Prepared in cooperation with the New Hampshire Geological Survey

Geophysical Logging of Bedrock Wells for Geothermal Gradient Characterization in New Hampshire, 2013

Data Series 823

U.S. Department of the Interior
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Cover. Borehole logging cable and pulley at North Conway New Hampshire.

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Suggested citation:
Degnan, J.R., Barker, Gregory, Olson, Neil, and Wilder, Leland, 2014, Geophysical logging of bedrock wells for geothermal gradient characterization in New Hampshire, 2013: U.S. Geological Survey Data Series 823, 19 p., at *http://dx.doi.org/10.3133/ds823*.

ISSN 2327-638X (online)

Acknowledgments

The authors thank all who assisted with and supported this project. Permission and support from private land owners who allowed access to their wells made data collection possible. Equipment and technical advice provided by Carole Johnson of the U.S. Geological Survey (USGS) helped in the understanding of logging results and data processing. Equipment provided by John Williams and Alton Anderson of the USGS made high-quality data collection possible. Reviews of this report were done by Stephen Curtin and Richard Moore. Technical advice from Paul Staples of Mount Sopris Instruments was helpful for temperature calibration. Kelseyann Regan and Ellen Finch of the USGS provided assistance with logging.

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Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Rate	
foot per minute (ft/min)	0.3048	meter per minute (m/min)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Geophysical Logging of Bedrock Wells for Geothermal Gradient Characterization in New Hampshire, 2013

By James R. Degnan[1], Gregory Barker[2], Neil Olson[2], and Leland Wilder[2]

Abstract

The U.S. Geological Survey, in cooperation with the New Hampshire Geological Survey, measured the fluid temperature of groundwater and other geophysical properties in 10 bedrock wells in the State of New Hampshire in order to characterize geothermal gradients in bedrock. The wells selected for the study were deep (five ranging from 375 to 900 feet and five deeper than 900 feet) and 6 had low water yields, which correspond to low groundwater flow from fractures. This combination of depth and low water yield reduced the potential for flow-induced temperature changes that would mask the natural geothermal gradient in the bedrock. Eight of the wells included in this study are privately owned, and permission to use the wells was obtained from landowners before geophysical logs were acquired for this study. National Institute of Standards and Technology thermistor readings were used to adjust the factory calibrated geophysical log data. A geometric correction to the gradient measurements was also necessary due to borehole deviation from vertical.

Maximum groundwater temperatures at the bottom of the logs ranged from 11.2 to 15.4 degrees Celsius. Geothermal gradients were generally higher than those typically reported for other water wells in the United States. Some of the high gradients were associated with high natural gamma emissions. Groundwater flow was discernible in 4 of the 10 wells studied but only obscured the part of the geothermal gradient signal where groundwater actually flowed into, out of, or through the well. Temperature gradients varied by mapped bedrock type but can also vary by localized differences in mineralogy or rock type within the wells.

Introduction

Information collected from geophysical logs, including groundwater temperature logs, can be used to assess the development potential of geologic formations as sources of geothermal energy. The temperature of groundwater within wells, in the absence of significant groundwater flow, reflects the temperature of the surrounding geologic formations. Geothermal gradients, defined as the increase in temperature with depth, from various rock units measured in mines and drill holes around the world range from 0.46 to 2.29 degrees Celsius (°C) per 100 feet (ft) of depth (Skinner and Porter, 1992). The typical range of geothermal gradients observed in groundwater wells is 0.47 to 0.60 °C per 100 ft (Keys, 1990), which is slightly lower than the range 0.56 to 0.72 °C per 100 ft that was documented in Degnan and others, (2012). Degnan and others (2012) described an initial assessment of geothermal gradients in selected wells in New Hampshire. Ten additional wells were analyzed in the state in 2013 by the U.S. Geological Survey in cooperation with the New Hampshire Geological Survey (NHGS).

Purpose and Scope

The NHGS is interested in the potential for geothermal energy production from the bedrock in the State. The purpose of this report is to present geophysical data that can be used to characterize lithology and geothermal gradients in crystalline bedrock wells in the State of New Hampshire. The information in this report can help researchers and decision makers to evaluate the geothermal potential of the bedrock in New Hampshire. For this study, wells were logged to determine temperature and other geophysical properties, and the data collected will become part of a national inventory of data used to evaluate geothermal potential across the United States. Geophysical log data in the log ASCII standard (LAS) format are part of this report. The digital data are available at http://pubs.usgs.gov/ds/823/.

Previous Investigations

There is a long history of efforts to study the geothermal properties of rocks in New Hampshire. Geothermal gradients within the Earth's crust are driven by the conduction of heat from the core that travels with convection currents through the mantle (Skinner and Porter, 1992). Variations in geothermal

[1]U.S. Geological Survey.

[2]New Hampshire Geological Survey.

gradients are attributable to the location of the convection cells, crustal thickness, rock type, and heat production by the decay of radioactive minerals. Birch and others (1968) reported geothermal gradients between 0.55 and 0.67 °C per 100 ft for sites in central New Hampshire. Degnan and others (2012 and 2013) reported mean geothermal gradients between 0.56 and 0.72 °C per 100 ft for sites in Hillsboro and Belknap Counties, New Hampshire. Kim and others (2013) reported preliminary gradients between 0.21 and 0.47 °C per 100 ft from temperatures measured in wells in the State of Vermont. Geothermal gradients as high as 0.7 °C per 100 ft with an average of 0.5 °C per 100 ft were reported for wells logged in Maine (Keith Sorota, Hager GeoScience, Inc., written commun., 2014).

Previous geothermal studies in New Hampshire, focusing largely on the Conway granite in the White Mountains of New Hampshire, were summarized by Wilder (2003). High heat production in plutonic bedrock in New Hampshire is associated with the decay of radioactive minerals, which was quantified by Billings and Keevil (1945). Hoag and Stewart (1977) provided a detailed lithologic and geophysical description of the geothermal test hole in Redstone (a village in Conway, New Hampshire), including a temperature log. The Redstone geothermal test hole had an average gradient of 0.85 °C per 100 ft. Caruso and Simmons (1985) investigated the distribution of uranium in the Redstone geothermal test hole core. Uranium is found within minerals and microfractures that were emplaced and formed during, and likely after, crystallization of the granite found in the Redstone test hole. Redistribution of uranium from hydrothermal fluid circulation after crystallization can, in part, account for the high concentrations.

Methodology

Ten wells were selected for geophysical logging. Fluid and physical borehole property values, including fluid temperature, fluid conductance, natural gamma radiation emissions, hole diameter (caliper log), and inclination, were recorded in logs. An optical televiewer (OTV) log was used to record an oriented 360-degree image of the structure and lithology in the boreholes. Well construction data were entered into the U.S. Geological Survey (USGS) groundwater site inventory (GWSI) database. Log data are stored and archived in log ASCII standard (LAS) format and are available as part of this report at http://pubs.usgs.gov/ds/823/.

Well Selection

The selection of wells was made by the NHGS on the basis of depth, bedrock type, accessibility, and lack of pumps and plumbing in the well. Wells with a low potential for intraborehole flow (low yield, less than a gallon per minute) were also given a higher priority for logging. The Water Well Inventory Program database (Chormann, 2001 , and New Hampshire Department of Environmental Services, undated) of the State of New Hampshire was queried to find candidate wells. Eight of the wells included in this study are privately owned. Permission to use the wells was obtained from landowners or managers. Ten bedrock wells (from 375 to greater than 2,200 feet in depth), including six with low water yield, were identified (table 1).

In all, 10 wells were logged in central and southeastern New Hampshire (fig. 1). The locations of wells were viewed in a geographic information system along with data on bedrock formation (Lyons and others, 1997; Bennett and others, 2006) to determine the bedrock types that may occur either within or near the well on the basis of geologic information that is mapped at 1:250,000 scale. The actual bedrock formation within the well may vary owing to local scale heterogeneity of the rocks. Wells drilled in igneous rocks, as determined from the State geologic map, were given the highest priority for logging because of the high potential for heat production associated with the presence of radioactive minerals (Roy and others, 1968). Wells completed in metamorphic formations adjacent to targeted igneous bodies were also identified so that potential heat propagation into these bodies could be better understood.

