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Temperature Logging of Groundwater in Bedrock Wells for Geothermal Gradient Characterization in New Hampshire, 2012

Data Series 728

U.S. Department of the Interior
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Cover. Borehole logging cable and well at Mason, New Hampshire. U.S. Geological Survey photograph.

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Reviews of this report were done by Tom Mack, Mike Brayton, Rich Moore, and Anna Glover. Technical advice from Paul Staples of Mount Sopris Instruments was helpful for temperature calibration. Kelsey Regan of the USGS provided assistance with logging and data management. Permission and support from private land owners who allowed access to their wells made data collection possible.

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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)

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

$$°F=(1.8\times°C)+32$$

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).

Temperature Logging of Groundwater in Bedrock Wells for Geothermal Gradient Characterization in New Hampshire, 2012

By James 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 in deep bedrock wells in the State of New Hampshire in order to characterize geothermal gradients in bedrock. All wells selected for the study had low water yields, which correspond to low groundwater flow from fractures. This reduced the potential for flow-induced temperature changes that would mask the natural geothermal gradient in the bedrock. All the wells included in this study were privately owned, and permission to use the wells was obtained from homeowners before logging.

Maximum groundwater temperatures at the bottom of the logs were between 11.7 and 17.3 degrees Celsius. Geothermal gradients were generally higher than 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 5 of the 10 wells studied but only obscured the portion of the geothermal gradient signal where groundwater actually flowed through the well. Temperature gradients varied by mapped bedrock type but can also vary by differences in mineralogy or rock type within the wells.

Introduction

Information collected from groundwater temperature logs can be used to assess the potential of geologic formations for development of geothermal energy. The temperature of groundwater within wells reflects the temperature of the surrounding geologic formations, in the absence of significant groundwater flow. Geothermal gradients 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 0.6°C per 100 ft (Keys, 1990), which is the range that was expected to be found in this study.

Purpose and Scope

The New Hampshire Geological Survey (NHGS) is interested in the potential for developing geothermal energy in the State. The purpose of this report is to present data regarding geothermal gradients reflected in fluid temperature of groundwater in crystalline bedrock wells in the State of New Hampshire. The information in this report can help decision-makers to evaluate the geothermal potential of the bedrock in New Hampshire. For this study, wells were logged to determine temperature, and the data collected will become part of a national inventory of data used to evaluate geothermal potential across the United States. Temperature and gamma log data in the log ASCII standard format are part of this report.

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 gradients are attributable to the location of the convention cells, crustal thickness, rock type, and heat production by the decay of radioactive minerals. Birch and others (1968) reported uncorrected geothermal gradients between 0.55 and 0.67°C per 100 ft for sites in central New Hampshire.

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

[1]U.S. Geological Survey.

[2]New Hampshire Geological Survey.

was quantified by Billings and Keevil (1945). Hoag and Stewart (1977) provide a detailed lithologic and geophysical description of the geothermal test hole in Redstone (a village in Conway, New Hampshire), including a temperature log. 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 temperature logging. Additional fluid and physical borehole properties, such as fluid conductance and natural gamma radiation emissions, were collected at selected wells. Well construction data were entered into the U.S. Geological Survey (USGS) groundwater site inventory database. Log data are stored and archived in log ASCII standard format and are available as part of this report.

Well Selection

The selection of wells was made by the NHGS based on depth, bedrock type, accessibility, lack of pumps and plumbing in the well, and low potential for intraborehole flow (low yield, ranging from 0 to 4 gallons per minute). The Water Well Inventory Program database (New Hampshire Department of Environmental Services, undated) of the State of New Hampshire was queried to find candidate wells. Ten deep (deeper than 900 ft, except one that was 440 ft in depth) bedrock wells with low water yield were selected (table 1).

All ten of the deep bedrock wells selected were logged. Two of the wells are in east-central New Hampshire, and eight are in south-central New Hampshire (fig. 1). The locations of wells were viewed in a geographic information system (GIS) 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, based on geologic information that is mapped at 1:250,000 scale. The actual bedrock formation within the well may vary because of heterogeneity of the rocks on a site scale. 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).

Geophysical Logging

Borehole fluid temperature data were collected at 10 wells using a Mount Sopris Instrument Company 2FPA–1000 (7 wells) and 2SFB-1000 (3 wells) probes, both with a resolution of 0.01°C. Factory calibrations with reported 1-percent accuracy were used for logging in the field. However, before logging, temperature readings from the probe were recorded in concert with a digital thermometer (0.05°C accuracy, 0.001 resolution) in warm- and cold-water baths designed to bracket the temperatures expected in the wells. Thermometer readings were later used to adjust the factory-calibrated data from the probe by applying a two-point linear correction. The median difference in temperature between the probes and the thermometer from both the warm and cold water was then used to correct the probe data. Temperature gradients were determined from temperature measurement differences at 100-ft intervals.

In addition to temperature logs, standard borehole geophysical logs, including natural gamma and fluid conductance, were collected at selected wells, as feasible. Changes in mineralogy and bedrock type are indicated with gamma logs. Fluid conductance logs indicate groundwater flow in a borehole and can indicate where the geothermal gradient information may be masked. Temperature was logged first, going down the hole; logging rates were between 12 and 13 ft 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).

Temperature and Other Borehole Logs

Ten wells that were drilled into igneous rock in New Hampshire were logged with a temperature probe to create a temperature profile of the water column with depth (figs. 2–11). In wells with very low yield, 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 after data collection based on low and high temperature calibration check measurements that were made in the field. The two temperature probes used were calibrated and adjusted separately; the 2PFA–1000 probe had a low and high correction of -1.33°C and -1.45°C; the 2SFB–1000 probe had a low and high correction of -1.32°C and -2.35°C.

Log depths ranged from 442 to 1,400 ft, and the average well water temperature gradients increased by 0.56 to 0.72°C per 100-ft depth (table 2). The coldest temperatures measured near the top of the wells were between 7.49 and 9.97°C, and the warmest temperatures measured at the bottom of the wells ranged from 11.69 to 17.34°C. Warm temperatures measured near the top of the water column are due to seasonal surface temperature influence and were not included in the data summary of gradient calculations.

Deflections in the temperature gradient from well B4W 571 in Brookline indicate that there may be groundwater flow between 1,100 and 1,150 ft in the well. The sharp decrease in gradient at well B4W 422 in Brookline in the bottom 50 ft of

Table 1. Information for bedrock wells used for temperature logging of groundwater for geothermal gradient characterization in New Hampshire, in 2012.

