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PRELIMINARY DATA FROM SIX TEMPERATURE GRADIENT HOLES NEAR CODY, WYOMING

by

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INTRODUCTION

Six holes were drilled near Cody in northwest Wyoming in an effort to define a low- to moderate temperature hydrothermal resource. The holes were drilled during January, February, and March of 1980. The total depths of the holes ranged from 116.0 meters (380.5 ft.) to 56.4 meters (185.0 ft.). The project was financially supported by Cooperative Agreement DE-FC07-791-D12026 between the U.S. Department of Energy and the University of Wyoming. This report briefly summarizes the mechanical details of the drilling and casing, and presents preliminary geothermal data for the holes.

EVIDENCE FOR HYDROTHERMAL SYSTEM

The DeMaris Hot Springs, a group of at least seven vents ranging in temperature from 24° to 37° C are one mile west of Cody in northwest Wyoming (see Figure 1). The springs occur on the southeastern flank of a large anticline, the Rattlesnake anticline, where the impermeable Chugwater Formation has been eroded through by the Shoshone River. Within 1000 feet of the hot springs a well that passed through the Chugwater Formation yeilds 208 gallons per minute of water at 34°C. This well and the hot springs appear to define the northern boundary of the hydrothermal system.

A series of travertine and sulfur deposits crop out along the eastern flank of the Rattlesnake anticline. The deposits are near the contact of the Chugwater Formation and the underlying rock units. The travertine deposits extend approximately two miles south of the DeMaris Hot Springs. In this area the Rattlesnake anticline merges into a smaller structure known as the Horse Center anticline.

The thermal data for the Horse Center anticline suggest that the regional hydrothermal system extends as much as seven miles south of Cody. The most

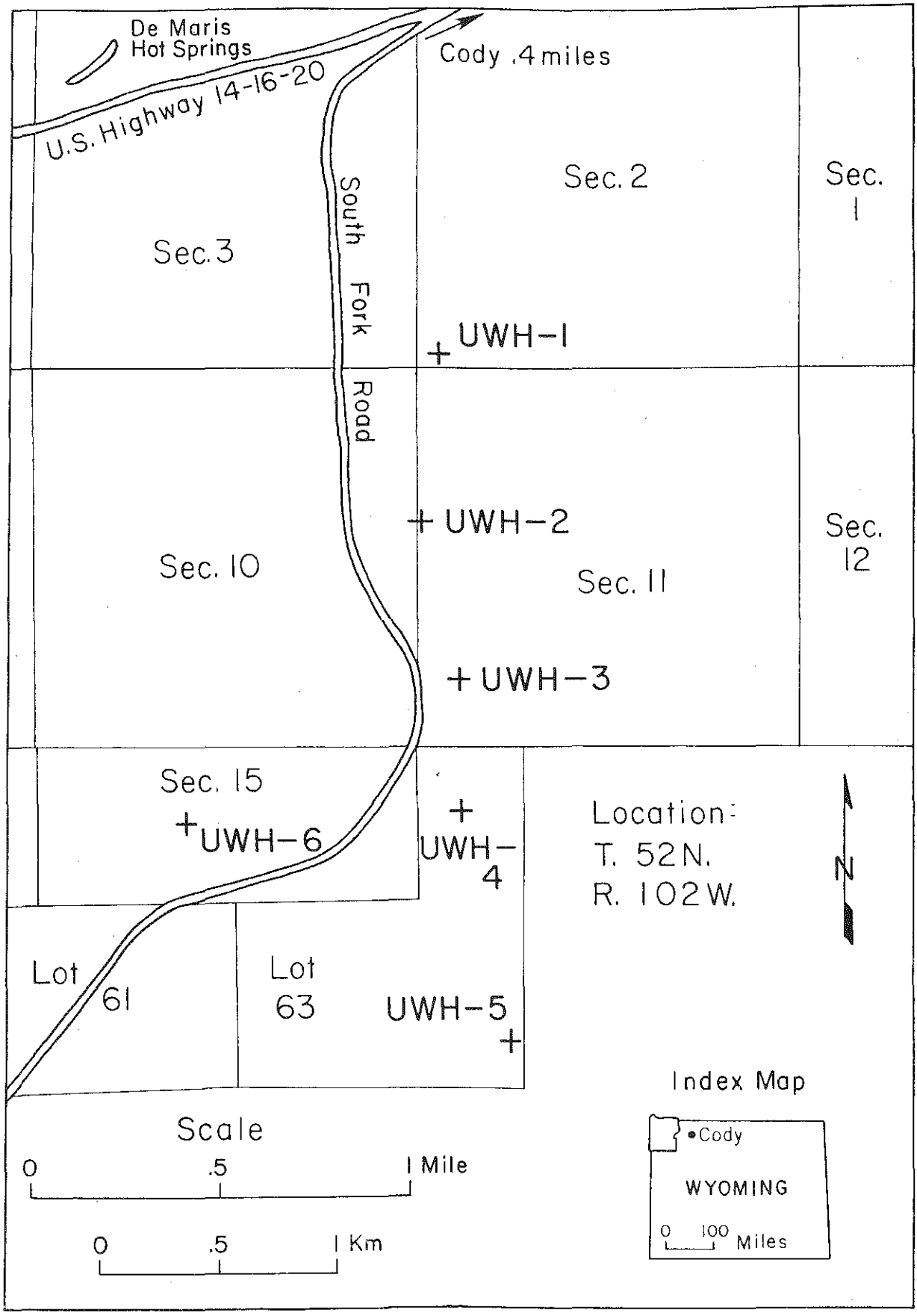

Figure 1. Locations of drill holes (UWH-1 through UWH-6).

convincing data are the thermal gradients of 49 to 205 °C/km in the anticline, based on bottom hole temperatures in eleven oil wells. (Twenty-three "dry" oil wells have been drilled in the structure. Of these, eleven wells yield gradients of 49 to 205 °C/km, five wells yield normal to slightly high gradients of 24 to 37 °C/km, while seven wells had no reported bottom hole temperature).