Geophysical Logging

Borehole fluid temperature data were collected at 10 wells using a Mount Sopris Instrument Company 2FPA–1000 probe with a resolution of 0.01 °C. Factory calibrations with reported 99-percent accuracy were used for logging in the field. However, before logging each well, temperature readings from the probe were recorded in concert with a National Institute of Standards and Technology thermistor (0.05 °C accuracy, 0.001 °C resolution) with current certification to ensure the accuracy of the temperature values. The median difference in temperature between the thermistor and probe readings from warm- and cold-water baths (designed to bracket the temperatures expected in the wells) was later used to adjust the factory calibrated data from the probe by applying a two-point linear correction. Temperature gradients were determined from temperature measurement differences at 100-ft intervals below the depth where the gradient was observed to be increasing. The borehole deviation from vertical, including inclination, was used to produce a geometric correction to the gradient measurement.

In addition to temperature logs, geophysical logs, including fluid conductance, natural gamma radiation (gamma ray emissions), 3-arm caliper, inclination, and optical televiewer, were collected. Changes in gamma ray emissions in the gamma log indicate changes in mineralogy and bedrock type with depth. The caliper log records hole diameter and indicates locations of greater borehole width where the bedrock may be fractured. Fluid conductance logs indicate groundwater flow in a borehole and can indicate

Table 1. Information for bedrock wells logged for geothermal gradient characterization in New Hampshire, in 2013.

[Measurements are in feet (ft) below the land surface; gal/min, gallons per minute; ID, identification number; N/A, no other units mapped nearby; USGS, U.S. Geological Survey;--, no data are available]

			Driller-reported						Lyons and others (1997)		
Date drilled	State well ID	USGS well ID	Well depth, in ft	Depth to bedrock, in ft	Casing length, in ft	Yield, in gal/min	Static water level, in ft	Town	Mapped rock unit[1]	Distance and direction to nearby contacts	Nearby mapped rock unit[1]
10/2/1989	239.0175	TZW 150	900	15	71	0.5	75	Tuftonboro	Winnipesaukee Tonalite (Early Devonian)	N/A	N/A
10/4/1989	239.0174	TZW 149	702	15	81	0	75	Tuftonboro	Winnipesaukee Tonalite (Early Devonian)	N/A	N/A
10/27/1989	164.0379	MWW 269	855	80	91	0	--	Moultonborough	Winnipesaukee Tonalite (Early Devonian)	N/A	N/A
7/8/2010	052.0838	CWW 246	1,228	18	40	0.05	1,200	Conway	Conway Granite (Late? and Middle Jurassic)	1,300 ft southeast	Mount Osceola Granite (Middle and Early Jurassic)
7/9/2010	052.0837	CWW 247	700	20	52	0.08	650	Conway	Conway Granite (Late? and Middle Jurassic)	1,000 ft southeast	Mount Osceola Granite (Middle and Early Jurassic)
7/21/2005	118.0400	HRW 86	845	60	70	7	0	Holderness	Madrid Formation (Upper Silurian?)	400 ft east	Smalls Falls Formation (Upper to Middle Silurian)
										2,000 ft west	Littleton Formation (Lower Devonian)
3/27/1999	256.1444	WPW 1068	905	2	20	0	--	Windham	Berwick Formation[2] (Silurian? To Ordovician?)	N/A	N/A
--[3]	--	HUW 261	375	--	--	--	--	Hopkinton	Kinsman Granodiorite (Early Devonian)	1,700 ft southeast	Smalls Falls Formation (Upper to Middle Silurian)
2/4/1982[3]	--	BBW 283	>2,200	--	--	325	--	Barrington	Berwick Formation [2] (Silurian? To Ordovician?)	N/A	N/A
3/20/1971[3]	--	HUW 262	470	41	52	2	20	Hopkinton	Spaulding Tonalite (Early Devonian)	400 ft southeast	Kinsman Granodiorite (Early Devonian)

[1]From Lyons and others, 1997.

[2]Berwick Formation of the Merrimack Group.

[3]Wells not in State database; data from well owner or driller.

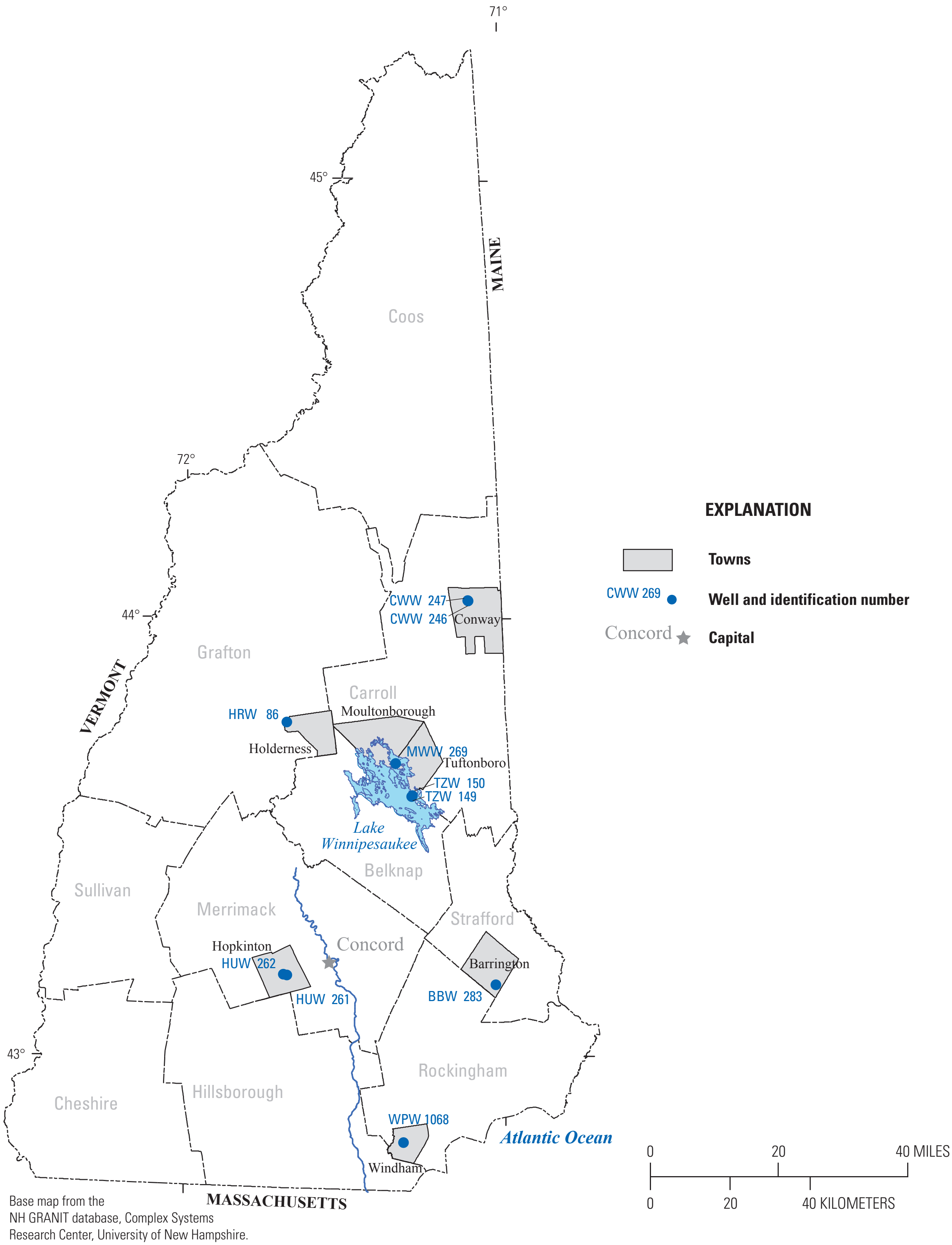

Figure 1. Locations of bedrock wells logged for geothermal gradient characterization in New Hampshire in 2013. Well identification numbers are from the U.S. Geological Survey groundwater site inventory database.

where the geothermal gradient information may be masked. Fluid temperature and conductance were logged first, going down the hole; logging rates were between 11 and 12 feet per minute. Results from well logging are presented for each borehole investigated. Descriptions of standard borehole-geophysical logging methods and interpretation can be found in Keys (1990). The methods of collection and analysis of OTV logs are described by Johnson and others (2005).

