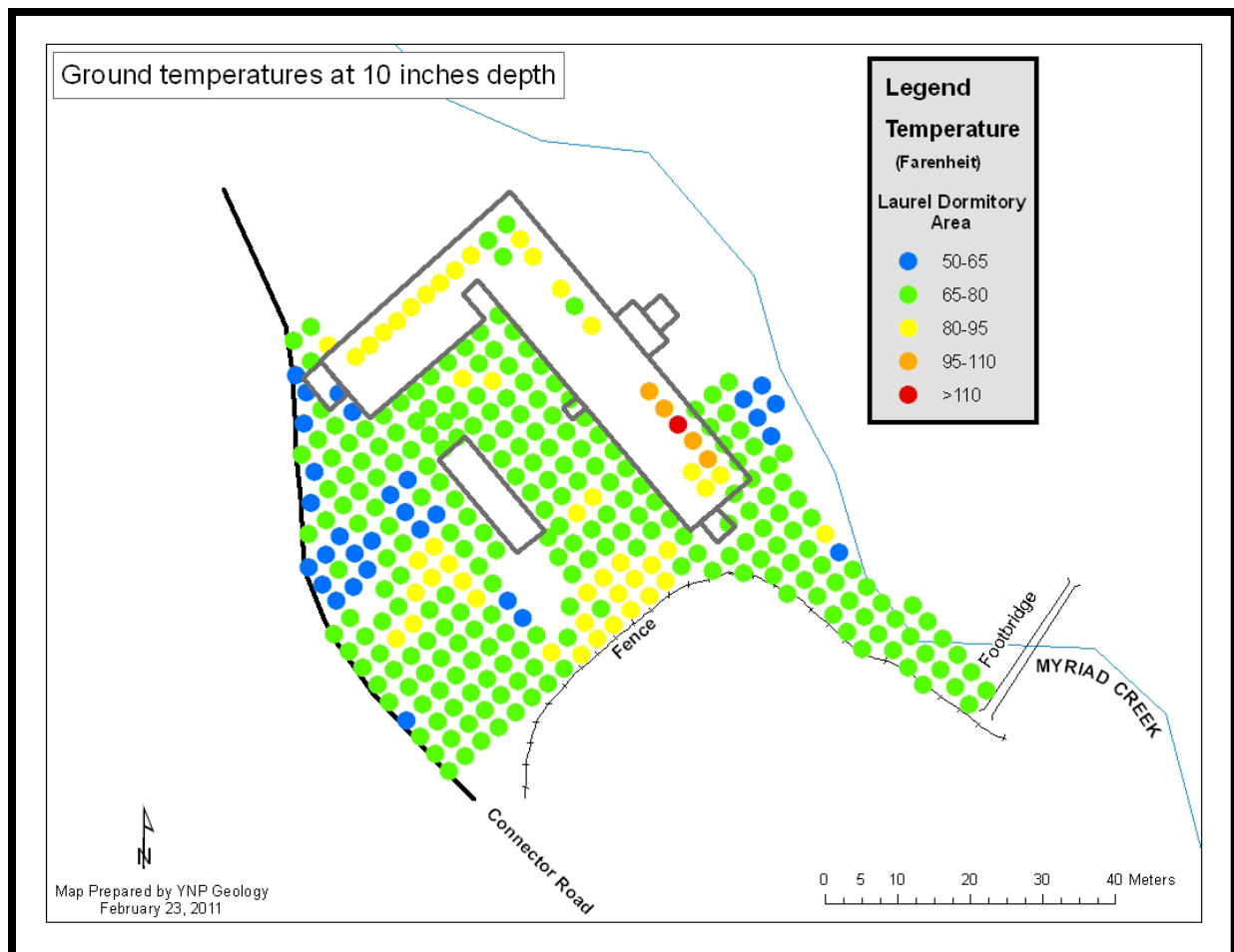


Figure 4. Laurel Dormitory area temperature measurements (in degrees Fahrenheit) at 10 inches (25 cm) depth. Temperatures measured 7 to 22 June 2010.