Our agreement with the U.S. Department of Energy has made it possible for us to log temperatures in three of the five unplugged wells in the Horse Center anticline. The resulting temperature-depth profiles for the wells are plotted in Figure 2. Figure 3 shows the locations of the holes in the area.

Well Letha C-4 may be on the southern edge of the thermal high because the bottom hole temperature of 38.4 °C at 320 meters yields the lowest gradient of 96 °C/km (see Fig. 2). A maximum temperature of 47.5 °C was measured at 500 meters in hole Rose Government 1 (Fig. 2). In contrast, the bottom hole temperature is 45.1 °C at 185 meters in Gains Government C-2 (Fig. 2) and the calculated gradient is 190 °C/km.

Referring to drill hole geology, the three remeasured wells were collared in the Chugwater Formation. Two of the holes ended in the Tensleep Sandstone, with the depth to the Tensleep ranging from 138 to 290 meters.

GEOLOGIC AND DRILLING STRATEGY

The Horse Center - Rattlesnake anticlines geothermal system may be explained by the combined effects of local geology, local hydrology and the regional geothermal gradients. Briefly, we believe that waters in deep porous units are warmed by the thermal gradients outside the middle portions of the anticlines. These waters then quickly gain access to shallower depths by moving upward along the steep limbs of the anticlines. The Chugwater Formation

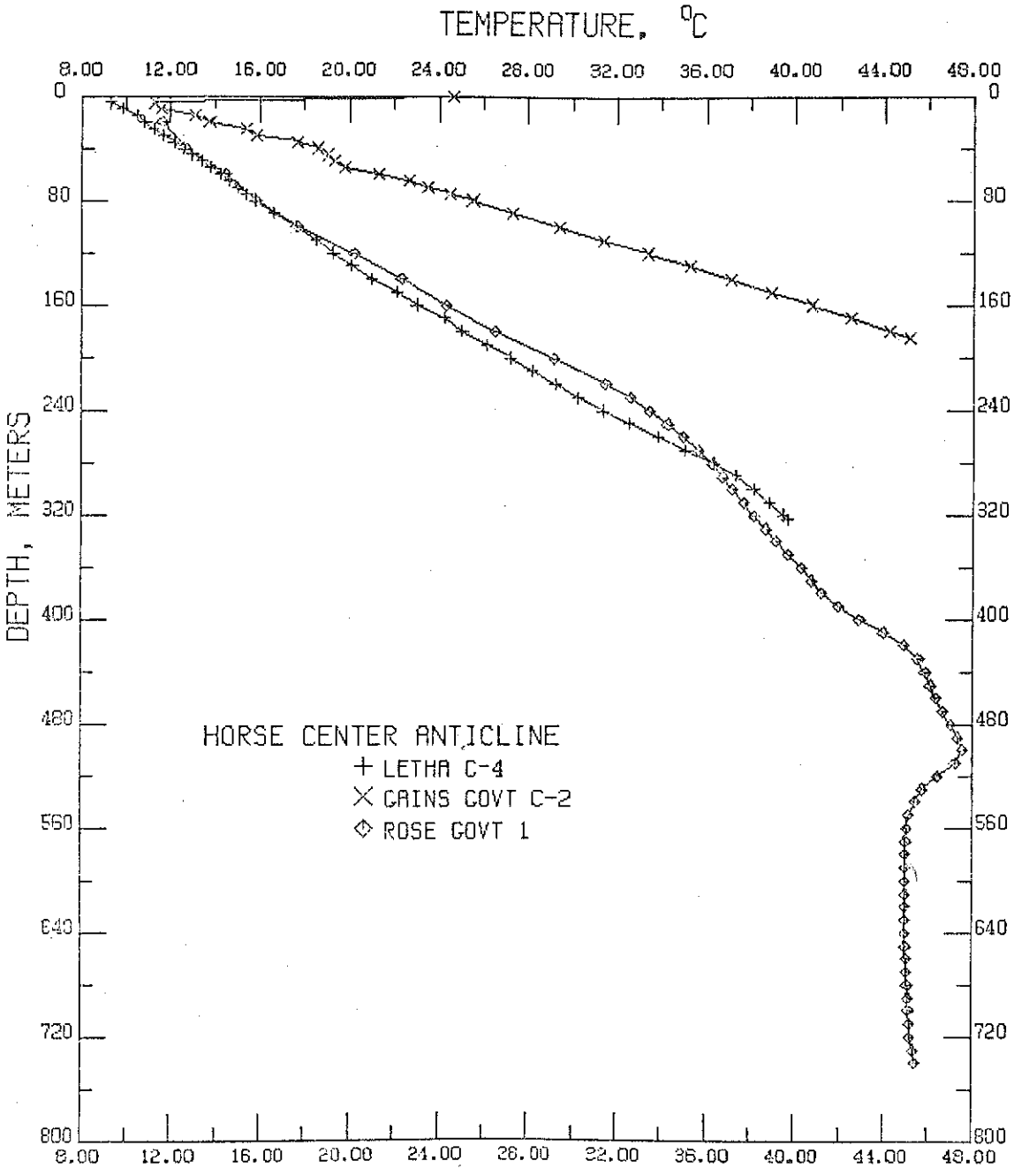

Figure 2. Temperature plots for three oil wells on the Horse Center anticline.