Temperature and Other Borehole Logs

Ten wells that were drilled into igneous or metamorphic rock in New Hampshire were logged with a temperature probe to create a temperature profile of the water column with depth (figs. 2–11). Fluid conductance, natural gamma radiation (gamma ray emissions), 3-arm caliper, inclination, and optical-televiewer geophysical logs were also collected. The digital data are available at http://pubs.usgs.gov/ds/823/. The following is a brief description of the results. In wells with minimal intraborehole flow and very low yield (less than a gallon per minute), the water temperature can be assumed to represent the bedrock temperature, which is influenced by the Earth's geothermal gradient. A two-point linear correction to the factory calibrated data was made on the basis of low and high temperature calibration-check measurements that were made in the field. The 2PFA–1000 fluid temperature probe data were calibrated and adjusted using a low and a high correction of -3.7 °C and +1.3 °C. All of the wells had some degree of borehole deviation from vertical, including inclination, but well CWW 246 had a maximum inclination of 56°, which highlighted the need for a geometric correction to the temperature gradient measurement. A true vertical depth was calculated from the deviation data and used to calculate the gradients. All well depths presented are referenced to the top of the casing.

Log depths ranged from 368 to 1,223 ft below the top of the casing, and the mean well water temperature gradients ranged from 0.45 to 0.80 °C per 100-ft depth (table 2). The minimum temperatures measured near the top of the wells ranged from 7.5 to 10.2 °C, and the maximum temperatures measured at the bottom of the wells ranged from 11.2 to 15.4 °C. Warm temperatures measured near the top of the water column were due to seasonal surface temperatures and were not included in the data summary of gradient calculations.

Intraborehole flow was indicated by deviation of the temperature and (or) conductivity logs in 4 of the 10 wells logged. Deflections in the fluid temperature gradient and conductivity from well MWM 269 in Moultonborough indicate that there may be groundwater flow into or out of the borehole at 366 and 513 ft in the well (fig. 4). The drop in fluid conductance in well CWW 246 in Conway below 1,204 ft indicates possible groundwater flow into or out of the borehole (fig. 5). The fluid conductivity change at 173 ft in well CWW 247 in North Conway indicates flow may be entering or exiting the borehole here (fig. 6). The fluid conductivity log from well WPW 1068 in Windham indicates flow at depths of 33 and 64 ft below the top of the casing (fig. 8). The gradients show an increase in temperature with depth, even in cases where groundwater flow may slightly affect the temperature measurement in small parts of these wells.

Wells CWW 247 and CWW 246 in North Conway had the highest mean gamma responses (291 and 288 counts per second, respectively). Well CWW 247 had a higher gamma response at depths from around 50 ft to 300 ft below the top of the casing, which corresponds to a rock with a red color observed in the OTV log. This well also has the highest mean gradient (table 2).

Summary

Geophysical logs were obtained from 10 bedrock wells during an investigation by the U.S. Geological Survey and the New Hampshire Geological Survey to characterize geothermal gradients in bedrock in New Hampshire. The well temperatures measured at the bottom of the logged intervals ranged from 11.2 to 15.4 degrees Celsius (°C). The coldest temperatures, measured near the top of the wells, ranged from 7.5 to 10.2 °C. Mean geothermal gradients ranged from 0.45 to 0.80 °C per 100 feet (ft). These gradients are close in value to (or higher than) the range (0.47 to 0.60 °C per 100 ft) previously identified (Keys, 1990) for water wells in the United States and are similar in range to those reported for other wells in New Hampshire (Birch and others, 1968; Degnan and others, 2012).

Well CWW 247 in North Conway had the highest mean geothermal gradient, 0.80 °C per 100 ft, and the highest mean gamma response (291 counts per second). The second highest mean natural gamma radiation count (288 counts per second) was measured in an adjacent well CWW 246. Well MWW 269 in Moultonborough had the highest maximum and second highest mean gradients per 100-ft interval of the wells logged in this study, 0.91 °C and 0.79 °C, respectively. This is consistent with the geothermal gradient observed in the same bedrock unit from a methane-producing water well in Wolfeboro, New Hampshire (Degnan and others, 2008). The mapped bedrock units at the two wells with the highest geothermal gradients are the Conway Granite (Late? and Middle Jurassic) and the Winnipesaukee Tonalite (Early Devonian) (Lyons and others, 1997), respectively.

Possible intraborehole groundwater flow was indicated in 4 of the 10 wells logged, based on deviation of the temperature and (or) conductivity logs; the four wells are MWW 269, CWW 246, CWW 247, and WPW 1068. Fluid conductance logs were used to corroborate the temperature logs at two of the wells. Groundwater flow may slightly affect the measurement of the geothermal gradient in portions of these

Table 2. Summary of depth, temperature, and gamma properties of wells logged in 2013.

[Measurements are in feet (ft) below top of casing; °C, degrees Celsius]

Well	Date of logging	Depth logged, in ft	Bottom or blockage reached	Depth to water, in ft	Temperature, in °C		Temperature gradient °C per 100-ft depth interval			Gamma, summary of entire log, in counts per second		
					Minimum (near top of water column)	Maximum (bottom)	Mean	Median	Maximum	Mean	Median	Maximum
TZW 150	6/26/2013	835.5	No	32.82	9.7	14.4	0.59	0.60	0.72	59	56	160
TZW 149	6/27/2013	697.5	Yes	13.95	9.5	13.4	0.45	0.50	0.50	71	66	261
MWW 269	7/2/2013	842.1	No	130.10	9.9	15.4	0.79	0.79	0.91	57	51	334
CWW 246	7/31/2013	1,223.0	Yes	3.63	7.5	15.4	0.76	0.76	0.83	288	291	669
CWW 247	8/1/2013	697.9	Yes	17.96	8.1	13.3	0.80	0.83	0.83	291	289	498
HRW 86	8/8/2013	838.4	Yes	19.75	8.9	13.9	0.64	0.64	0.71	97	96	377
WPW 1068	8/13/2013	915.9	No	27.55	10.2	14.1	0.54	0.55	0.63	99	92	292
HUW 261	8/21/2013	368.0	Yes	29.00	8.9	11.2	0.76	0.76	0.76	49	47	146
BBW 283	8/22/2013	460.5	Yes[1]	23.50	9.5	11.5	0.64	0.64	0.68	44	42	119
HUW 262	10/28/2013	448.2	Yes	14.37	9.5	11.2	0.57	0.57	0.58	71	72	130

[1]An obstruction was encountered, limiting the depth logged. Steel casing was present along the entire logged interval.

wells but does not obscure the overall gradient. In general, the gradients show an increase in temperature with depth.

The two adjacent wells logged in Tuftonboro, New Hampshire, had among the lowest temperature gradients measured. The lowest temperature gradient in the study was measured at TZW 149 with a mean of 0.45 °C per 100 ft of depth. The bedrock at this location is mapped as Winnipesaukee Tonalite (Early Devonian) (Lyons and others, 1997), which also has some of the highest geothermal gradients measured in New Hampshire.