[Measurements are in feet (ft) below the ground surface. gpm, gallons per minute; ID, identification number; NA, no other units mapped nearby; USGS, U.S. Geological Survey; --, no data are available]

Date drilled	State well ID	USGS well ID	Well depth,[1] in ft	Depth to bed-rock,[1] in ft	Casing length,[1] in ft	Yield,[1] in gpm	Static water level,[1] in ft	Town	Mapped rock unit[2]	Distance and direction to nearby contacts[2]	Nearby mapped rock unit[2]
11/11/1993	007.0405	AMW 462	1,000	4	20	0.25	100	Amherst	Gray biotite granite (Permian)	400 ft to the southeast	Massabesic Gneiss Complex (late Proterozoic)
3/22/2006	020.2610	BIW 1622	1,500	4	60	0.25	--	Bedford	Massabesic Gneiss Complex (late Proterozoic)	NA	NA
1/9/1991	033.0274	B4W 221	440	10	24	4.00	10	Brookline	Massabesic Gneiss Complex (late Proterozoic)	2,500 ft to southwest and northwest	Gray biotite granite (Permian)
8/29/2003	033.0987	B4W 571	1,400	2	40	0.25	1,000	Brookline	Gray biotite granite (Permian)	NA	NA
7/20/1995	033.0650	B4W 422	920	8	20	0.50	20	Brookline	Massabesic Gneiss Complex (late Proterozoic)	2,500 ft to southwest and northwest	Gray biotite granite (Permian)
--	--	CWW 245	1,250	--	--	--	--	Conway	Two-mica granite (Pennsylvanian or Mississippian)[3]	NA	NA
2/2/2012	--	MGW 86	1,480	1	30	0.25	320	Mason	Massabesic Gneiss Complex (late Proterozoic)[4]	800 ft to southeast 1,400 ft north	Berwick Formation[6] (Silurian-Ordovician) Gray biotite granite (Permian)
5/29/2012	--	MGW 87	1,720	1	32	0.00	--	Mason	Massabesic Gneiss Complex (late Proterozoic)[5]	800 ft to southeast 1,400 ft north	Berwick Formation[6] (Silurian-Ordovician) Gray biotite granite (Permian)
10/16/1989	187.0281	OXW 117	1,120	20	40	0.50	144	Ossipee	Two-mica granite (Pennsylvanian or Mississippian)[3]	1,300 ft to west	Littleton Formation (Devonian)
9/18/2001	254.0261	WNW 120	1,300	7	40	0.25	760	Wilton	Spaulding Tonalite (Early Devonian)	NA	NA

[1]Driller-reported (Skillings and Sons, written commun., 2012).

[2]From Lyons and others, 1997.

[3]Two-mica granite of the Sebago batholith and Effingham Pluton of eastern New Hampshire.

[4]Driller-reported granite (Skillings and Sons, written commun., 2012).

[5]Driller-reported gray granite (Skillings and Sons, written commun., 2012).

[6]Berwick Formation of the Merrimack Group.

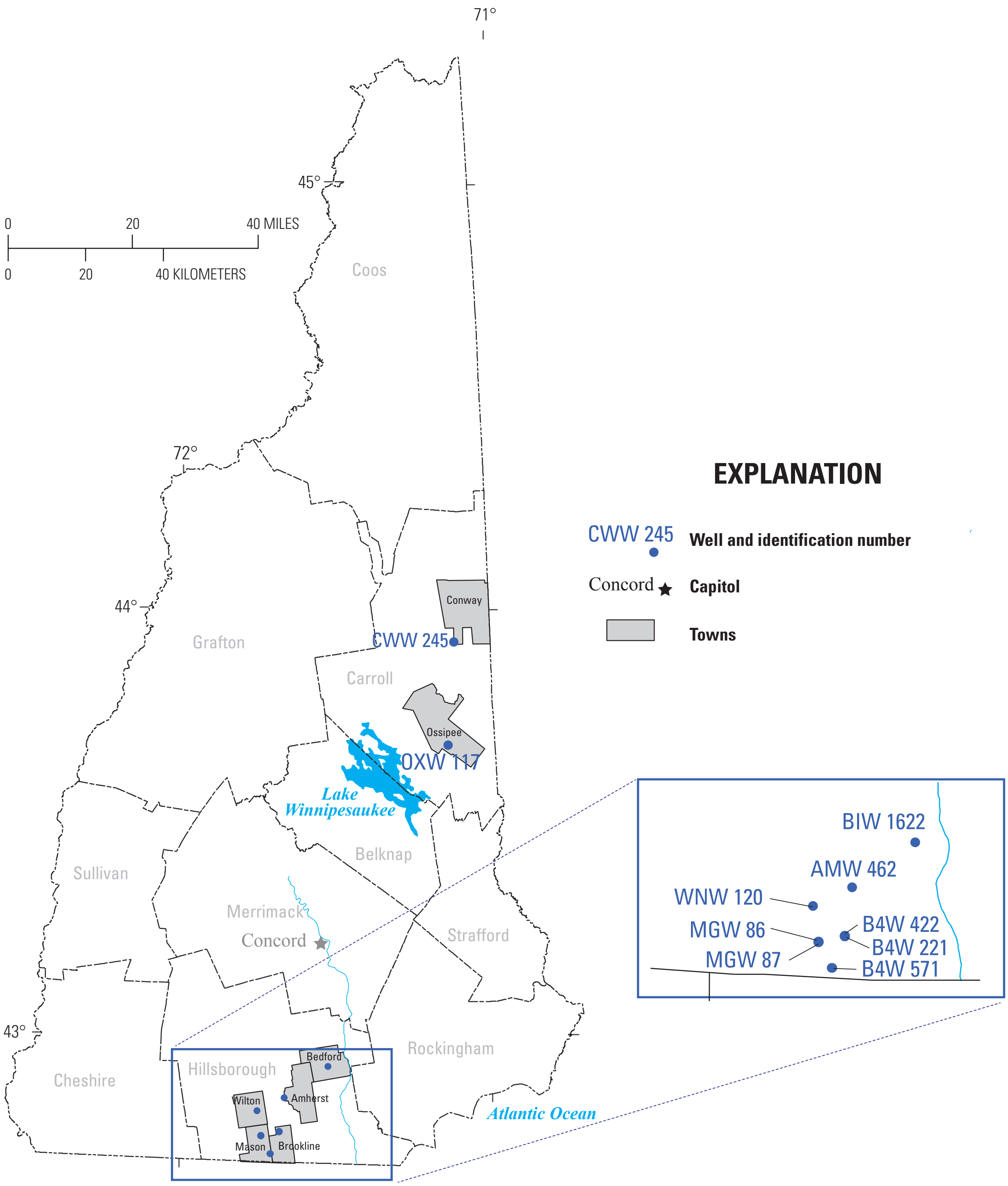

Figure 1. Locations of bedrock wells logged in New Hampshire in 2012 for geothermal gradient characterization. Well identification numbers are from the U.S. Geological Survey Groundwater Site Inventory Database of the National Water Information System (U.S. Geological Survey, 2012).