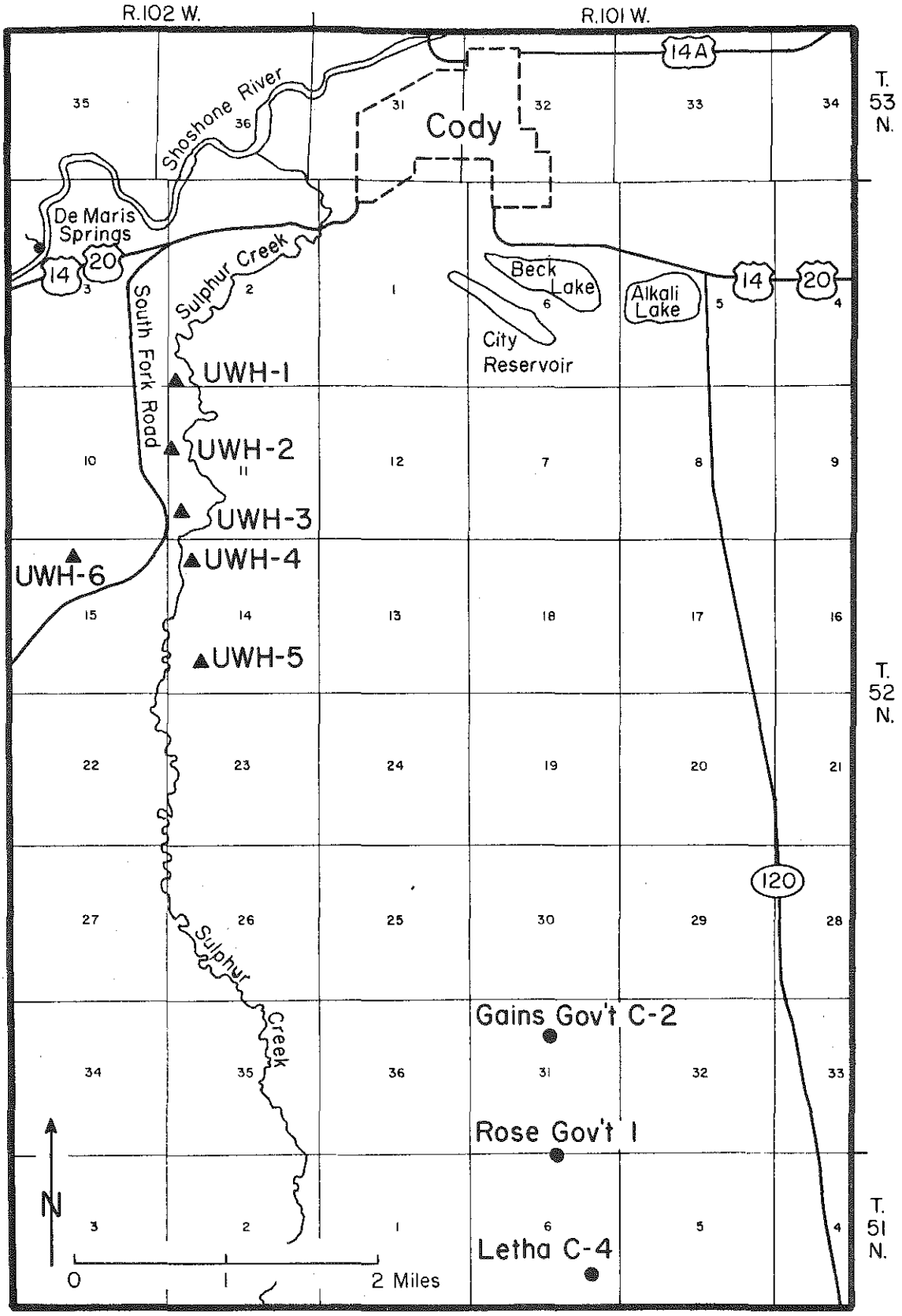

Figure 3. Map showing locations of drilled holes (triangles) and the three thermally logged oil wells (circles).

appears to be an impermeable cap rock above the water bearing units in the central parts of both structures.

The above described model is shown in a general way in Figure 4. The six holes in the Cody-Horse Center region were drilled in the vicinity of a "potential site area" on the southeastern flank of the Rattlesnake anticline.

DRILLING METHODS

The holes were drilled with air or foam using a Frank's Model FJ4HP truck mounted drill rig. The rig was capable of drilling to a depth of 610 meters (2,000 feet). A 5 1/8" tri-cone rotary bit was used to drill the softer units. This bit could not be used for all of holes UWH-3, UWH-4, and UWH-6 because extremely hard units were encountered; therefore a 5 1/8" down hole hammer was used to drill portions of these holes.

The air and foam drilling mediums worked successfully when "dry" fractures etc., were encountered. At some sites, however, water flows or aquifers were encountered and fine sand flowed into the holes as rapidly as drilling proceeded. These "running" sands greatly impeded or prevented further drilling and so cementing was tried to hold the walls of the holes or "stabilize" the sands. The Dowell Company was employed for this grouting, and a special cement was used because the warm subsurface waters had high sulphate contents. This cement gelled in as little as three minutes, and interested readers are referred to the Dowell Company for details on components of the mixture.