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Figures 2–11

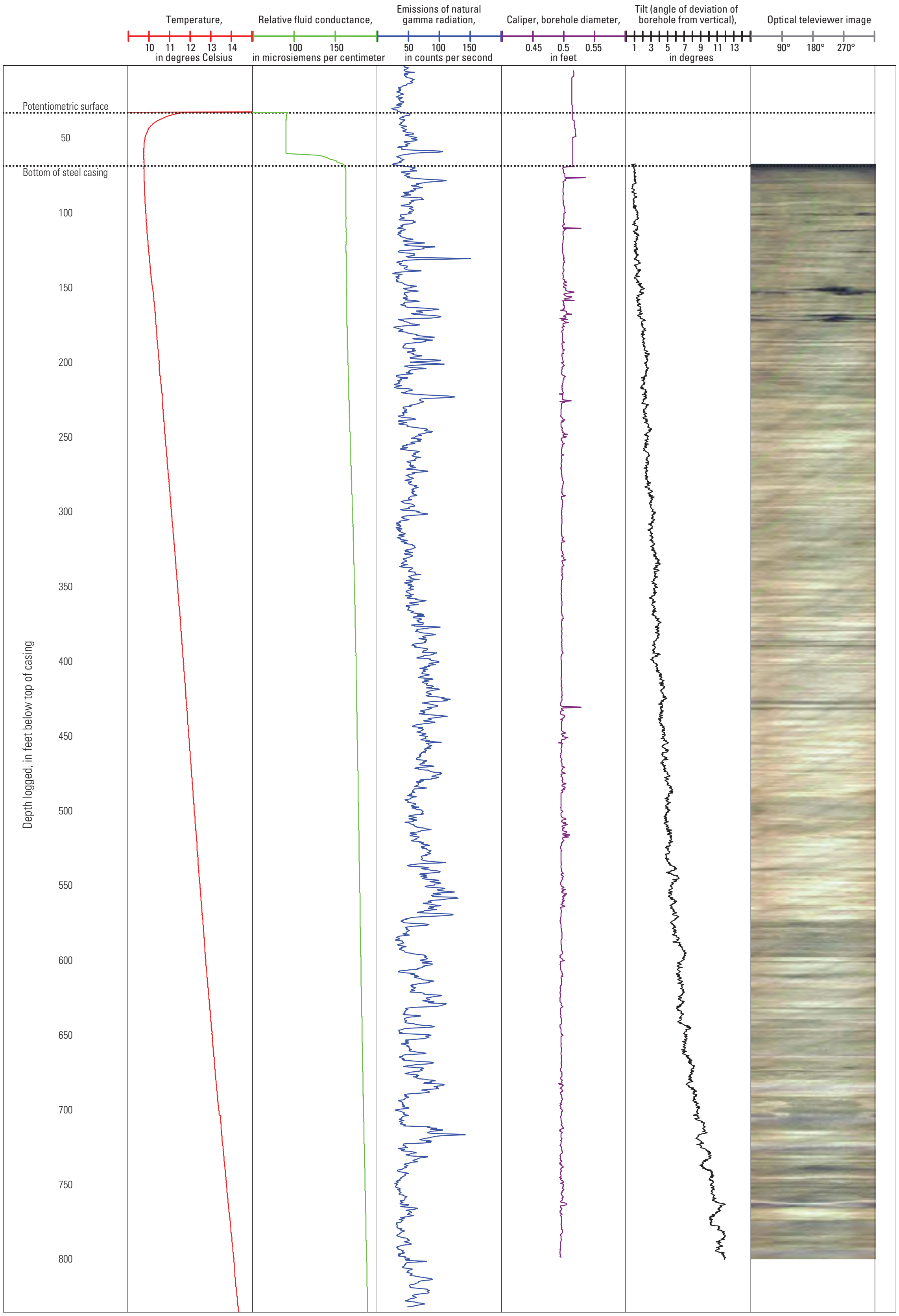

Figure 2. Bedrock well TZW 150 in Tuftonboro, New Hampshire, 2013.

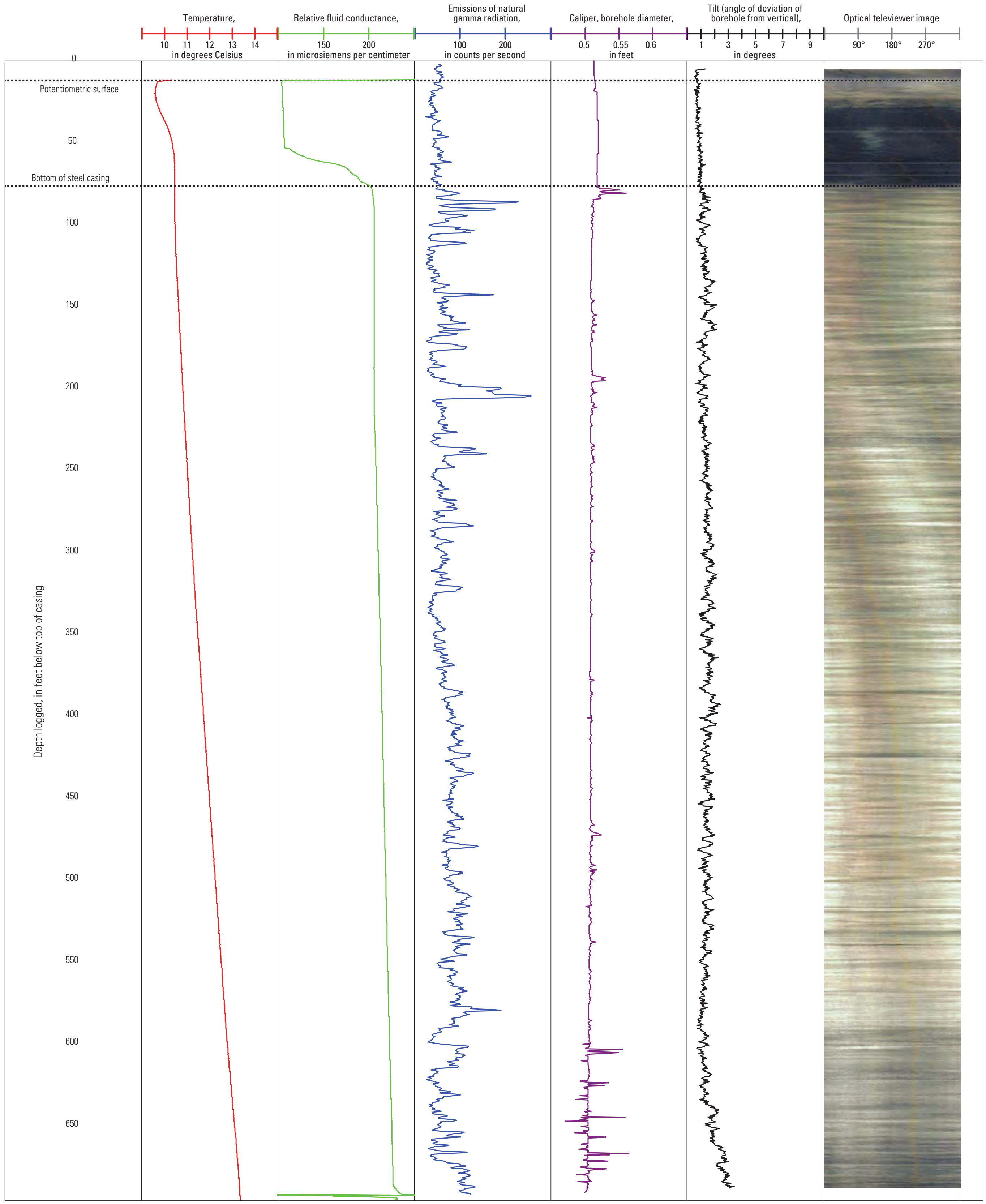

Figure 3. Bedrock well TZW 149 in Tuftonboro, New Hampshire, 2013.