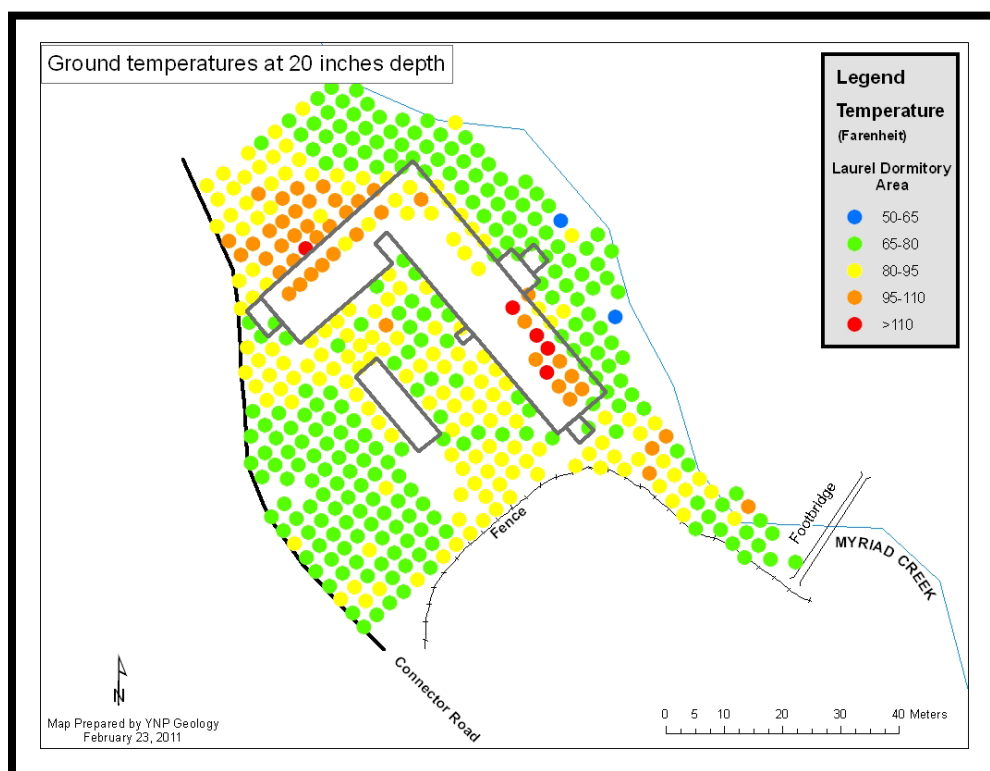


Figure 5. Laurel Dormitory area temperature measurements (in degrees Fahrenheit) at 20 inches (51 cm) depth. Temperatures measured 7 to 22 June 2010.

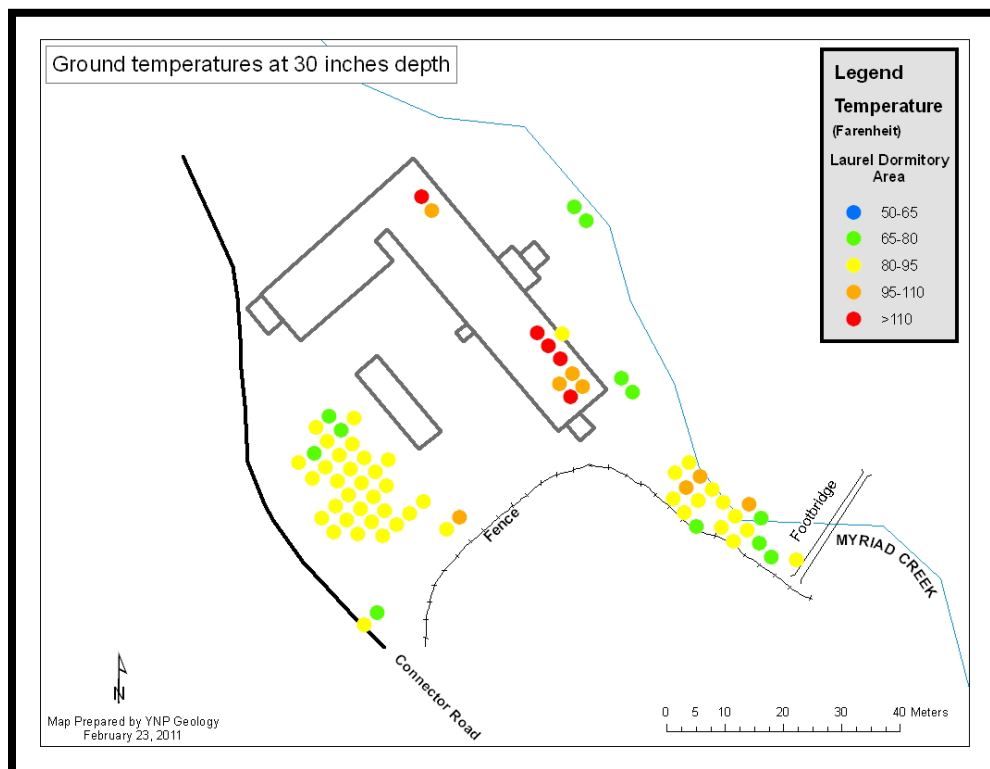


Figure 6 Laurel Dormitory area temperature measurements (degrees Fahrenheit) at 30 inches (76 cm) depth. Temperatures measured 7 to 22 June 2010.

SECTION 2: 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 Death 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 numerous 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. OSHA (2006) defines 20 ppm H₂S as the acceptable ceiling concentration, a 50 ppm exposure may occur once for 10 minutes only if no other measurable exposure occurs.

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.

Carbon dioxide concentrations were significant in the subsurface within the Laurel Dormitory area (Figures 7, 8 and 9). At 10 inches (25 cm) depth, many of the carbon dioxide levels were above the permissible exposure limit of 0.5%, over an 8-hour time-weighted average (OSHA, 2006). At 20 and 30 inches depth, many subsurface carbon dioxide values are above the lethal limit of 10 %. However, the total amount of carbon dioxide gas emitted in the area was not measured.

Hydrogen sulfide was detected at three locations, varying between 24.1 to 70 ppm. All three locations were near the northwestern most corner of Laurel Dorm.