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

[Measurements are in feet (ft) below top of casing. --, no data collected; °C, degrees Celsius; 1, 2PFA-1000 probe; 2, 2SFB-1000 probe]

Well	Probe	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	Maximum bottom	Mean	Median	Maximum	Mean	Median	Maximum
AMW 462	1	988.1	Yes	44.30	9.11	14.51	0.65	0.64	0.70	167	148	760
BIW 1622	1	1,350.0	No	9.76	9.33	17.34	0.66	0.65	0.73	108	107	479
B4W 221	1	442.0	Yes	29.60	9.77	11.69	0.65	0.65	0.69	157	143	483
B4W 571	1	1,391.2	Yes	29.20	9.88	16.47	0.56	0.56	0.66	125	120	529
B4W 422	1	910.0	Yes	3.22	9.97	14.20	0.58	0.53	0.66	123	114	733
CWW 245	2	1,248.1	Yes	18.81	7.49	16.15	0.72	0.71	0.84	--	--	--
MGW 86	1	1,322.3	Yes	50.21	8.35	15.10	0.56	0.56	0.65	--	--	--
MGW 87	2	1,400.0	No	30	8.15	15.51	0.56	0.57	0.66	--	--	--
OXW 117[1]	2	797.0 1,112.4	No Yes	26.96	8.80	12.63	0.56	0.57	0.73	314	305	841
WNW 120	1	1,222.7	Yes	44.82	9.03	16.12	0.67	0.67	0.74	247	228	1,160

[1]An obstruction was encountered with the larger probe that contained the temperature sensor, limiting the depth of that profile.

the well indicates possible groundwater inflow. The deflection in the gradient of well CWW 245 in Conway between 1,200 and 1,220 ft indicates possible slight groundwater flow. The temperature gradient from well MGW 87 in Mason is steepest and uniform between 100 and 600 ft of depth and decreases slightly between 600 and 1,000 ft. This decrease suggests groundwater flow and is corroborated by the fluid conductivity log. The gradient increases again below depths of 1,000 ft. This well has very similar temperature gradients to well MGW 86 in Mason and is located about 140 ft away and slightly downslope. The conductance log from well OXW 117 in Ossipee indicates possible groundwater flow between 620 and 675 ft of depth. Average gamma counts per second for the wells ranged from 108 to 314.

Summary

Ten deep bedrock wells were logged 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 11.69 to 17.34 degrees Celsius (°C). The coldest temperatures, measured near the top of the wells ranged from 7.49 and 9.97°C. Average geothermal gradients ranged from 0.56 to 0.72°C per 100 feet (ft). These gradients are in the upper half (or higher) of the range (0.47 to 0.6°C per 100 ft) previously identified (Keys, 1990) for water wells in the United States and were similar to the range reported for other wells in New Hampshire (Birch and others, 1968).

Well CWW 245 in Conway had the highest average and maximum geothermal gradients, 0.72°C per 100 ft and 0.84°C per 100 ft, respectively. Well WNW 120 in Wilton had the highest average and maximum gradients per 100-ft interval of the wells in south-central New Hampshire, 0.67 and 0.74°C, respectively. The second highest average natural gamma radiation count (247 counts per second) also was measured at this well. The mapped bedrock unit at the two warmest wells was a two-mica granite (Pennsylvanian or Mississippian) and the Spaulding tonalite (Early Devonian), respectively (Lyons and others, 1997).

Possible groundwater flow within a well was indicated in 5 of the 10 wells logged based primarily on deviation of the temperature log; the five wells were B4W 571, B4W 422, CON01, MGW 87, and OXW 117. Fluid conductance logs were available 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 wells but does not obscure the overall gradient. In general, the gradients were uniform and show an increase in temperature with depth.

The two adjacent wells logged in Mason had among the lowest temperature gradients measured, with an average of 0.56°C per 100 ft of depth. The bedrock is mapped as Massabesic Gneiss Complex (late Proterozoic), but it is not known if the wells penetrate contacts with the Berwick Formation (Silurian-Ordovician) or the gray biotite granite (Permian), which are mapped nearby. The driller reported the rock as gray granite, which is also the mapped unit at B4W 571 in the neighboring town of Brookline. The Brookline well also had a lower gradient than the others, with an average of 0.56°C per 100 ft.

Well OXW 117 in Ossipee had the highest (314) average gamma counts per second and was one of two wells that had a gradient increase deep in the well. Due to an obstruction in the well, temperature was not logged to the bottom of this well. The average temperature gradient was low (0.56°C per 100 ft) compared with that from the other wells. The maximum gradient was high, however, at 0.73°C per 100 ft. The bedrock near this well was mapped as a two-mica granite Pennsylvanian and the Littleton Formation (Devonian).

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Figures 2–11

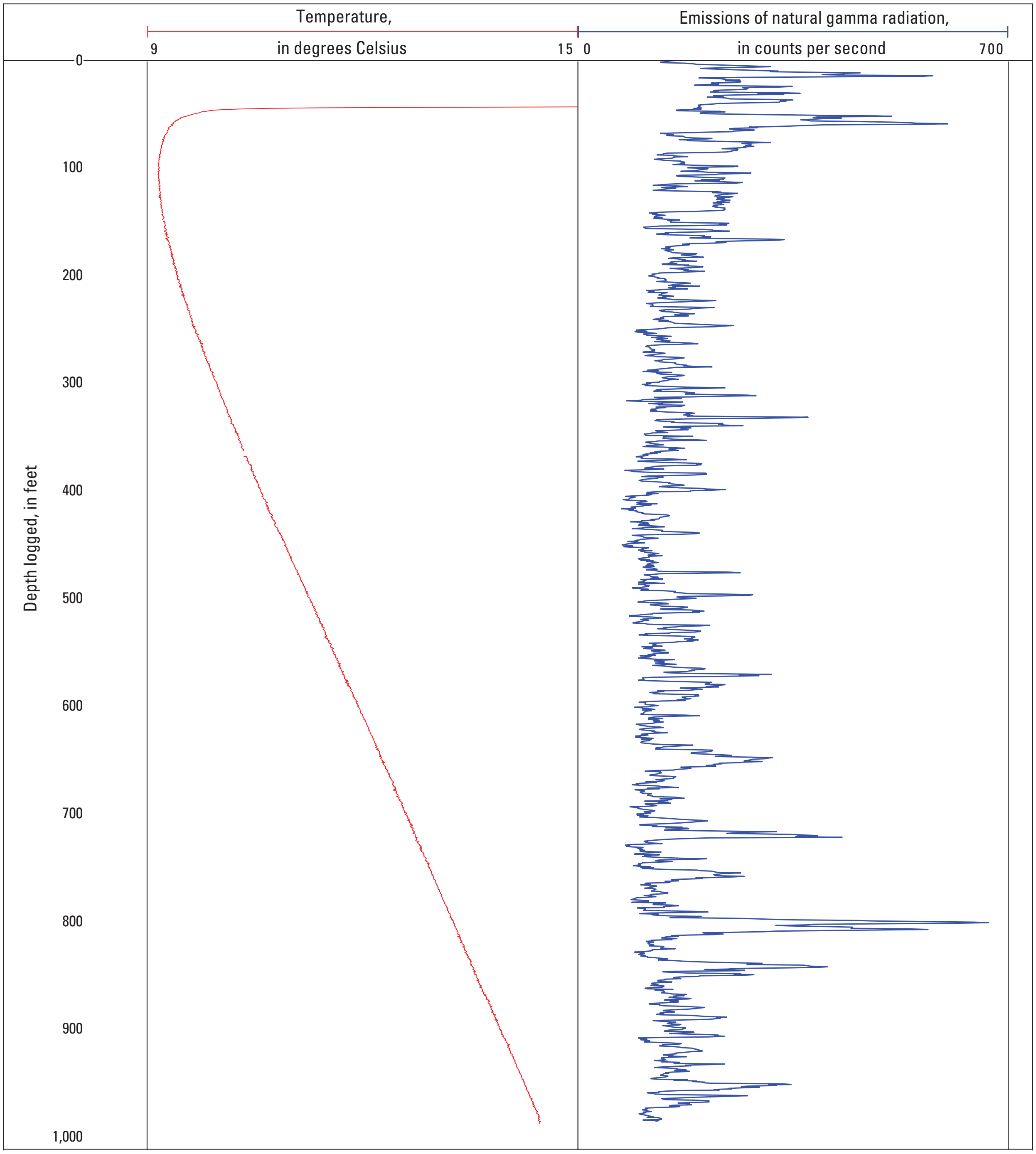

Figure 2. Temperature and gamma geophysical logs from bedrock well AMW 462 in Amherst, New Hampshire, 2012.