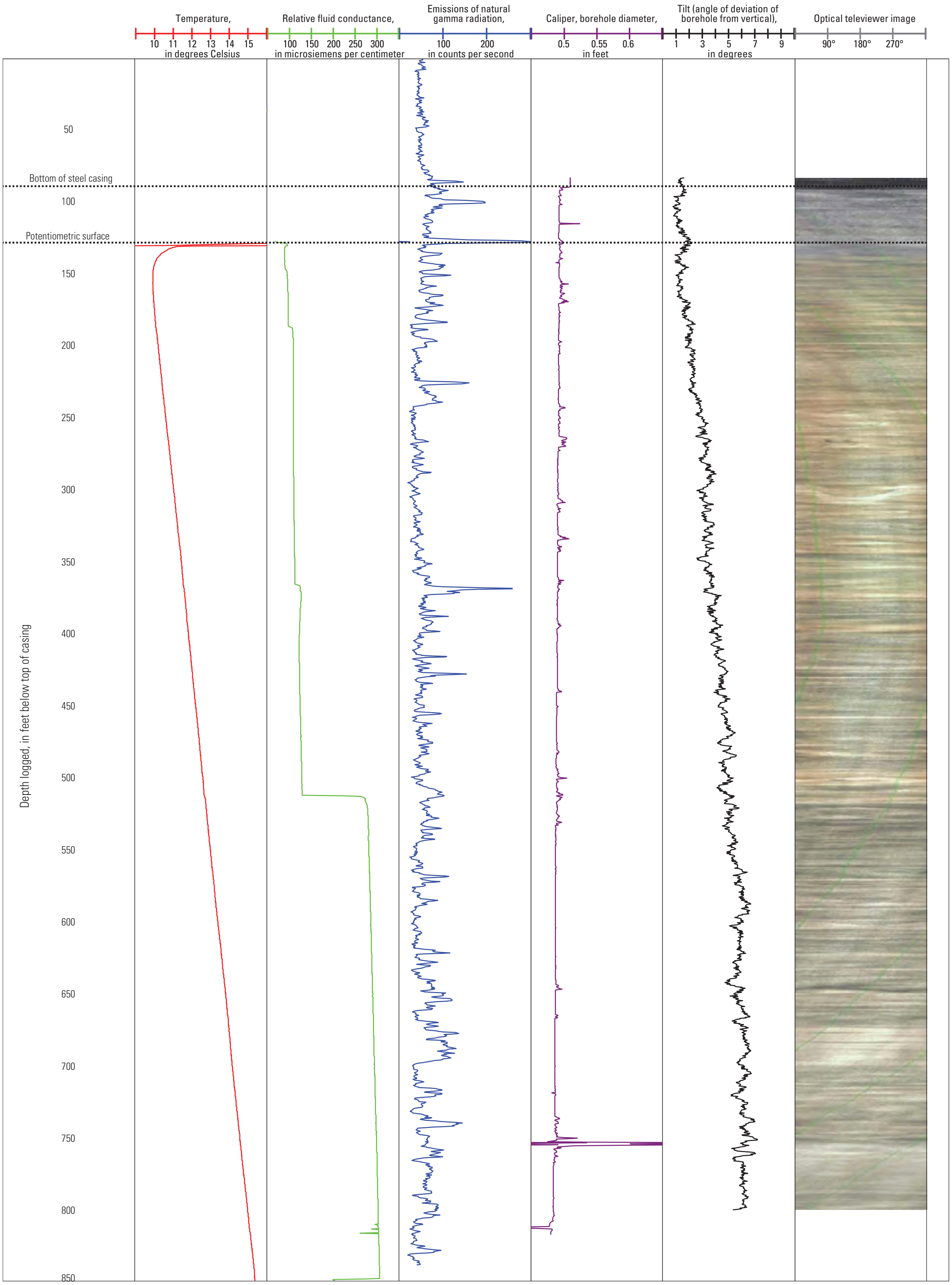

Figure 4. Bedrock well MWW 269 in Moultonborough, New Hampshire, 2013.

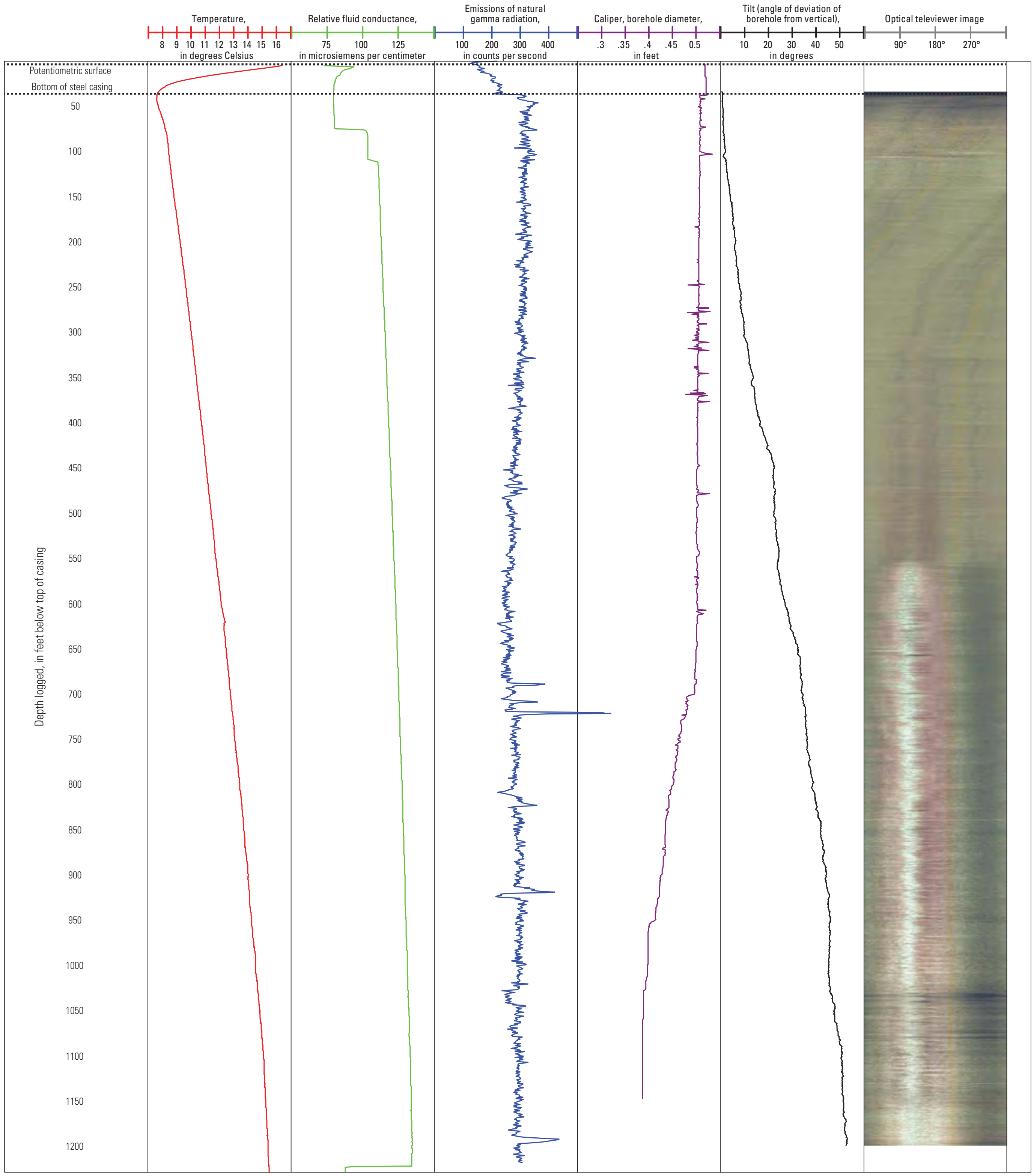

Figure 5. Bedrock well CWW 246 in North Conway, New Hampshire, 2013.