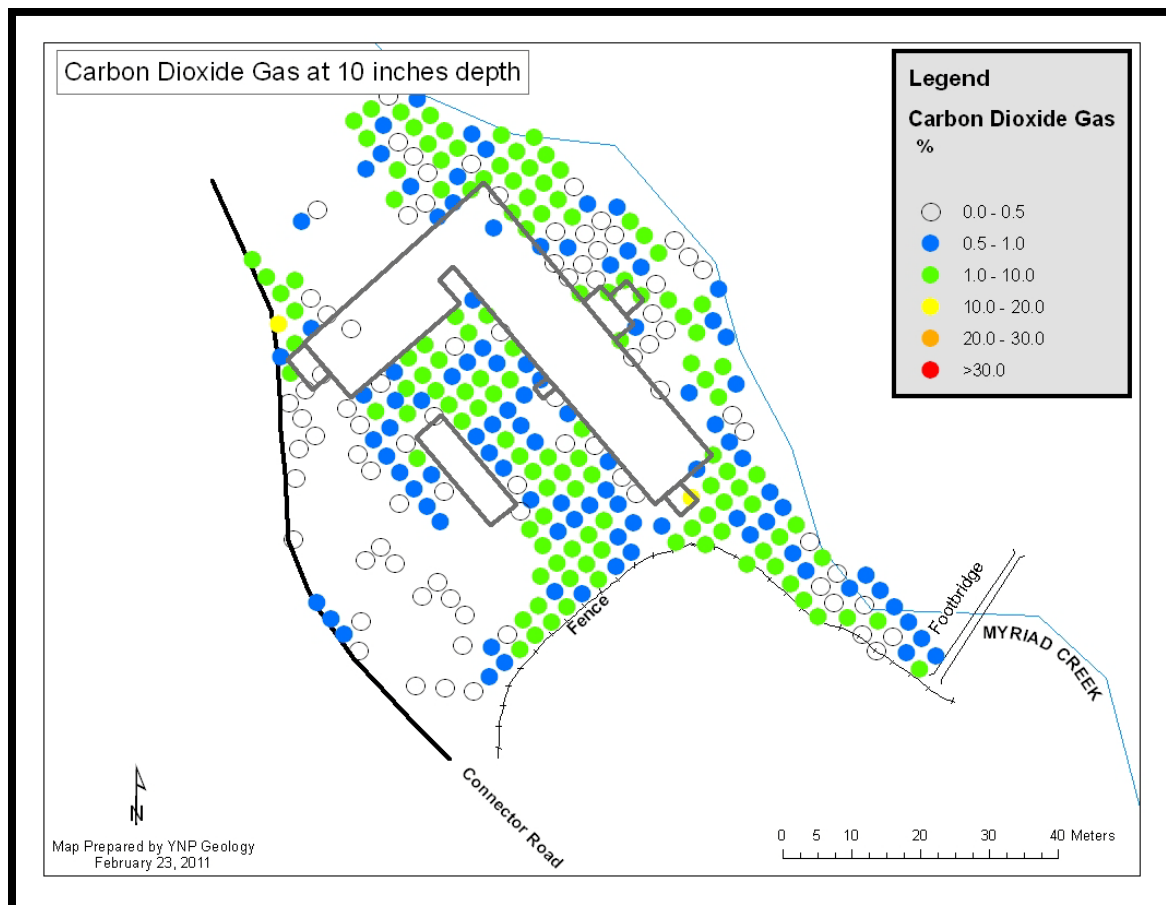


Figure 7. Laurel Dormitory area carbon dioxide measurements (percent) at 10 inches (25 cm) depth. Carbon dioxide measured 7 to 22 June 2010.

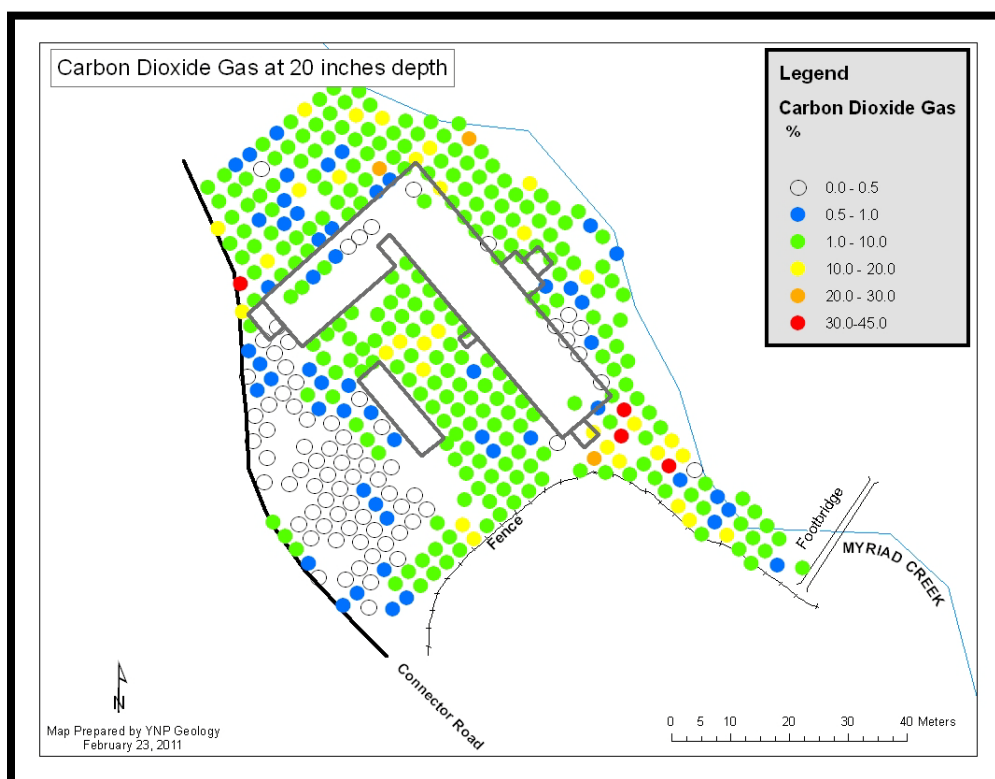


Figure 8. Laurel Dormitory area carbon dioxide measurements (percent) at 20 inches (51 cm) depth. Carbon dioxide measured 7 to 22 June 2010.