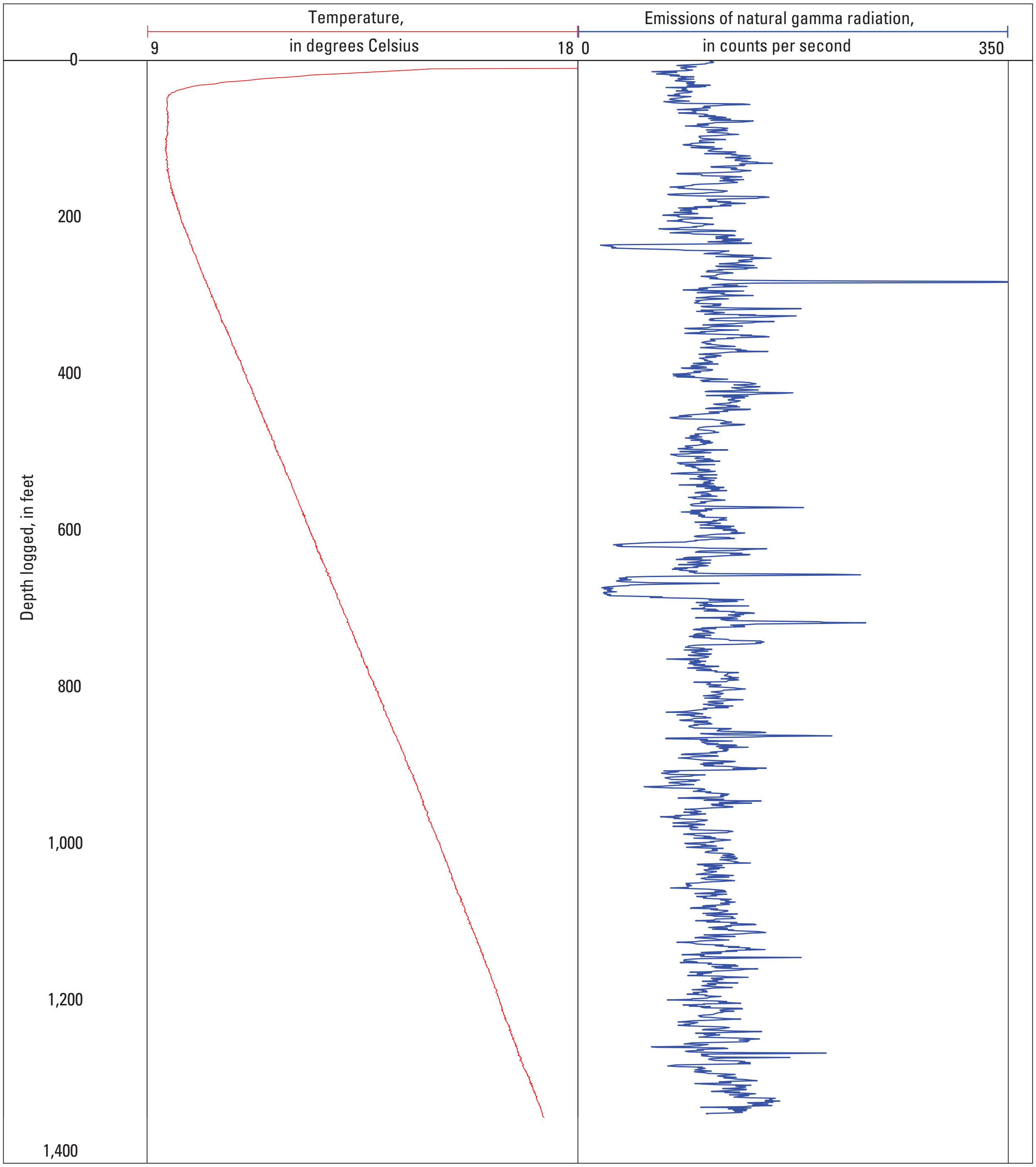

Figure 3. Temperature and gamma geophysical logs from bedrock well BIW 1622 in Bedford, New Hampshire, 2012.