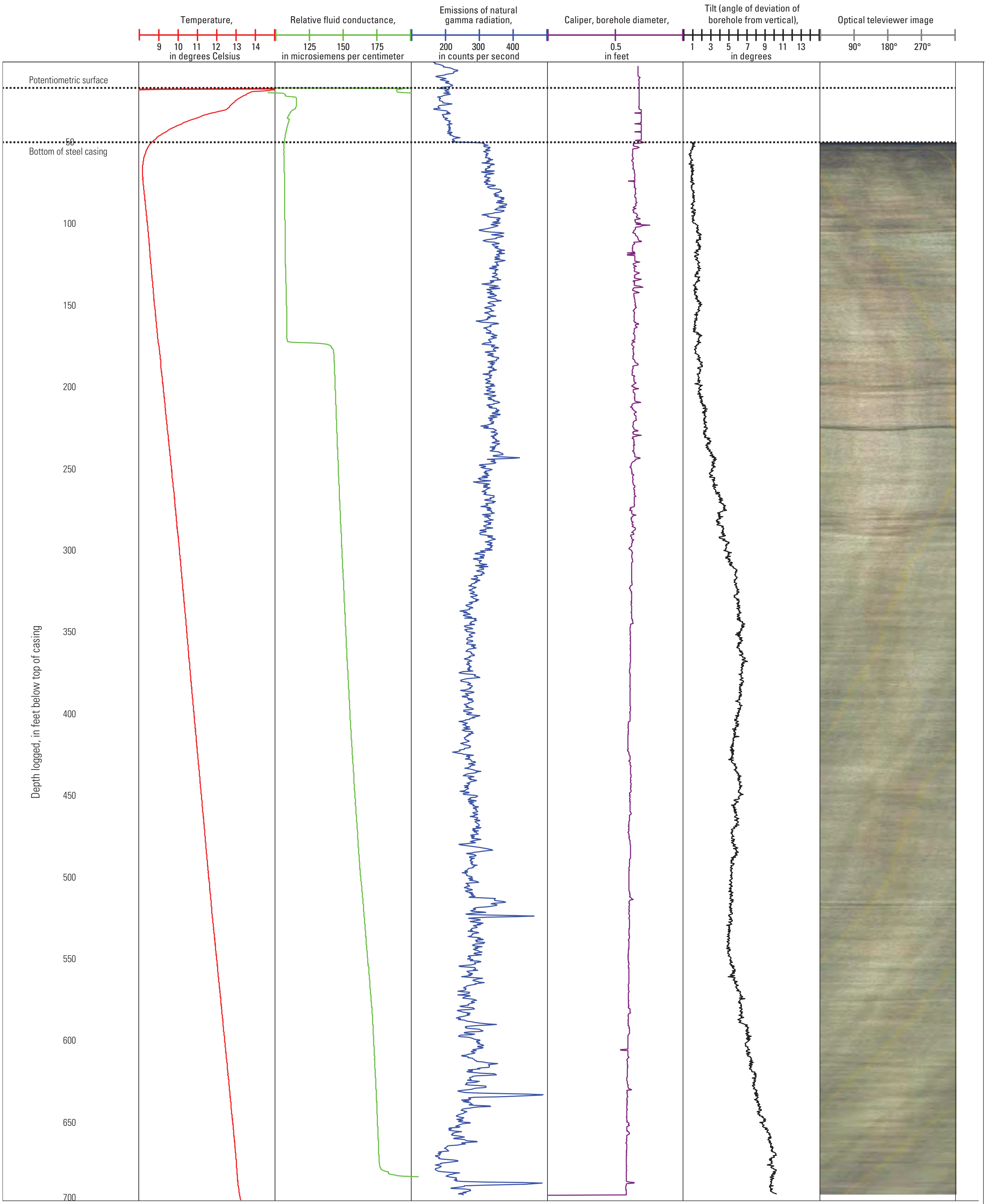

Figure 6. Bedrock well CWW 247 in North Conway, New Hampshire, 2013.

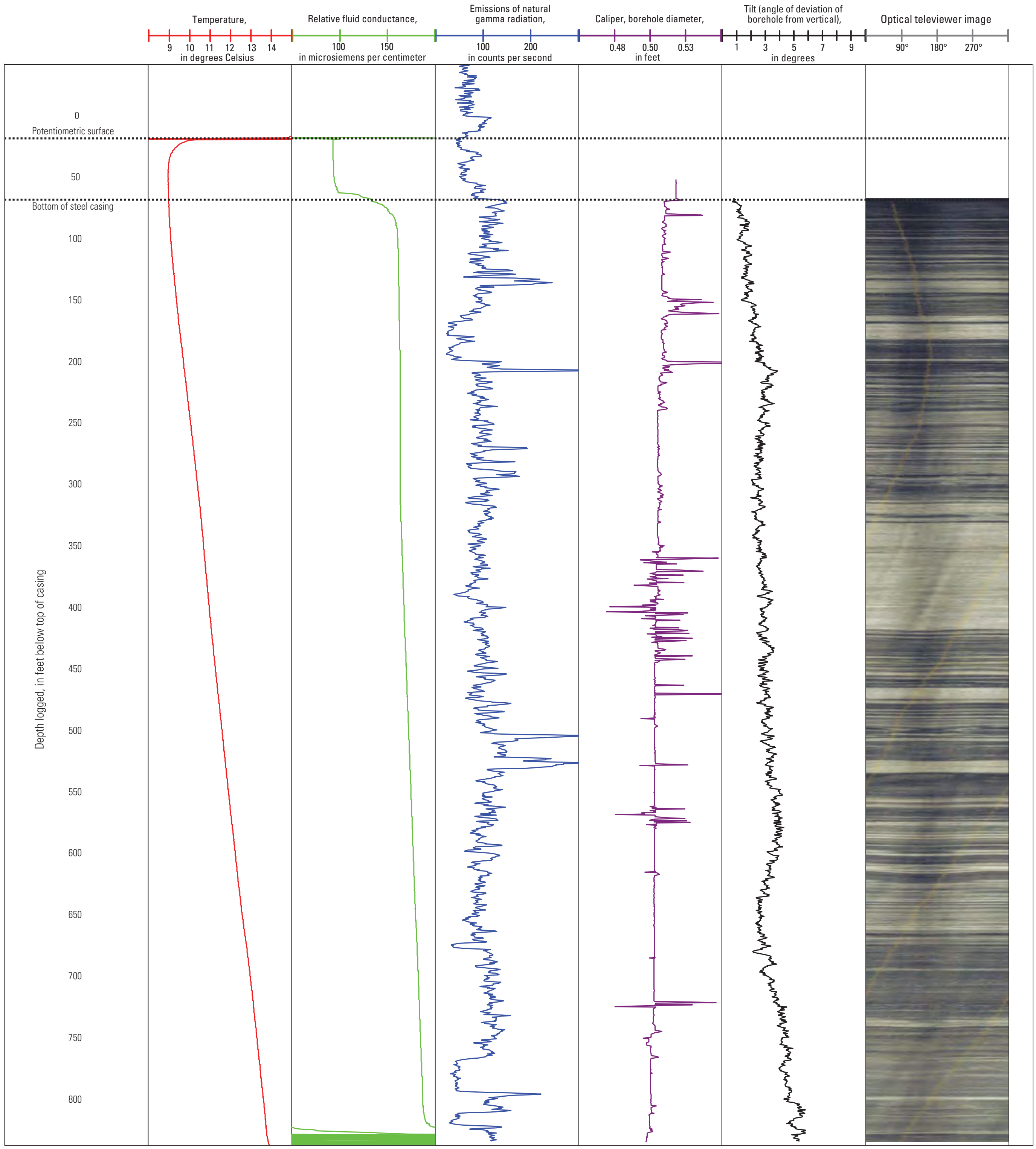

Figure 7. Bedrock well HRW 86 in Holderness, New Hampshire, 2013.