The Dowell company was able to cement zones in the upper part of hole UWH-2. When drilling continued downward in this hole, however, other zones of "bad" ground were encountered. These deeper zones could not be cemented because they were either in large caverns or in aquifers with very large volumes of water or high flow rate. A similar problem was encountered at the bottom

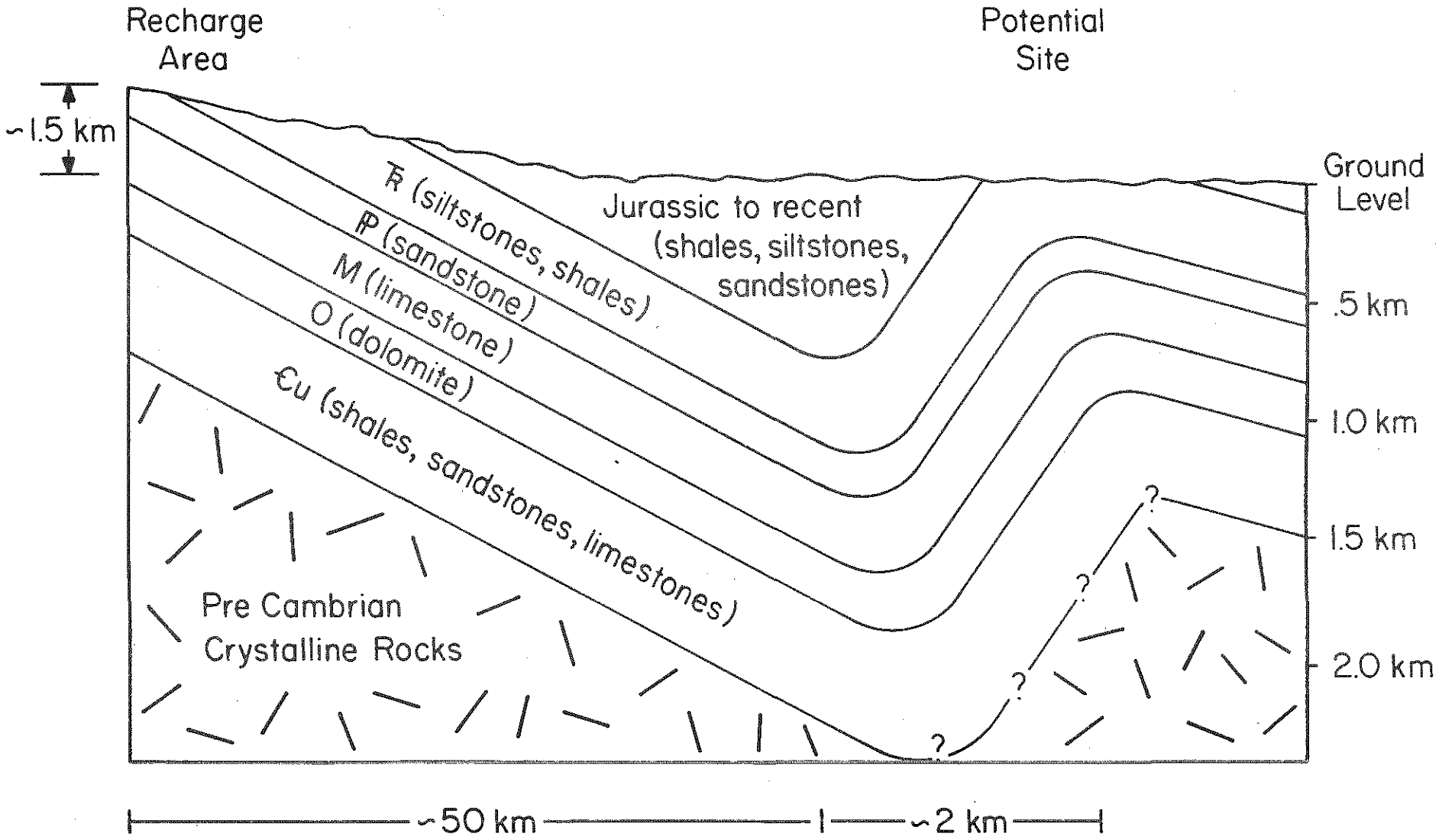

Figure 4. Generalized model of reservoir source and recharge area.

of hole UWH-4. For example only 1.7 meters (5 feet) of "fill up" occurred in UWH-2 when 2.3 meters^3 (80 ft^3) were pumped into the bottom of the hole. Consequently, drilling of UWH-2 and UWH-4 was terminated at 123 and 101 meters, respectively, because further drilling was not possible without very costly casing of the troublesome zones.

COMPLETION METHODS

Each well was completed so that temperature gradients could be monitored for an indefinite period of time. This was accomplished by setting an access pipe as deep as possible in each hole. The access pipe is $1\frac{1}{4}$ inch inside diameter schedule 40 black iron pipe.

The pipe in holes UWH-1, UWH-3, UWH-5 and UWH-6 is grouted with neat cement. The grouting procedure directly followed the methods outlined in Moses and Sass (1979). Grouting was done in an effort to stop vertical flows of water in the annuli between the pipe and the walls of the boreholes. This technique was not used at sites UWH-2 and UWH-2 because both holes bottomed in large cavities and/or very bad ground; therefore, cement would have flowed laterally rather than vertically up around the pipe. Another reason for not cementing pipe in UWH-2 is that it is desirable to deepen this hole in the future, if funding can be obtained.

A latching plug was "chased" to the bottom of the $1\frac{1}{4}$" pipe in all of the holes. The plug cleaned the pipe and created a tight seal at the end of each string of casing. Each string of pipe was then filled with water, the collars were capped, and each drill site was restored according to the requirements of the State of Wyoming and our agreement with the Department of Energy.