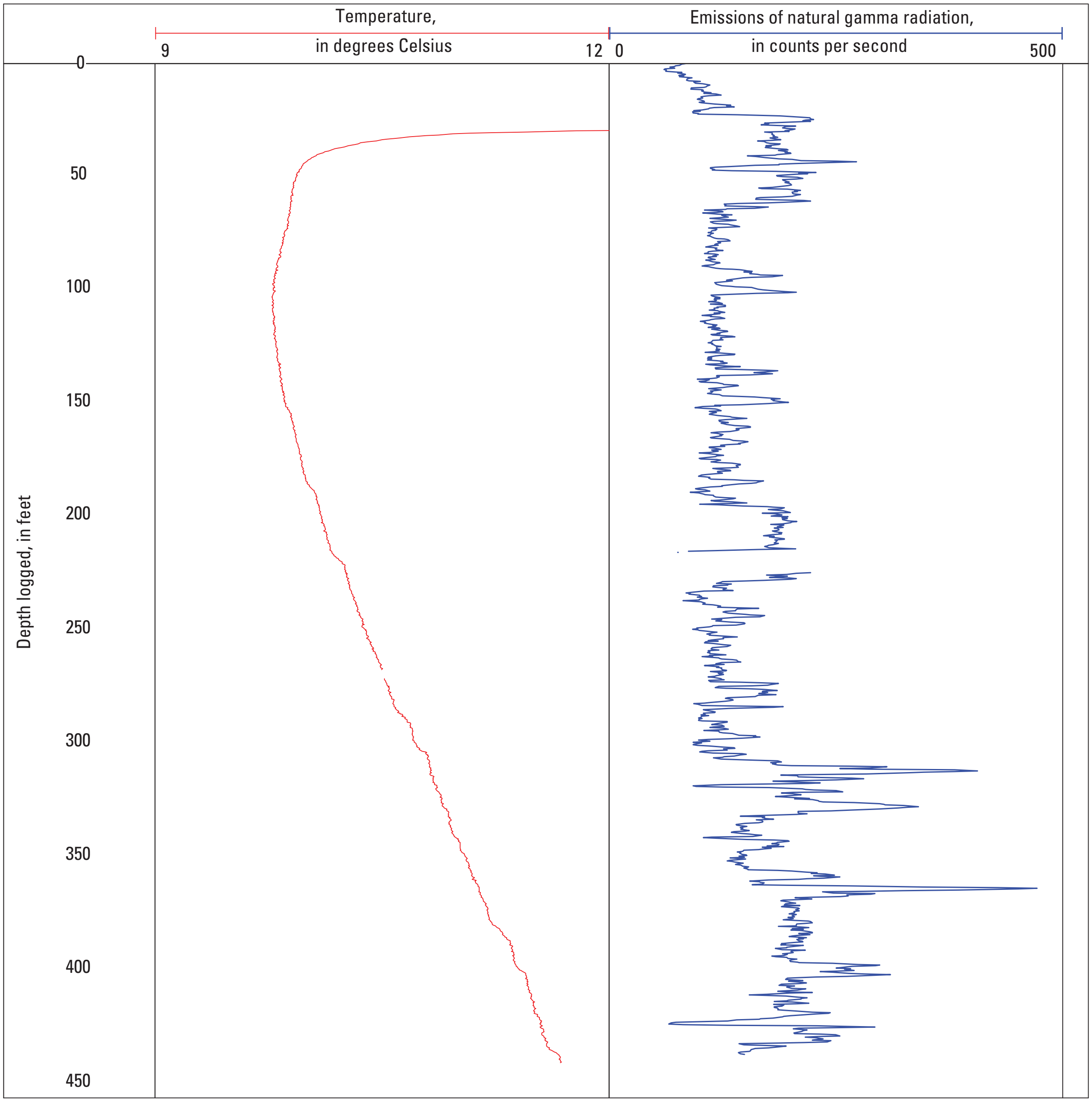

Figure 4. Temperature and gamma geophysical logs from bedrock well B4W 221 in Brookline, New Hampshire, 2012.

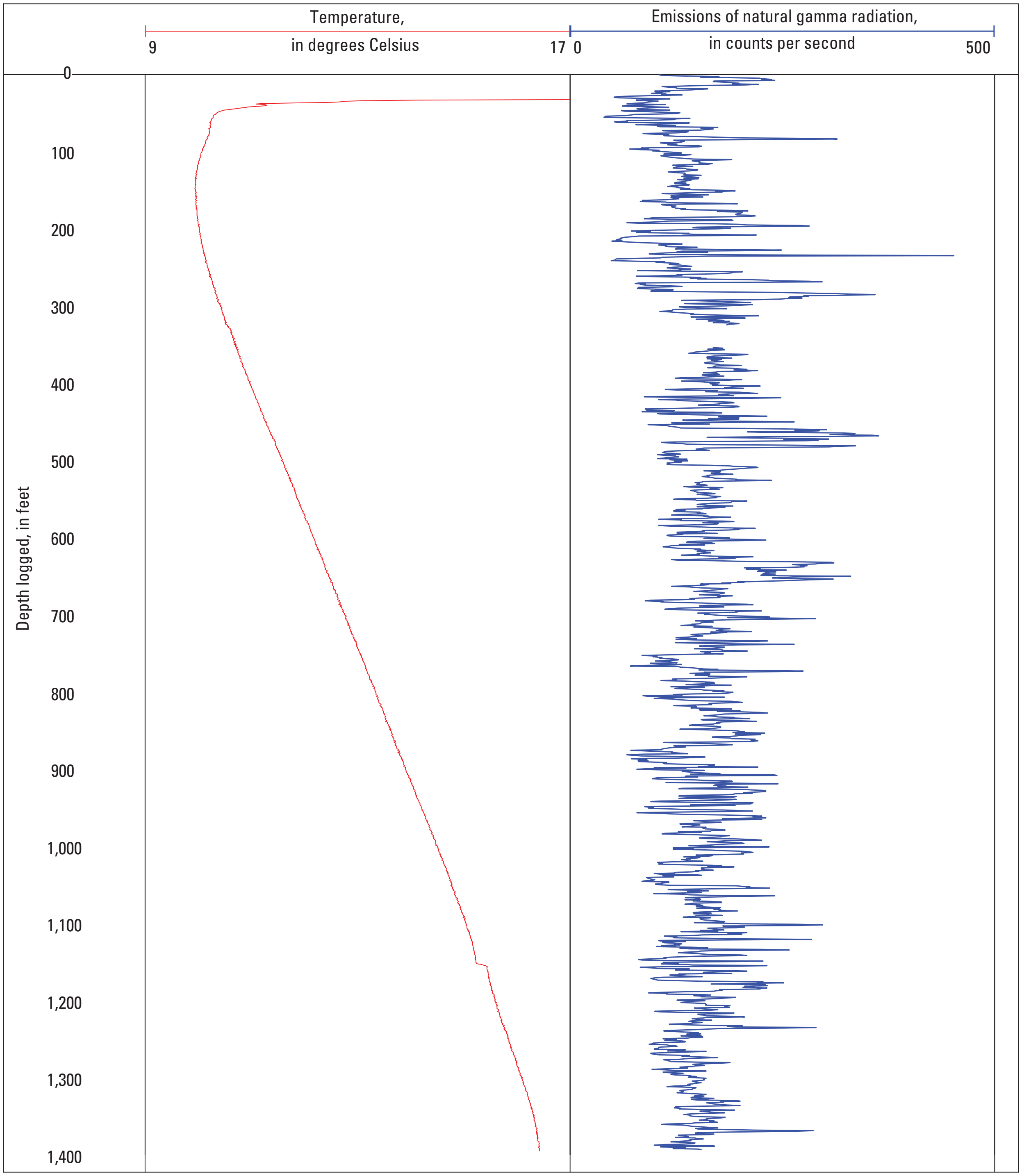

Figure 5. Temperature and gamma geophysical logs from bedrock well B4W 571 in Brookline, New Hampshire, 2012.