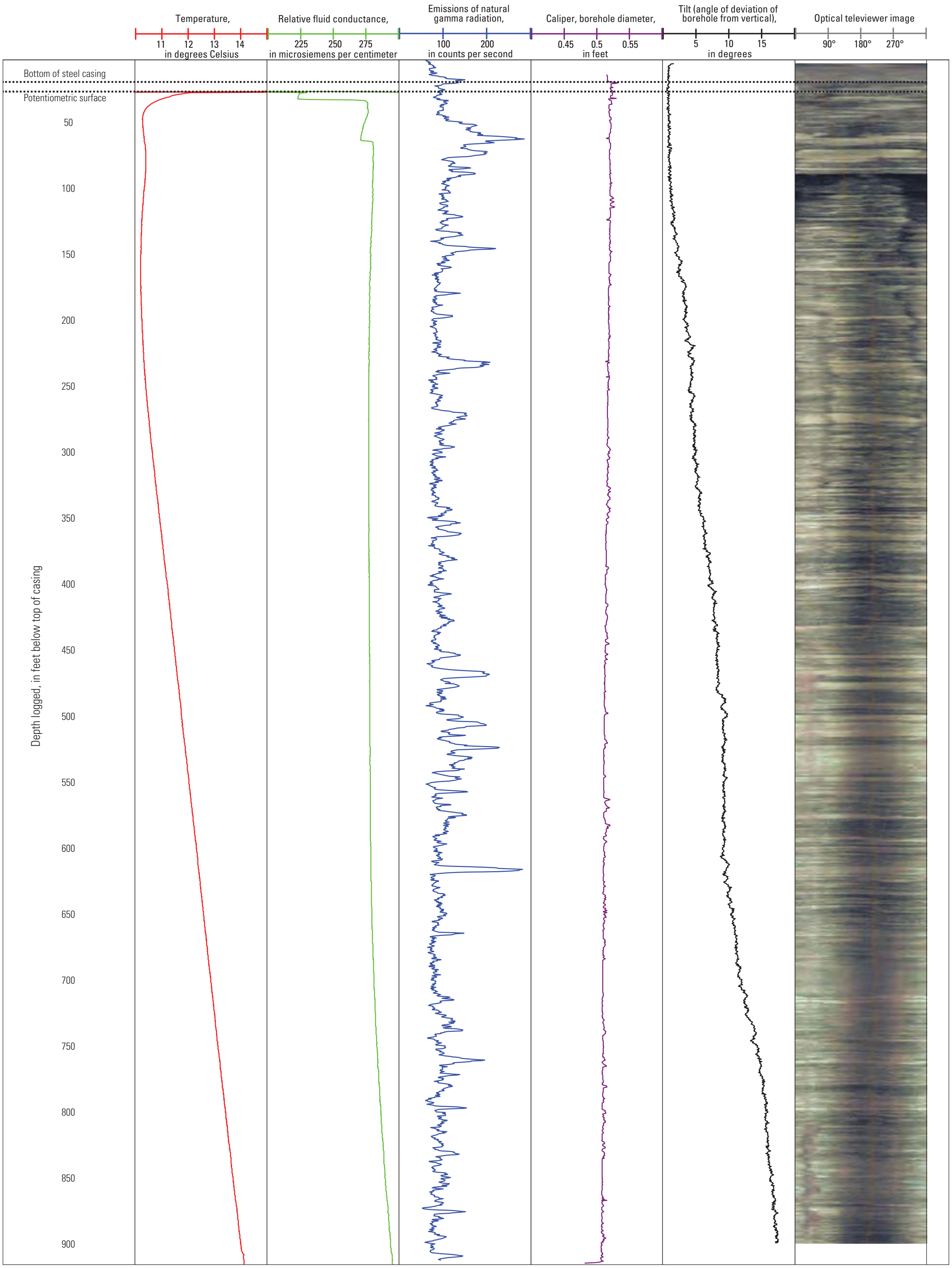

Figure 8. Bedrock well WPW 1068 in Windham, New Hampshire, 2013.

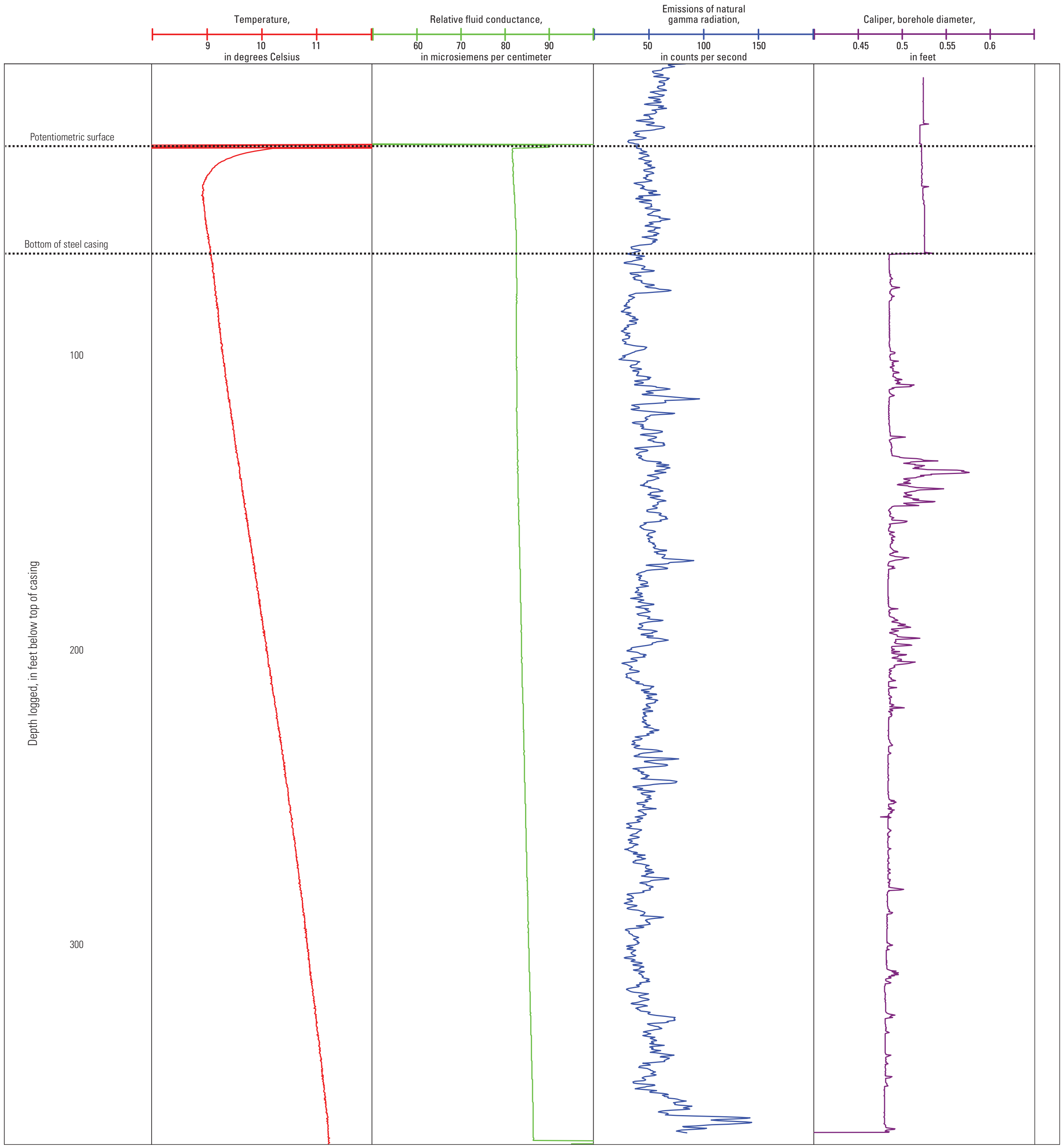

Figure 9. Bedrock well HUW 261 in Hopkinton, New Hampshire, 2013.