PRELIMINARY RESULTS

Figures 5-10 are plots of the preliminary temperature - depth data for the six holes. A combined plot of these data is in Figure 11. Other measurements in holes UWH-1 - UWH-5 are plotted in Figures 12-17; these measurements were made at times before those shown in Figures 5-9. Tables 1-6 list locations, land owner data, information on drilling, casing and cementing, and generalized lithology for the holes.

Bottom hole temperatures, cased depth, least squares estimates for the gradients in the holes and depth ranges for the gradient calculations are listed below.

Hole	Bottom Hole Temperature	Cased Depth	Gradient	Depth Range
	°C	meters	°C/km	meters
UWH-1	26.6	98.5	156.7	10- 98.5
UWH-2	35.4	116.0	161.4	10- 45
UWH-3	25.3	72.0	181.7	5- 72
UWH-4	13.2	96.7	14.6	5- 96.7
UWH-5	18.3	108.7	78.2	10-108.7
UWH-6	20.4	85.1	108.1	18- 85.1

Rotary chip samples were collected at 3 meter (10 feet) spacings for each hole. The chips were used to determine stratigraphy as drilling progressed. Related geothermal research involves thermal conductivity measurements of the samples. A final report on the resulting heat flow values and regional thermal interpretations for the holes should be fowarded in the next 4-6 months.

PRELIMINARY INTERPRETATION

The Cody-Horse Center hydrothermal system is believed to extend on a line south-southeast from the DeMaris Hot Springs to well Letha C-4 (see Figure 3). The width of this zone varies from one to about two miles.

The area of greatest potential use is in T. 52 N., R 102 W., S½ of section 2, and W½ of section 11 (see Figures 1 and 3). In this area warm waters (34 °C (93 °F)) can be reached at shallow depths (51 to 300 meters (168 to 1,000 feet)). The maximum temperature of this system may approach 55 to 65 °C (131 to 149 °F) at depths of 260 to 500 meters (853 to 1640 feet). Warm waters will be found at the shallower depths in the more western portions of this potential use area.

The main aquifers for the Cody-Horse Center hydrothermal system are the Tensleep Sandstone, Madison Limestone, and Bighorn Dolomite. These formations are reported to have good porositites and permeabilities with flows in the Madison Limestone and the Bighorn Dolomite sometimes exceeding 1,000 gallons per minute (Lowry, 1976). However, the water flow of wells drilled into these aquifers may vary greatly between wells due to secondary fracture permeability, secondary silica cementation of the Tensleep Sandstone, and the cavernous nature of the Madison Limestone and Bighorn Dolomite.

TABLE 1. Drilling and other data for the hole UWH-1

Well Name:	UWH-1
Area:	Cody, Wyoming
Location:	SW¼ SW¼ Sec. 2, T. 52 N., R. 102 W.
Elevation:	5120 ft.
Landowner:	Coy Gail; Cody, Wyoming
Commenced Drilling:	January 2, 1980
Completed Drilling:	January 3, 1980
Total Drilling Depth:	327 ft.
Casing Set:	January 4, 1980
Depth of Casing:	321 ft.
Casing Cemented:	January 4, 1980
Sacks of Cement Used:	60 sacks neat cement with 6 gallons water per sack used to cement casing
Lithology:	0 to 2 feet; surface gravels 2 to 327 feet: Triassic Chugwater Formation; red siltstones, red shales, and fine red sandstone
Notes:	Drilling on this hole progressed smoothly. The formation became moist at 40 feet but never flowed any quantity of water into the drill hole.

TABLE 2. Drilling and other data for hole UWH-2

Well Name:	UWH-2
Area:	Cody, Wyoming
Location:	SW¼, NW¼, Sec. 11, T. 52 N., R. 102 W.
Elevation:	5160 feet
Landowner:	Coy Gail
Commenced Drilling:	January 11, 1980
Completed Drilling:	March 19, 1980
Total Drilled Depth:	403 feet
Casing Set:	18 joints (378 ft.)
Depth of Casing:	378 feet
Casing Cemented:	No. (see notes)
Sacks of Cement Used:	45 sacks neat cement, 80 sacks Dowell 12-3 R.F.C. cement (see notes).
Lithology:	0 to 20 feet: Travertine; white, powdery 20 to 130 feet: Triassic Chugwater Formation; red siltstones, red shales and fine red sandstone. 140 to 180 feet: Triassic Dinwoody Formation; tan and gray siltstone and dolomite. Started making over 5 gallons per minute water at 140 feet. 180 to 200 feet: No sample return. 200 to 403 feet: Pennsylvannian Tensleep Sandstone; light gray to tan, sometimes siliceous sandstone. At 220 feet small cubes (1/16 inch) of pyrite were present.
Notes:	The hole was making up to 200 gallons per minute of H_2S smelling water starting at 280 feet. The temperature of the water measured at the surface was 18° C. Starting at this depth of high water flow, zones of loose, well washed sand were encountered. The hole

Table 2 continued

Notes continued:

would not stay open through these zones. Consequently various cement jobs (a total of 4) were tried. These were successful to a depth of 403 feet where it was decided that further cementing would be too costly.

The $1\frac{1}{4}$ inch casing was put in the hole but not grouted in place. It was felt that due to the large, warm water flows in the bottom of the hole the grout would have been washed away.