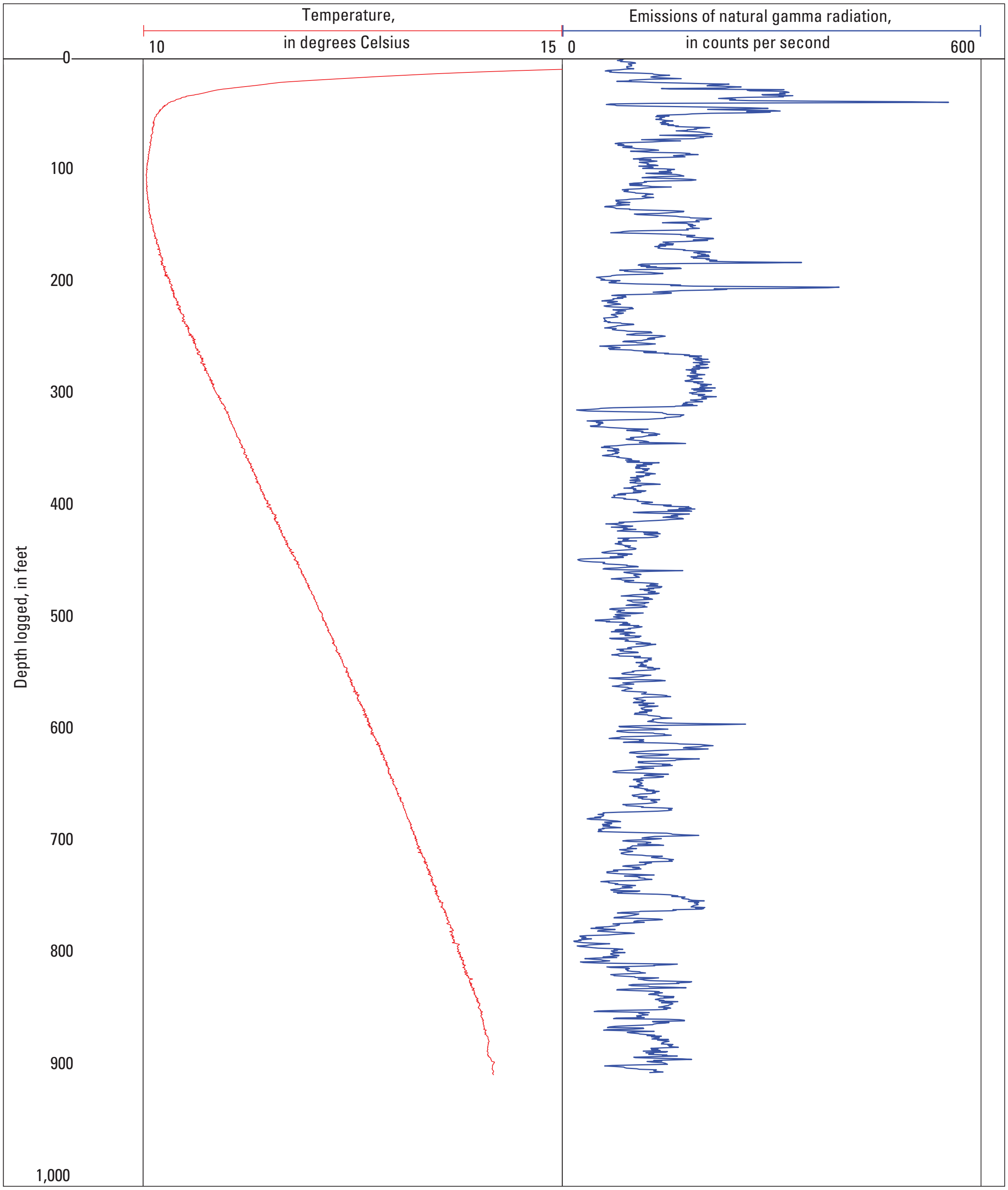

Figure 6. Temperature and gamma geophysical logs from bedrock well B4W 422 in Brookline, New Hampshire, 2012.

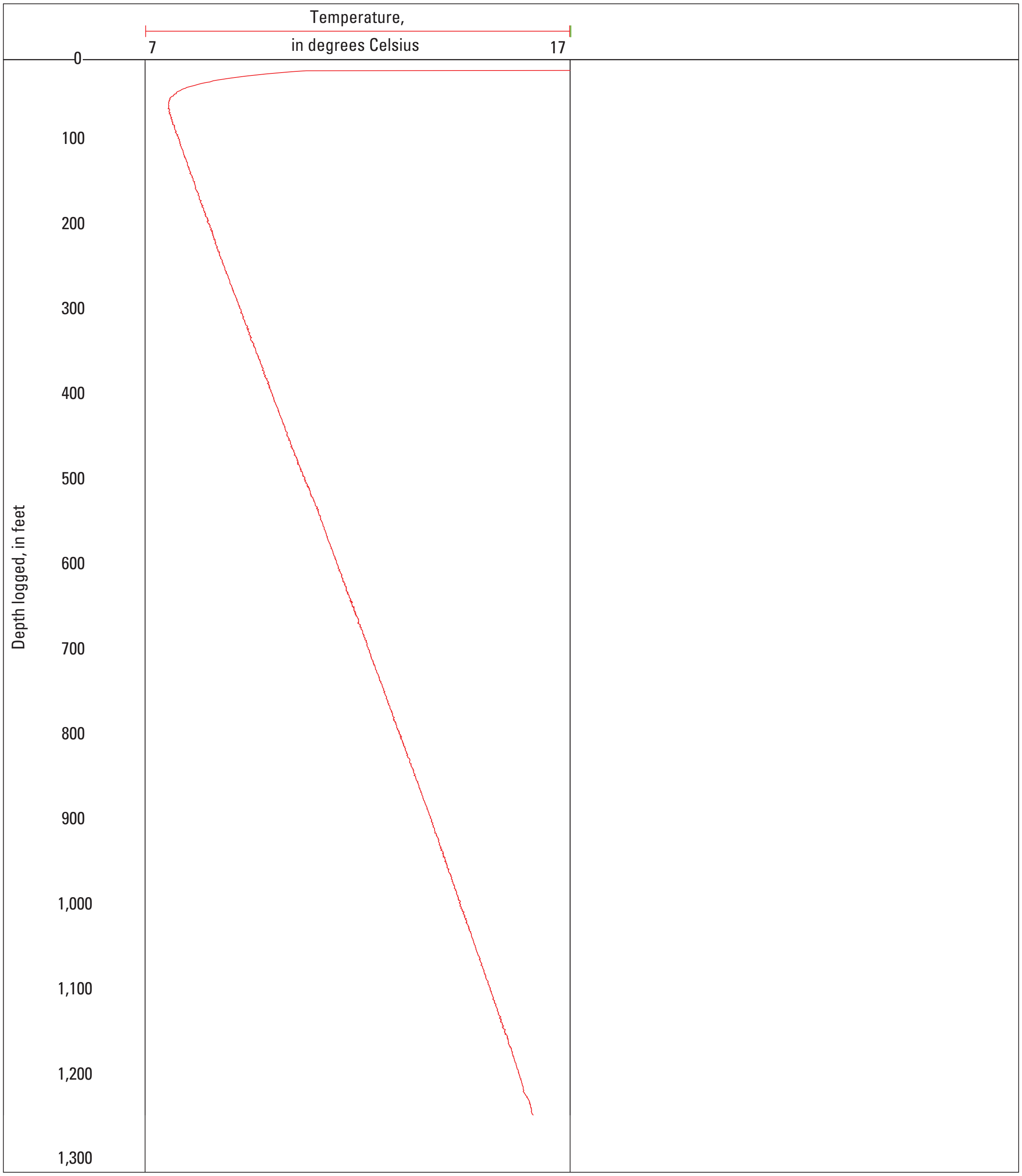

Figure 7. Temperature geophysical log from bedrock well CWW 245 in Conway, New Hampshire, 2012.