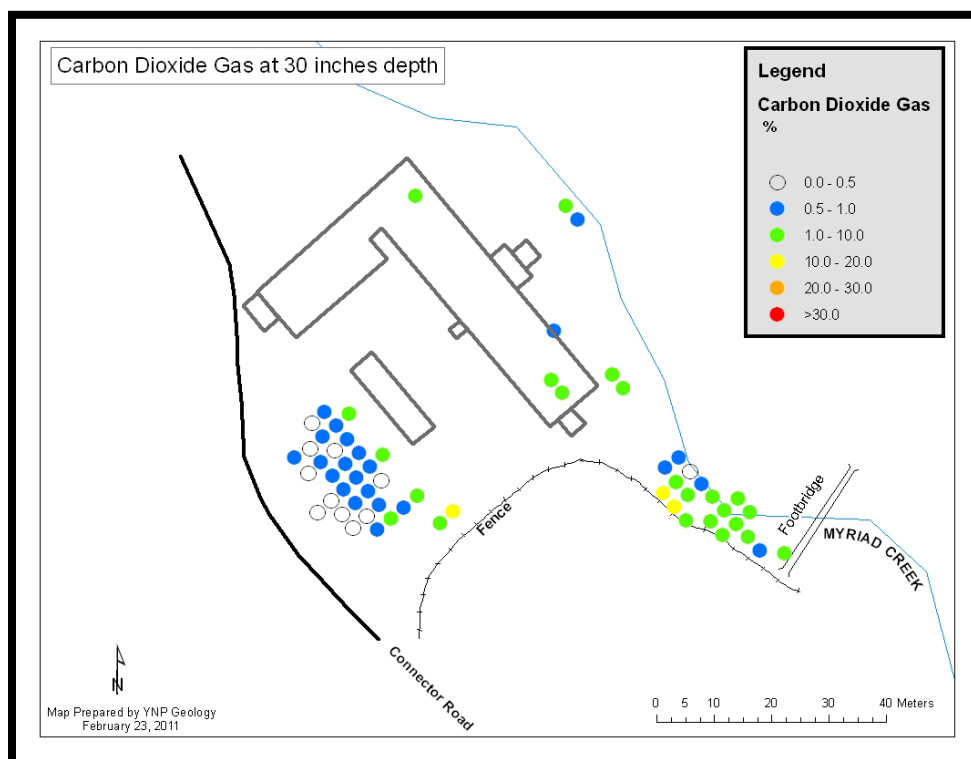


Figure 9. Laurel Dormitory area carbon dioxide measurements (percent) at 30 inches (76 cm) depth. Carbon dioxide measured 7 to 22 June 2010.

SECTION 3: Hydrothermal deposits and Hydrothermally Altered Ground

Hydrothermal deposits and hydrothermally altered ground are indicators of hydrothermal areas. Hydrothermal deposits in the Old Faithful area include silica-rich precipitates from the thermal waters such as siliceous sinter and geyserite. Hydrothermally altered ground in the old Faithful area includes a variety of colored clays (red, white, tan, and gray), altered rhyolitic bedrock, and altered obsidian sands.

The existence of hydrothermal deposits and hydrothermally altered ground in the area of Laurel Dormitory is shown in Figures 10, 11, and 12. Figure 10 is visible imagery from Google Earth showing the presence of red clay adjacent to Laurel Dormitory and extending towards Old Faithful Geyser. Figure 11 shows the borings that TetraTech encountered either clays or hydrothermal deposits. In Figure 12, the pervasiveness of the hydrothermally altered clay in the area of Laurel Dormitory and the Old Faithful Inn is visible.