TABLE 3. Drilling and other data for hole UWH-3

Well Name:	UWH-3
Area:	Cody, Wyoming
Location:	SW¼ SW¼ Sec. 11, T. 52 N., R. 102 W.
Elevation:	5180 ft.
Landowner:	Jerry and John Housel
Commenced Drilling:	January 3, 1980
Completed Drilling:	February 5, 1980
Total Drilled Depth:	333 ft.
Casing Set:	February 5, 1980
Depth of Casing:	13 joints (273 ft.)
Casing Cemented:	February 5, 1980
Sacks of Cement Used:	55 sacks, 6 gals. H_2O/sack
Lithology:	0 to 95 feet: Permian Park City Formation; gray to tan siliceous limestone. At 50 feet there was a strong sulfur odor. 100 to 333 feet: Lost circulation
Notes:	At 180 feet the rock becomes very hard. A hammer is used from this depth on to complete the hole. The 1¼ inch casing was set to 273 feet because of a zone at 275 feet that kept closing off.

TABLE 4. Drilling and other data for hole UWH-4

Well Name:	UWH-4
Area:	Cody, Wyoming
Location:	NW¼, NW¼, Sec. 14, T. 52 N., R. 102 W.
Elevation:	5160 feet
Landowner:	Dale and Roberta Pike
Commenced Drilling:	March 7, 1980
Completed Drilling:	March 18, 1980
Total Drilled Depth:	333 ft.
Casing Set:	March 18, 1980
Depth of Casing:	314 ft.
Casing Cemented:	No. (see notes)
Sacks of Cement Used:	50 sacks Dowell 12-3 RFC cement (see notes)
Lithology:	0 to 90 feet: Permian Park City Formation; grey to tan siliceous limestone. 90 to 106 feet: Poor sample recovery 106 to 218 feet: Pennsylvanian Tensleep Sandstone (?); light gray to tan siliceous sandstone with sometimes as much as 20% white silica chips. Small (1/16 inch) quartz spar present at 126 feet 218 to 333 feet: Lost circulation.
Notes:	At 218 feet a well washed sand was encountered before circulation was lost. A cement job was done by Dowell at 333 feet but was unsuccessful. Consequently, the 1¼ inch casing was not cemented in place due to the large water flow and/or cavern that was present.

TABLE 5. Drilling and other data for hole UWH-5

Well Name:	UWH-5
Area:	Cody, Wyoming
Location:	NW¼, SW¼, Sec. 14, T. 52 N., R. 102 W.
Elevation:	5210 feet
Landowner:	Glenn Nielson
Commenced Drilling:	February 27, 1980
Completed Drilling:	February 28, 1980
Total Drilled Depth:	360 ft.
Casing Set:	(17 joints) 357 ft.
Depth of Casing:	354 ft.
Casing Cemented:	February 28, 1980
Sacks of Cement Used:	35 sacks neat cement, 7 gals. H_2O/sack
Lithology:	0 to 360 feet: Jurassic Sundance Formation; green to gray shale, thin brownish limestone and sandstone layers. From 235 feet to 329 feet a red shaley zone was encountered.
Notes:	Drilling on this hole progressed smoothly. The formation became moist at about 100 feet but never flowed water into the drillhole.

TABLE 6. Drilling and other data for hole UWH-6

Well Name:	UWH-6
Area:	Cody, Wyoming
Location:	NE¼, NW¼, Sec. 15, T. 52 N., R. 102 W.
Elevation:	5280 feet
Landowner:	Carrol Koster
Commenced Drilling:	February 6, 1980
Completed Drilling:	February 26, 1980
Total Drilled Depth:	311 feet
Casing Set:	9 joints (189') (see notes)
Depth of Casing:	185 feet
Casing Cemented:	February 26, 1980
Sacks of Cement Used:	30 sacks neat cement with 6 gallons H_2O/sack
Lithology:	0 to 10 feet: Rounded stream gravel, ½ to 2 inches in diameter. 11 to 19 feet: Light tan mud out of hole. 20 to 269 feet: Pennsylvanian Tensleep Sandstone; hard silicified sandstone chips dark gray to tan colored. Sporadic, small (less tan 1/8 inch) sulfur veinlets in upper 90 feet. 270 to 310 feet: Lost circulation. 311 feet: Became stuck in hole.
Notes:	Stuck in hole from Feb. 7 until Feb. 25. During that time the bit was pulled free from 289 ft. up to 186 ft. by injecting 10 gallons diesel fuel in the compressed air. At 186 ft. the bit became plugged. Five gallons 33% HCl acid was put in the drill pipe. Circulation returned 4 hours later when the drill pipe broke free at the downhole hammer. The last 8 joints (164 feet) of drill pipe to come out of hole were covered with a black tarry substance. The substance was extremely black and had a musky to burnt odor.

Table 6 continued.

Notes continued:

The hammer was stuck in the hole at 186 feet. Consequently the 1¼ black iron pipe was set to that depth and cemented in place with 30 sacks neat cement.

A thermal log of the well was attempted only to find an obstruction in the 1¼ inch casing at a depth of 21 feet. Consequently the only downhole temperature-depth data was that taken during breaks in drilling.