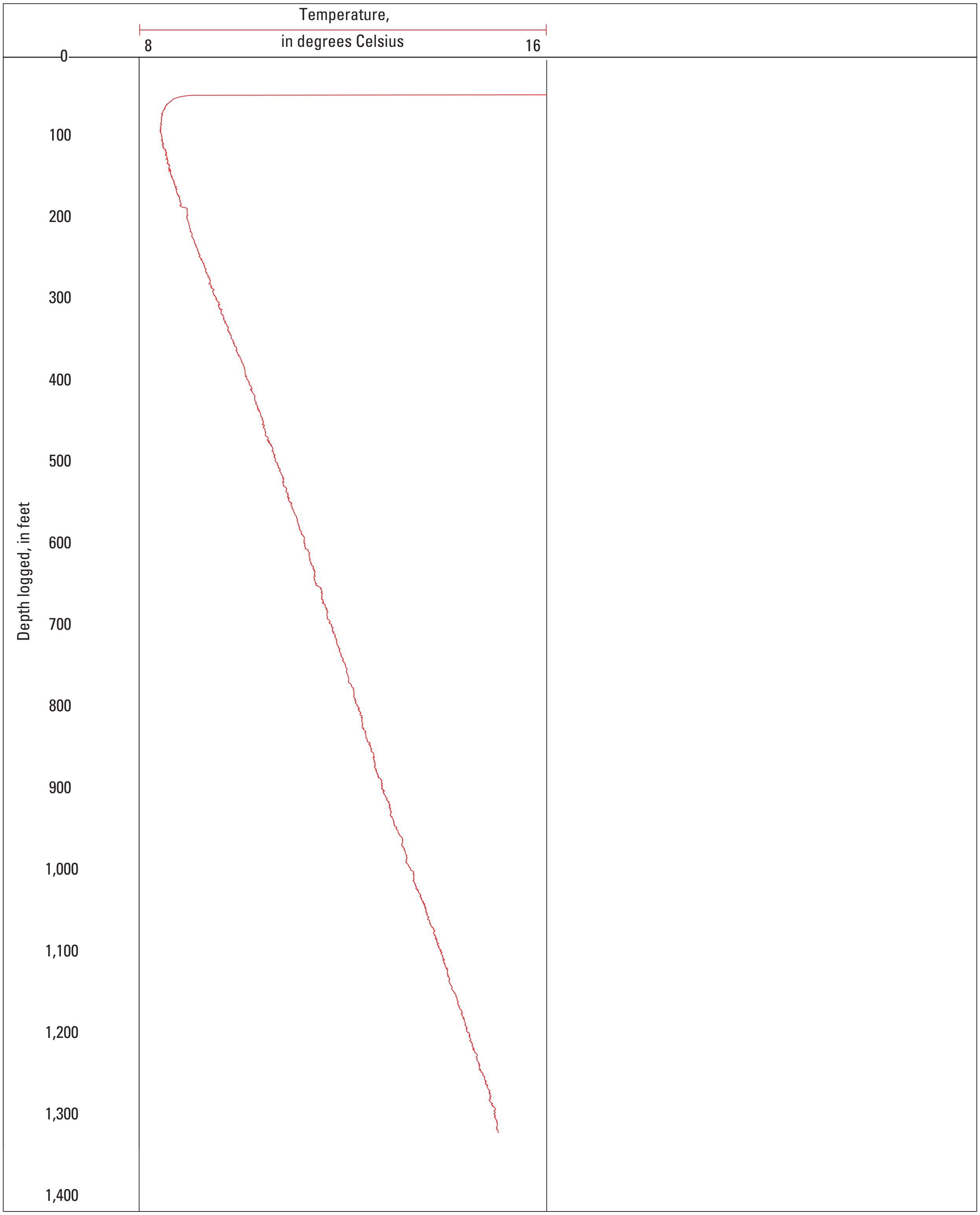

Figure 8. Temperature geophysical log from bedrock well MGW 86 in Mason, New Hampshire, 2012.

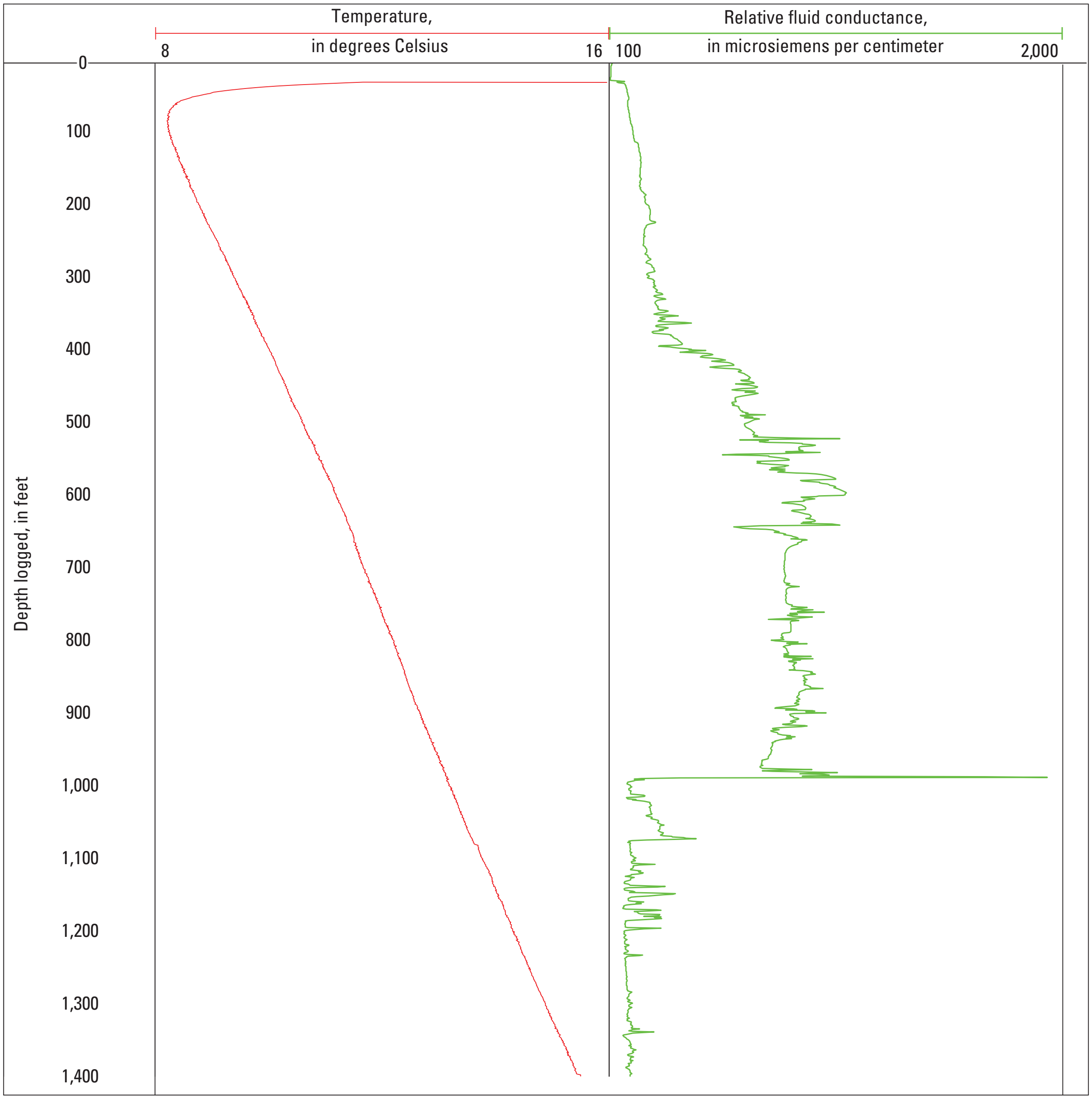

Figure 9. Temperature and conductance geophysical logs from bedrock well MGW 87 in Mason, New Hampshire, 2012.