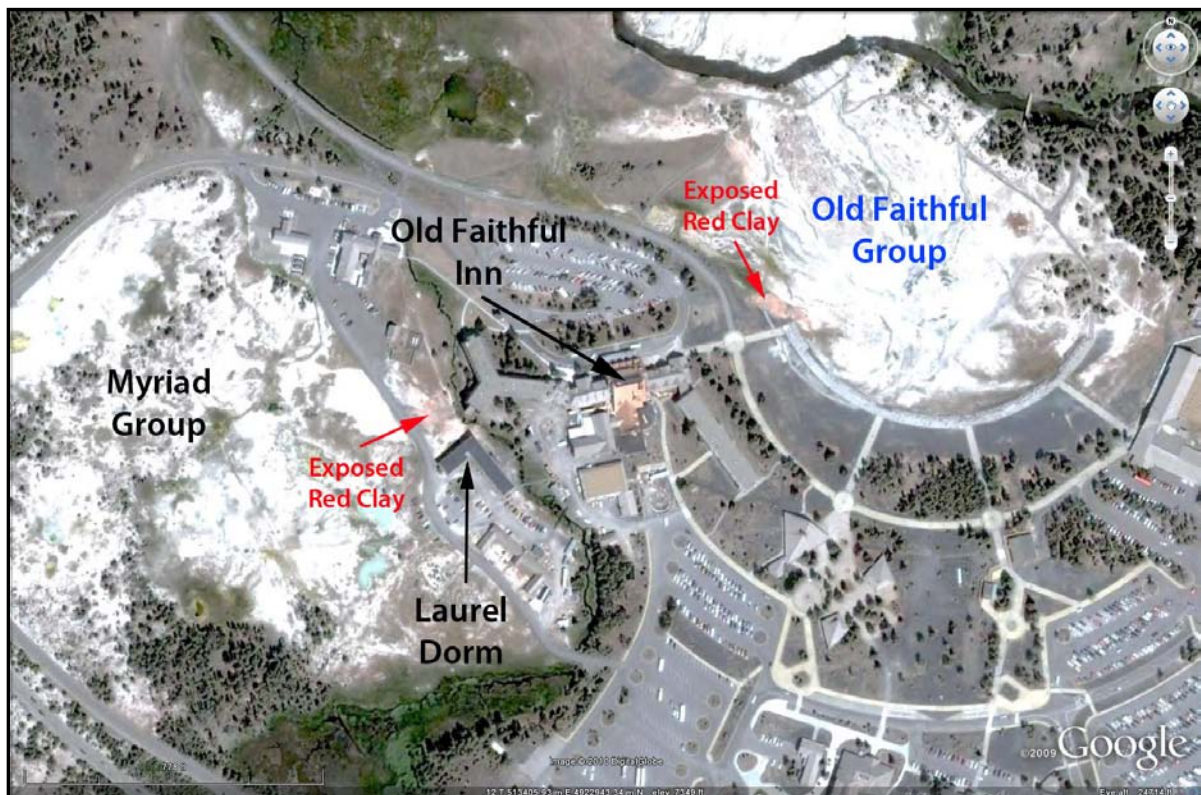


Figure 10. Visible image showing areas of exposed red hydrothermal clay that extends between the Myriad Group and the Old Faithful Group. Base image from Google Earth, February 2011.

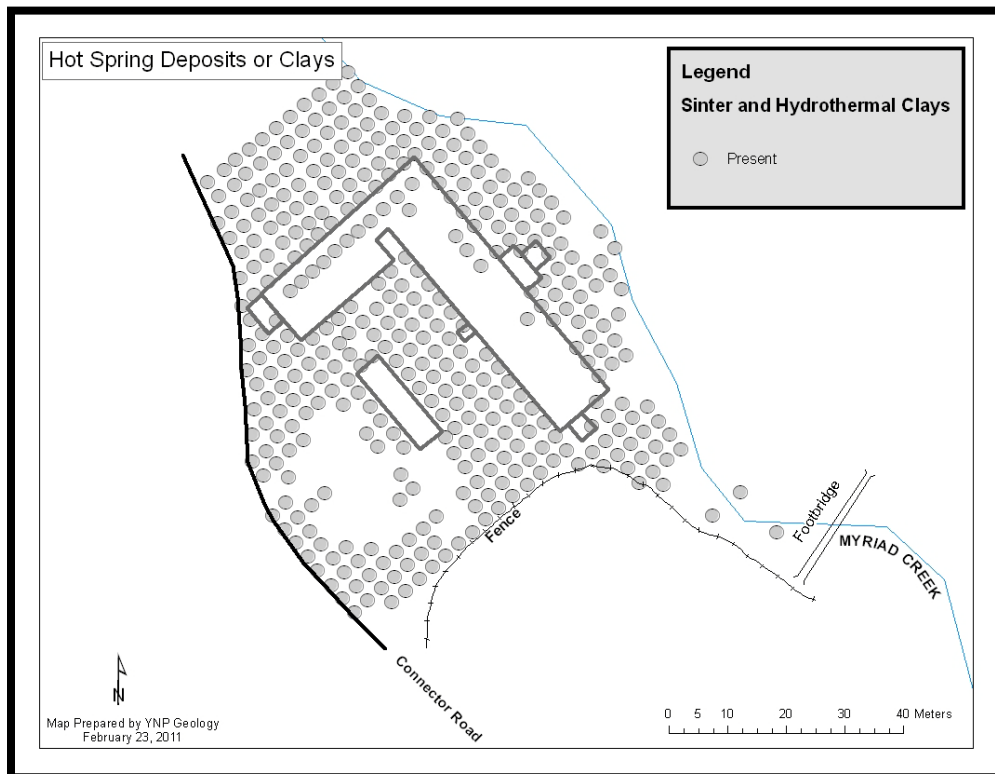


Figure 11. Map of locations where hot spring deposits were encountered at 10 inches (25 cm) depth, 20 inches (51 cm) depth, or 30 inches (76 cm) depth.



Figure 12. Photograph of a trench located approximately 125 feet northeast of Laurel Dormitory near the Old Faithful kitchen. Notice the bright red-clay layer below a disturbed layer of dark-brown fill. The thickness of intact red clay exposed in this photograph is 2 feet. Red clay and other hydrothermal clays cap hydrothermal fluids in the Old Faithful area. Myriad Creek and Laurel Dormitory are on the far side of the concrete pad. View looking west on 3 May 2010 during a spring snowstorm.

SECTION 4: Ground Surface Temperatures

Elevated ground surface temperatures are an obvious indicator of an active hydrothermal area. Unusual amounts of heat flowing from the subsurface to the surface will result in ground temperatures that are warmer than non-hydrothermally influenced areas. The unusual amount of heat flow may be due to hot water flowing on the ground surface or the presence of hot water at a relatively shallow depth. Professional judgment must be used when interpreting ground surface temperature images to consider the effects of solar heating and other variables.