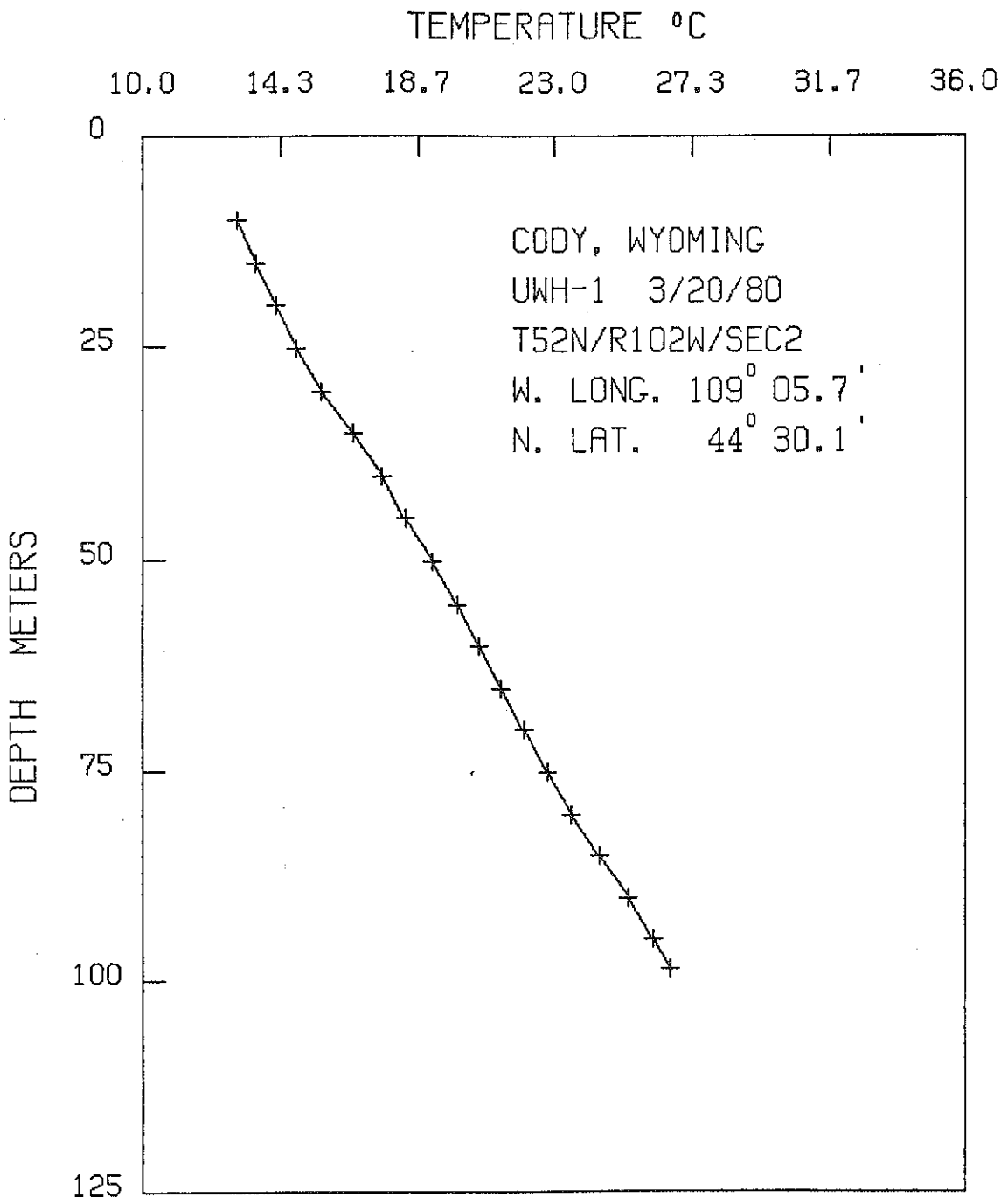

Figure 5. Temperatures as functions of depth in hole UWH-1 (3/20/80).