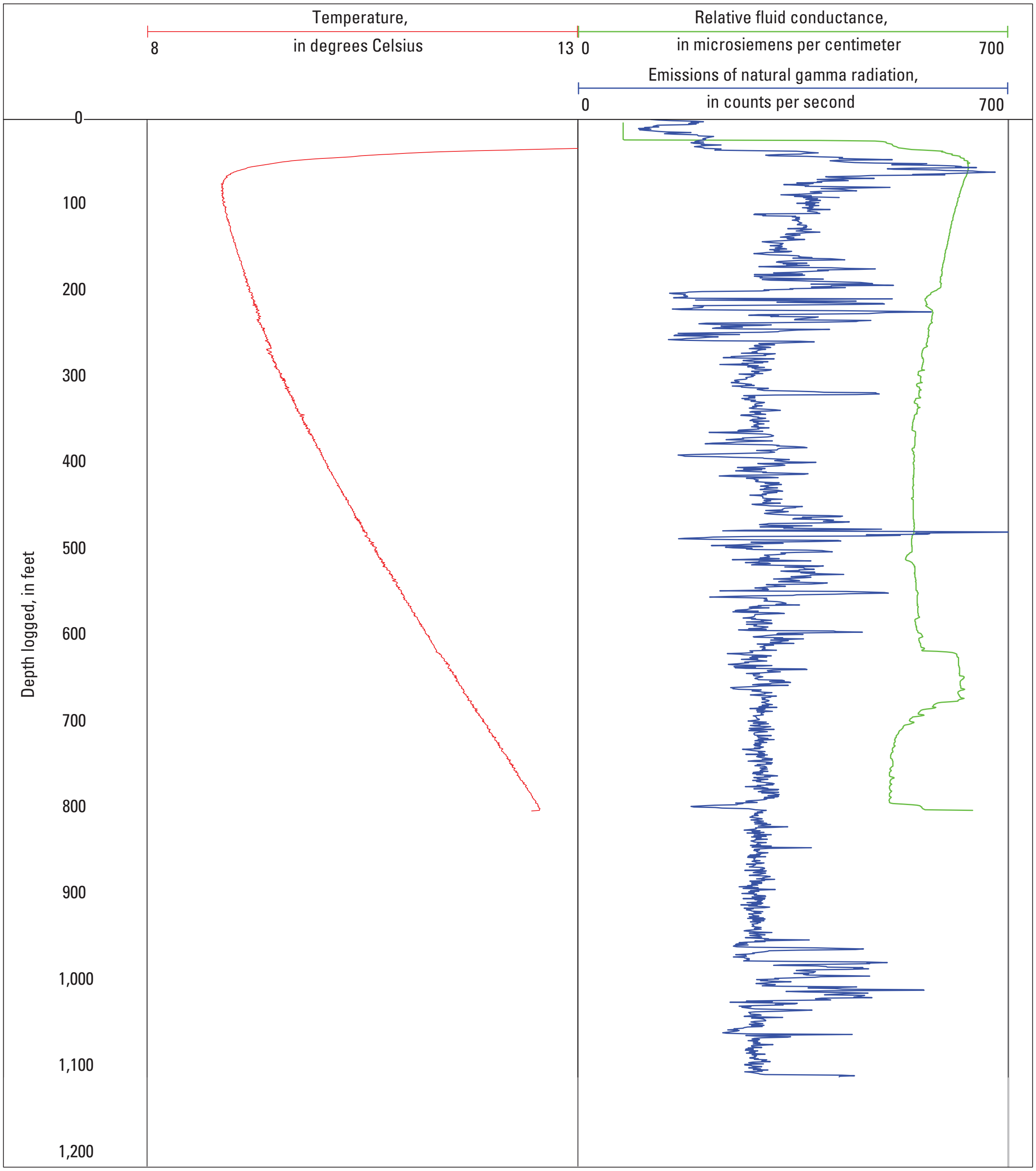

Figure 10. Temperature, conductance, and gamma geophysical logs from bedrock well OXW 117 in Ossipee, New Hampshire, 2012.

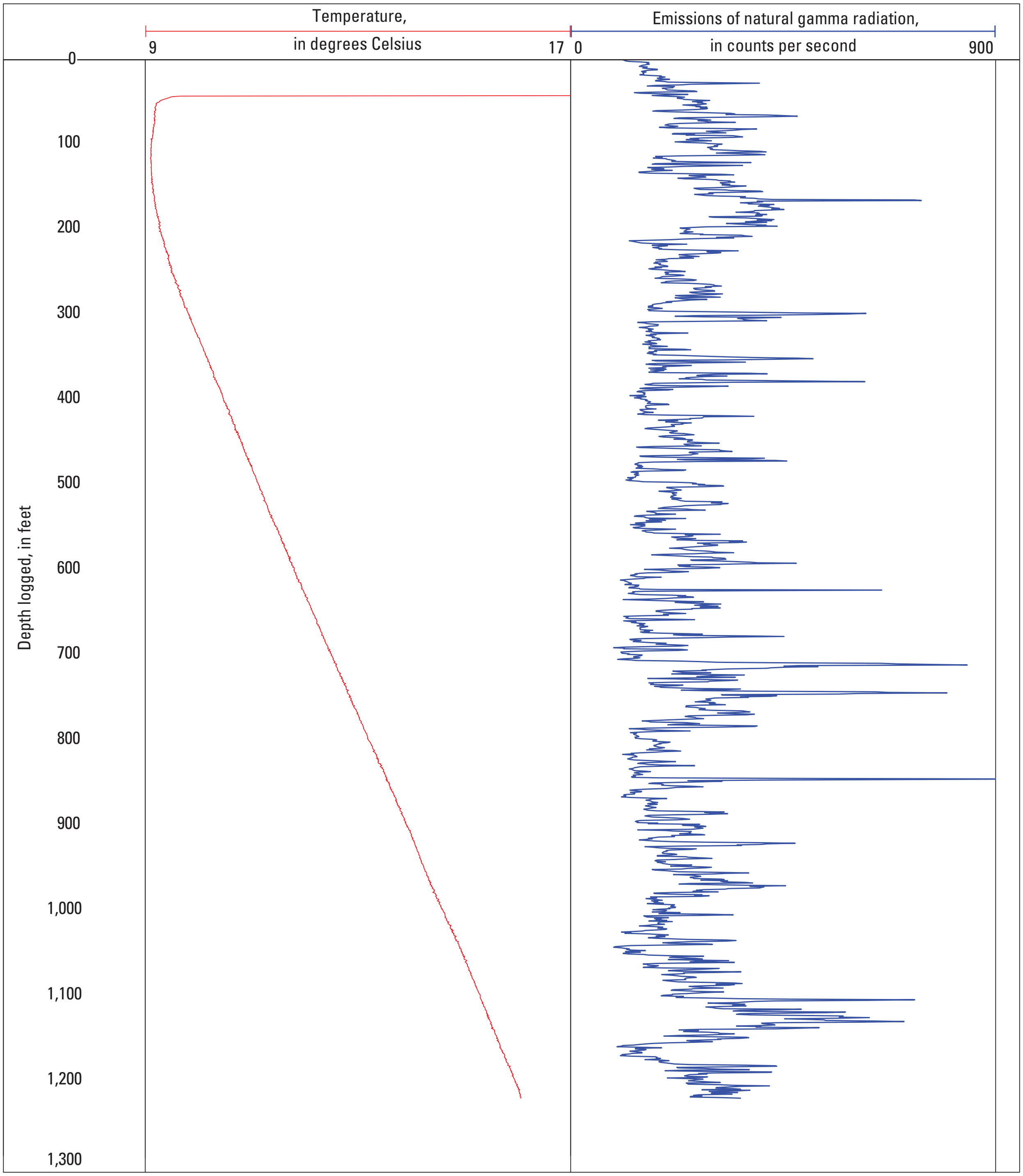

Figure 11. Temperature and gamma geophysical logs from bedrock well WNW 120 in Wilton, New Hampshire, 2012.

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