Both airborne and ground thermal infrared imagery allows the visualization of the pattern of heat being radiated from the ground, vegetation, buildings or other objects. A FLIR Systems ThermoCAM SC640 was used to capture the “skin-temperature” (the outermost few microns) of objects in thermal infrared images. The thermal infrared energy captured by the FLIR ThermoCAM SC640 was in the 8-12 micron range.

Figures 13, 14, and 15 show heat patterns associated with the Laurel Dormitory area. Figure 13 is an aerial oblique view looking east to the Myriad Group, Old Faithful (erupting), and Geyser Hill. Notice the patterns of heated ground in the Myriad Group, Old Faithful, and Geyser Hill. Also notice that the pattern of heated ground extends between these areas, indicating a continuous hydrothermal system. Figure 14 is an aerial oblique view centering on Laurel Dormitory. The surface heat patterns seen in the Myriad Group extend into the area of the Historic Old Faithful Pub and Laurel Dormitory. Figure 15 is ground-based imagery taken of the porch on the southwestern corner of Laurel Dormitory. The thermal infrared image shows the hydrothermal heating of the concrete associated with the porch and foundation in this area.

Elevated ground surface temperatures are a minimum indicator of an active hydrothermal area. This may be easily seen by comparing the thermal infrared image of the Laurel Dormitory area (Figure 14) to the subsurface temperature maps of the same area (Figures 4 through 6). The subsurface temperature maps indicate a larger hydrothermal area than the image showing surface temperatures. Given the continuity of the heat pattern seen in Figure 13 and Figure 3 of Jaworowski et al, (2010), Laurel Dormitory lies within a large, active, hydrothermal system.

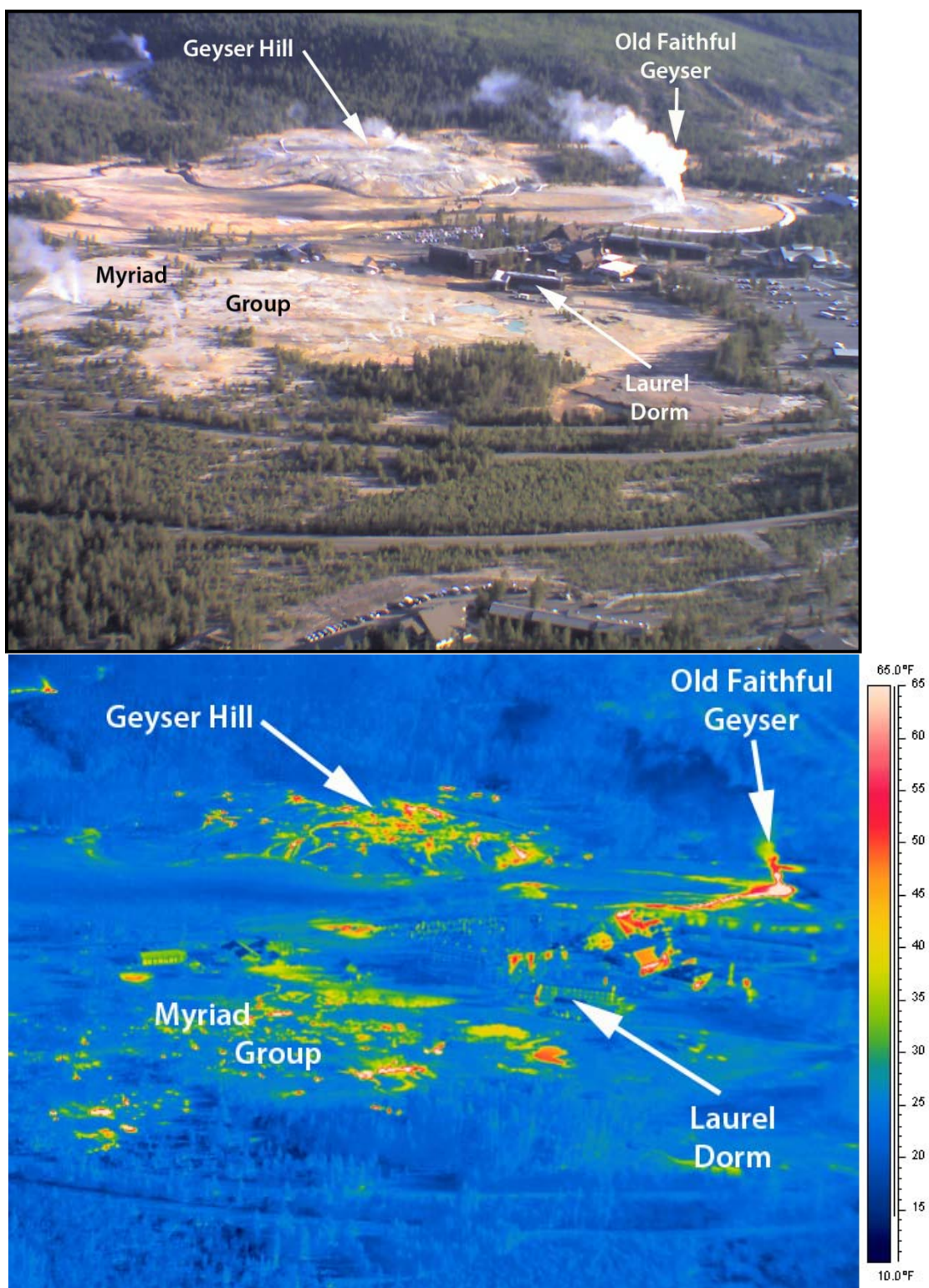


Figure 13. Visible (top) and forward looking thermal infrared image (bottom) showing the Myriad Hydrothermal Group, Laurel Dormitory, Old Faithful Inn, Old Faithful Geyser, and Geyser Hill.. Notice the temperature patterns associated with the Myriad Group and Geyser Hill. The roofs of buildings associated with the Old Faithful Inn are warm due to the effects of solar heating. Image taken 12 October 2010, 9:04 am MST. View to the northeast.