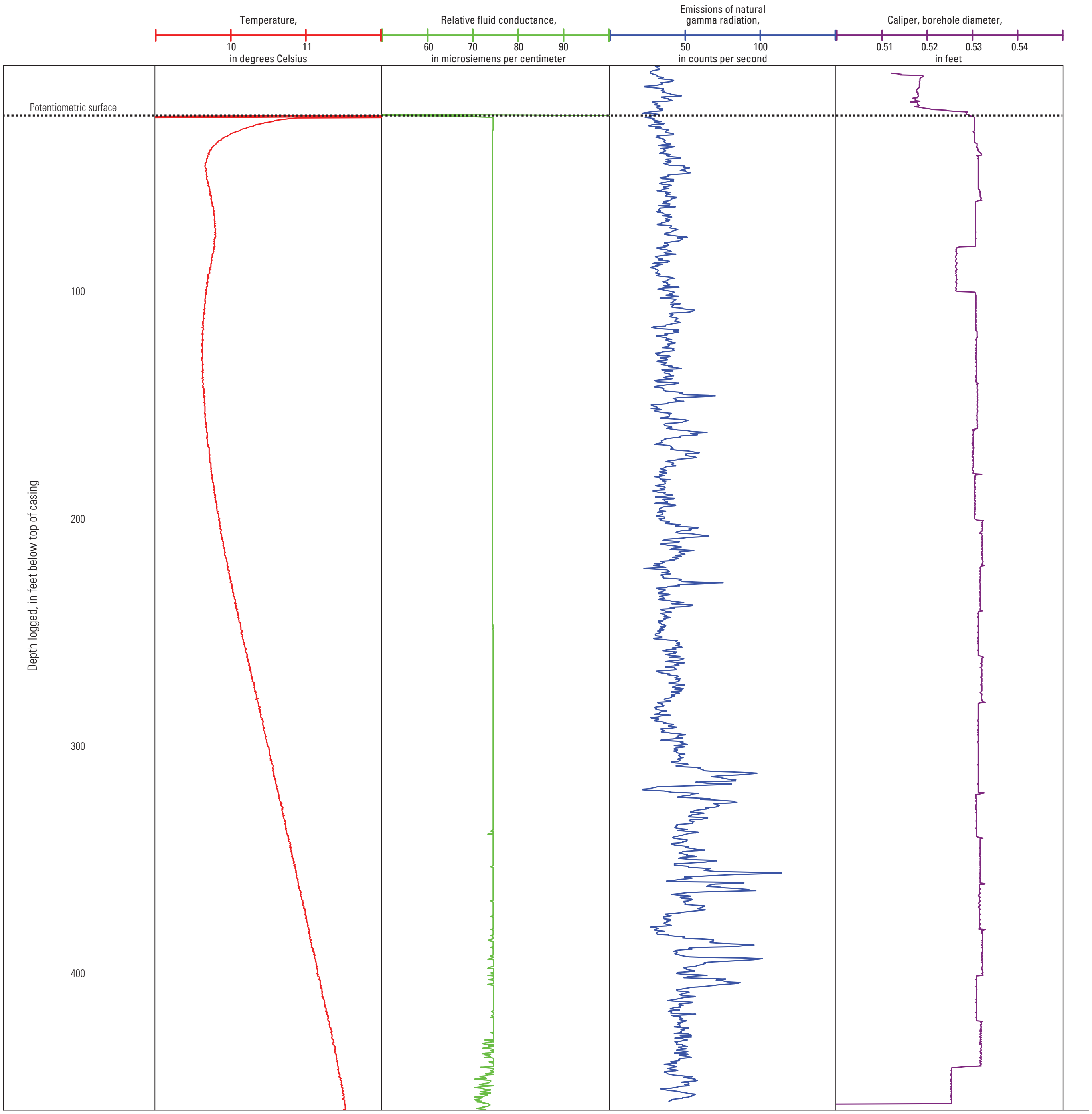

Figure 10. Bedrock well BBW 283 in Barrington, New Hampshire, 2013. Steel casing was present along the entire logged interval.

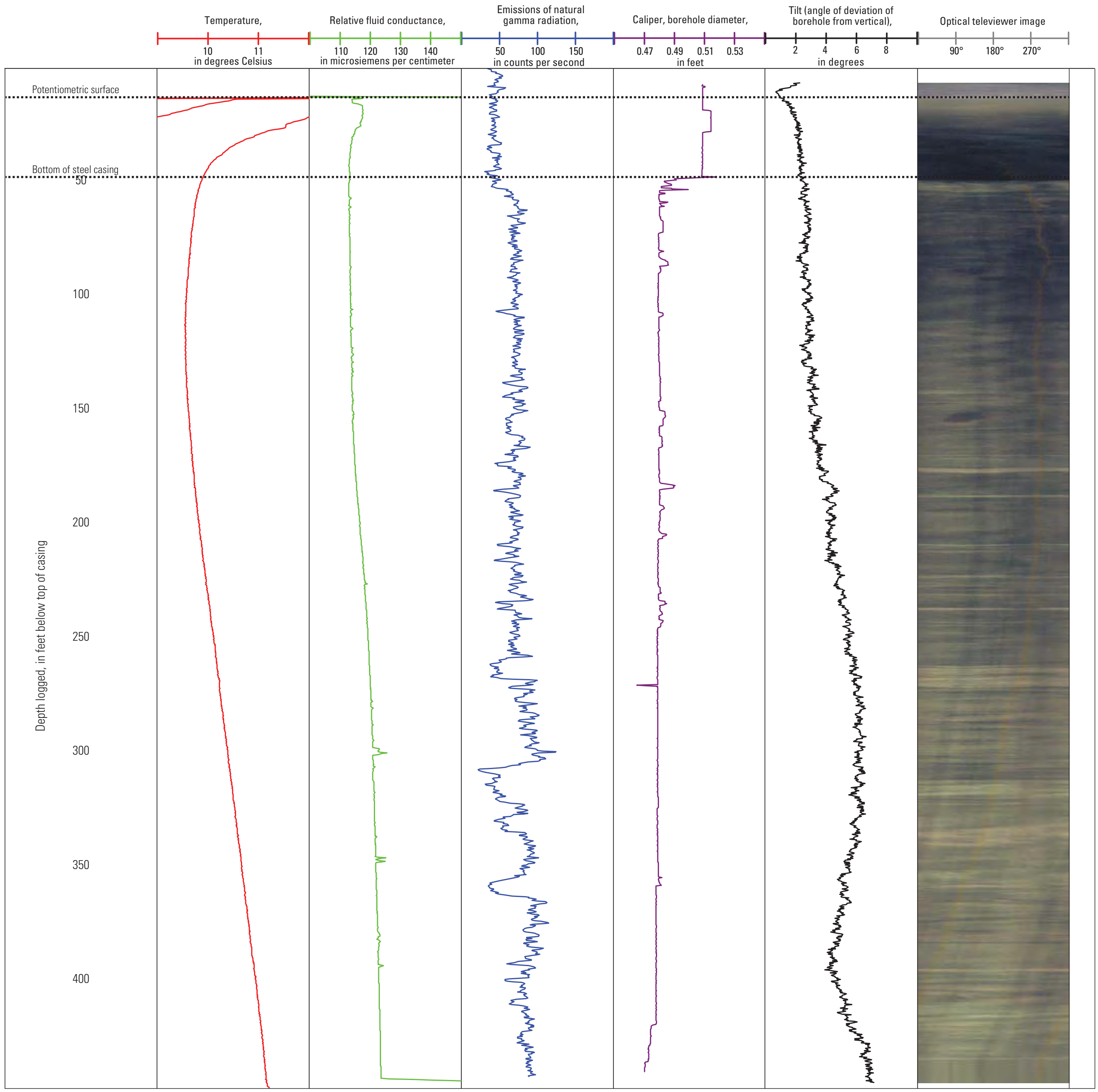

Figure 11. Bedrock well HUW 262 in Hopkinton, New Hampshire, 2013.

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Prepared by the Pembroke and West Trenton Publishing Service Center.

For more information concerning this report, contact:

Office Chief
U.S. Geological Survey
New England Water Science Center
New Hampshire-Vermont Office
331 Commerce Way, Suite 2
Pembroke, NH 03275
dc_nh@usgs.gov

or visit our Web site at:
http://nh.water.usgs.gov

Degnan and others—**Geophysical Logging of Bedrock Wells for Geothermal Gradient Characterization in New Hampshire, 2013**—Data Series 823

ISSN 2327-638X (online)
http://dx.doi.org/10.3133/ds823