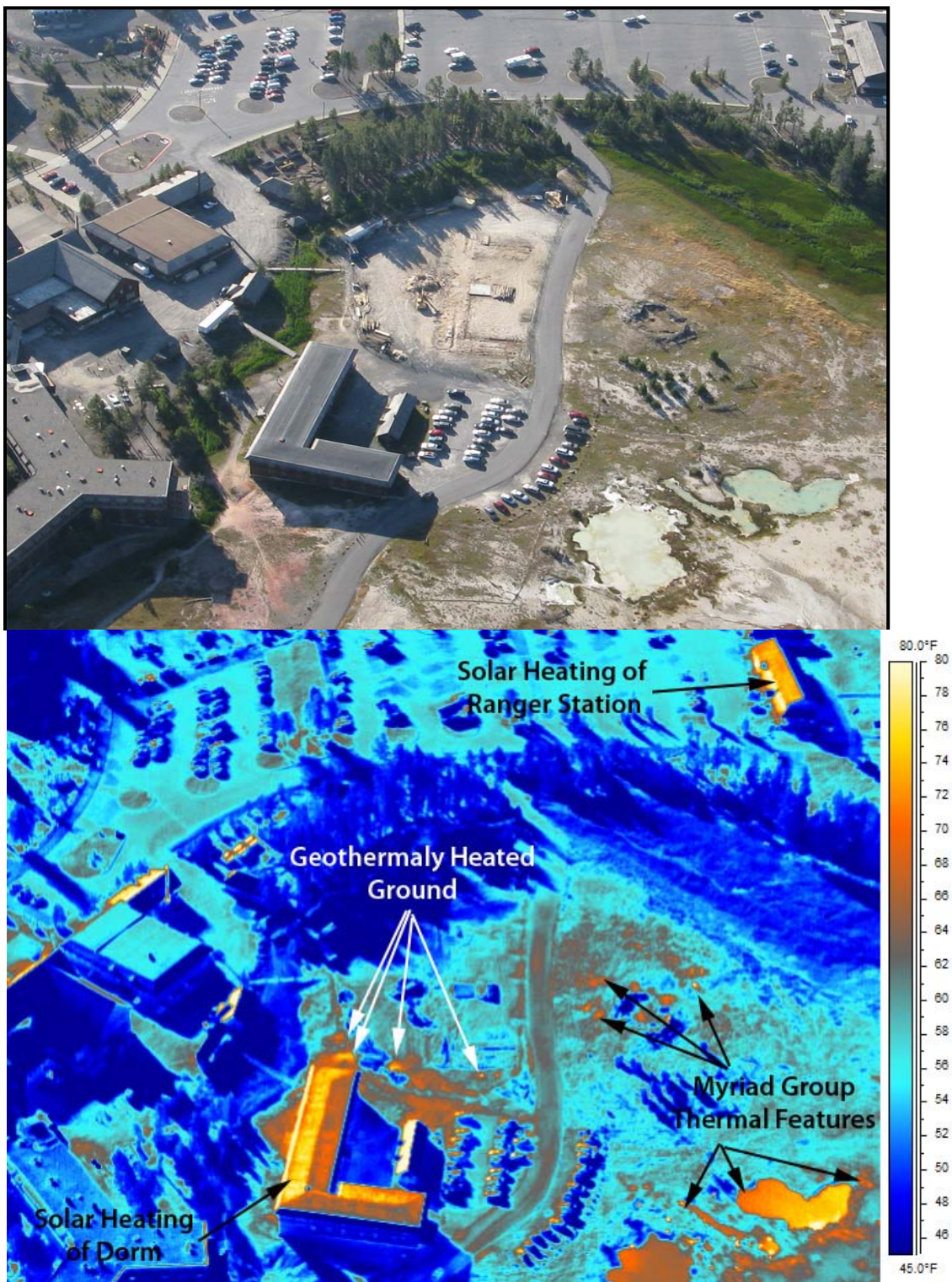


Figure 14. Visible (top) and forward looking thermal infrared image (bottom) taken 20 August 2009 at 8:48 a.m., MDT. Sunrise was approximately 6:30 a.m., MDT. Solar heating of the nearby dormitory and cars is evident. Solar heating is starting to mask the heat from the Myriad Group. Within the undisturbed Myriad Group, the small orange areas are thermal features.

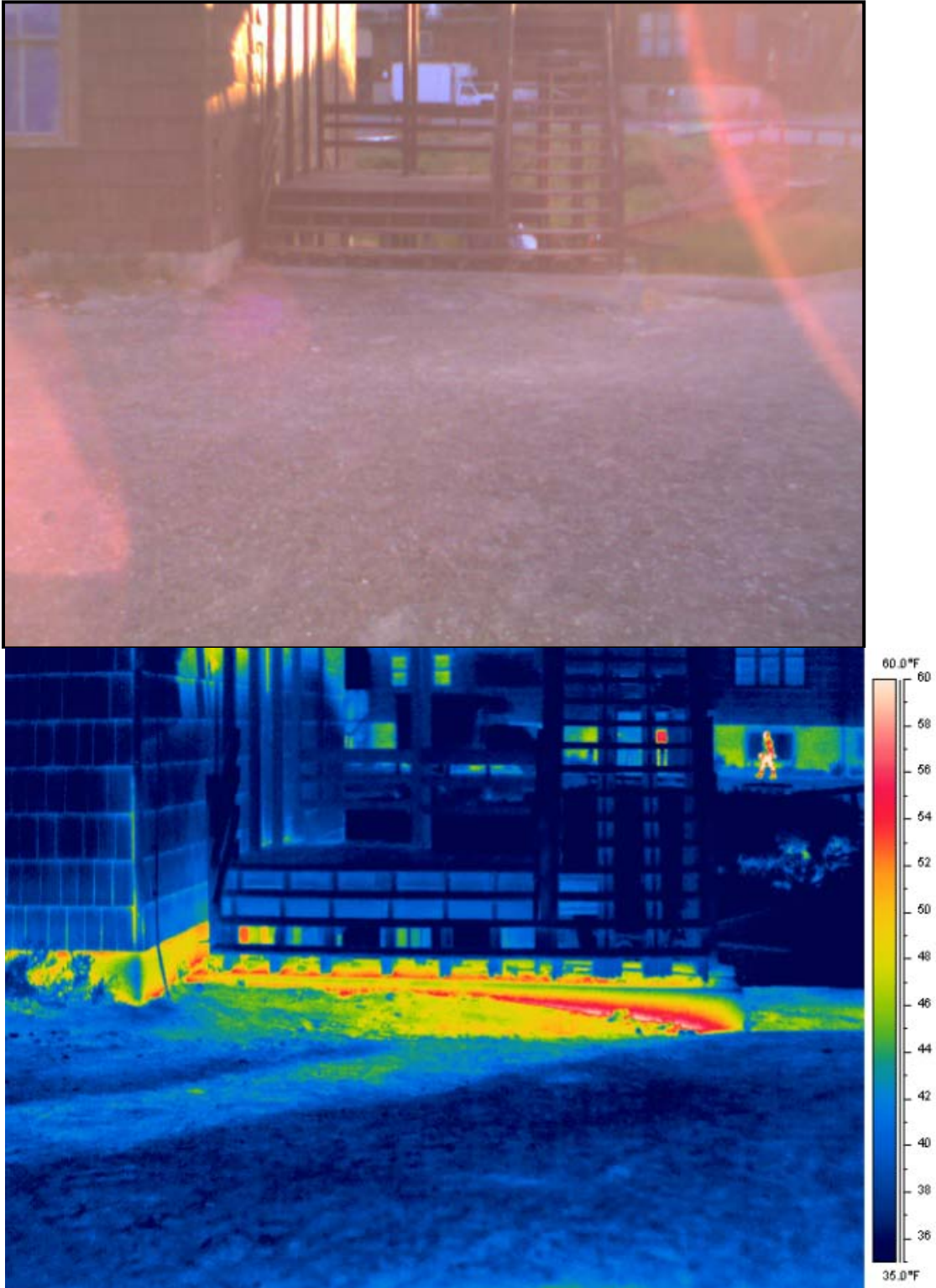


Figure 15. Visible (top) and forward looking thermal infrared image (bottom) showing heat being conducted from the ground through the concrete footer on the southwestern Corner of Laurel Dormitory. View to the east. Photograph taken 19 August 2009.

SUMMARY

The Laurel Dormitory at Old Faithful is located within an active hydrothermal area. A significant portion of the area contains hydrothermally altered clays. Hot spring deposits were encountered at 10 and 20 inch (25 and 51 cm) depths at a variety of locations. Maximum temperatures were 110.0 °F (43.9 °C) at 10 inches (25 cm) depth, 123.1 °F (50.6 °C) at 20 inches (51 cm) depth, and 134.1 °F (56.7 °C) at 30 inches (76 cm) depth. Maximum carbon dioxide values were 19.6 % at 10 inches (25 cm) depth, 42.2% at 20 inches (51 cm) depth, and 17.4% at 30 inches (76 cm) depth. Hydrogen sulfide was detected at three locations, varying between 24.1 to 70 ppm. Significantly elevated ground temperatures, the presence of geothermal gases, hydrothermally altered ground and hot spring deposits indicate an active hydrothermal area surrounding and beneath Laurel Dormitory.

The active hydrothermal nature of this area is discussed in two reports dealing with the adjacent area of the Historic Pub:

Temperature Measurements at the Historic Old Faithful Pub, Yellowstone National Park by Henry Heasler, Cheryl Jaworowski, Chelsea Feeney, and Duncan Foley Geology Program, Yellowstone Center for Resources, Yellowstone National Park, 27 July 2009, 8 p.

Preliminary Geothermal Analyses of the Area at the Historic Old Faithful Pub, Yellowstone National Park, by Henry Heasler, Cheryl Jaworowski, Chelsea Feeney, Brett Carr, and Duncan Foley, Geology Program, Yellowstone Center for Resources, Yellowstone National Park, 24 August 2009, 19 p.

Additional evidence of the active hydrothermal processes in this area are associated with the construction of a water line along the Old Faithful Connector Road (Refer to Figure 4 through 9). 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.

All data and information analyzed indicate an active hydrothermal area in the area of, and beneath, Laurel Dormitory.

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