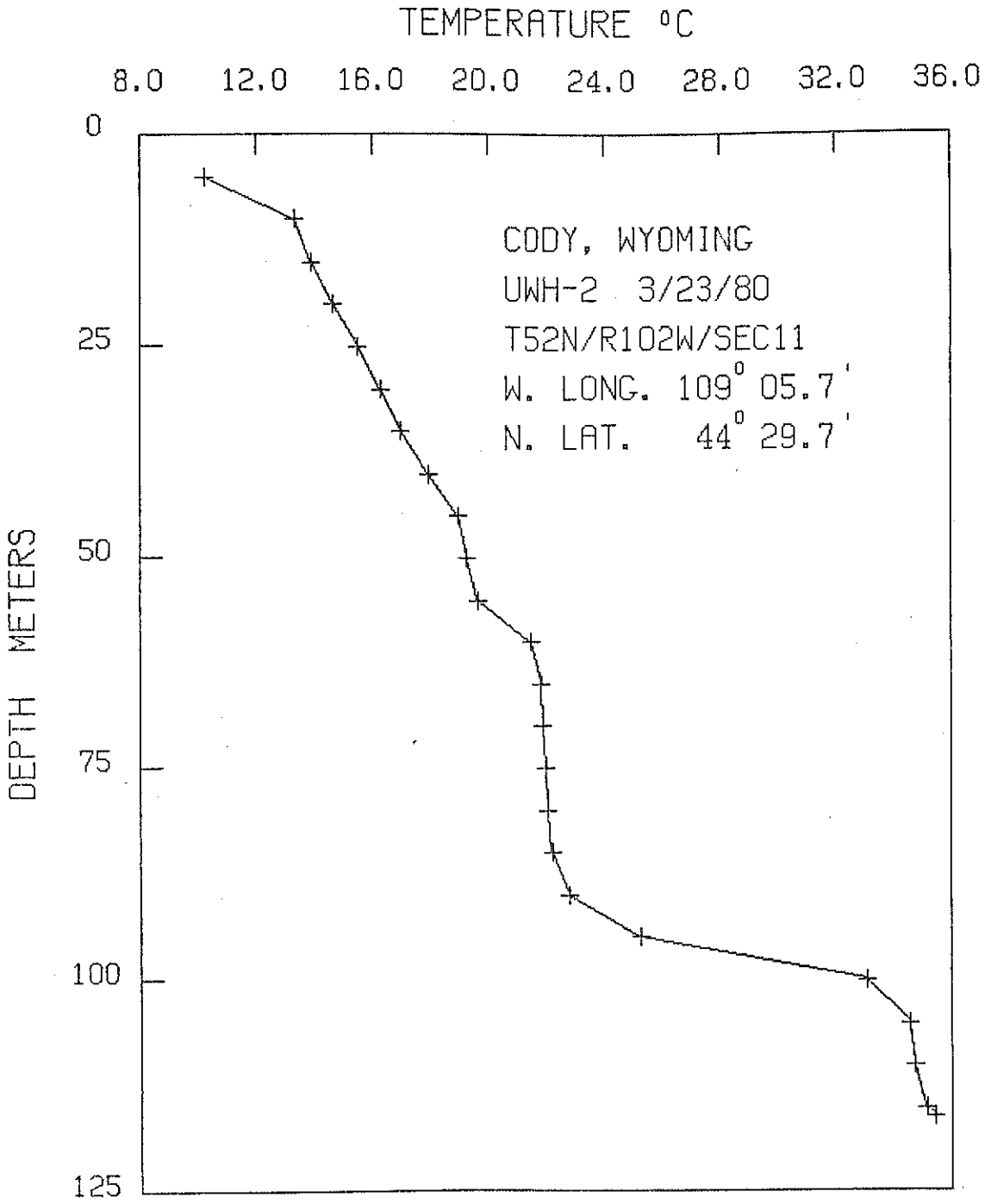

Figure 6. Temperatures as functions of depth in hole UWH-2 (3/23/80).

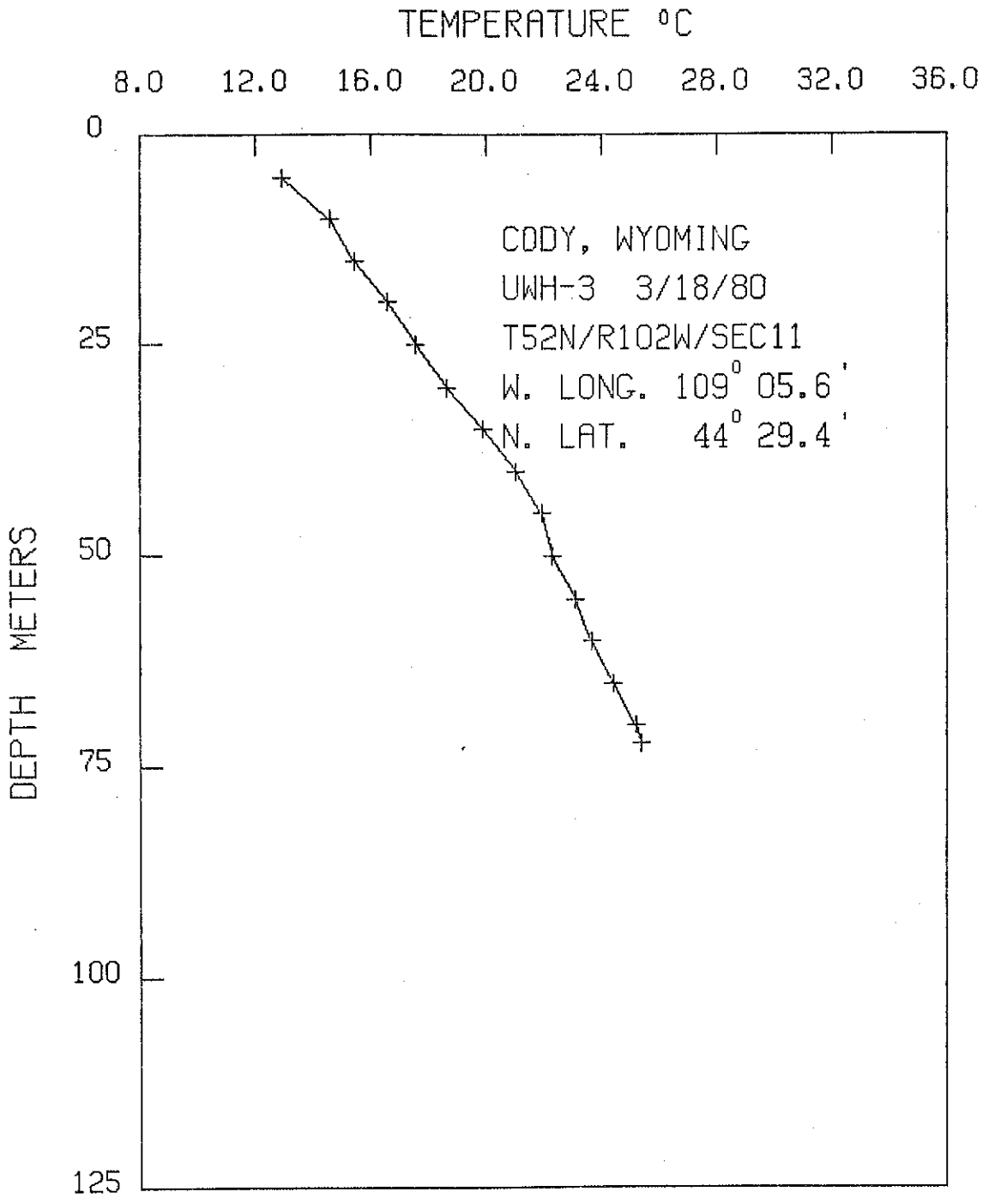

Figure 7. Temperatures as functions of depth in hole UWH-3 (3/18/80).

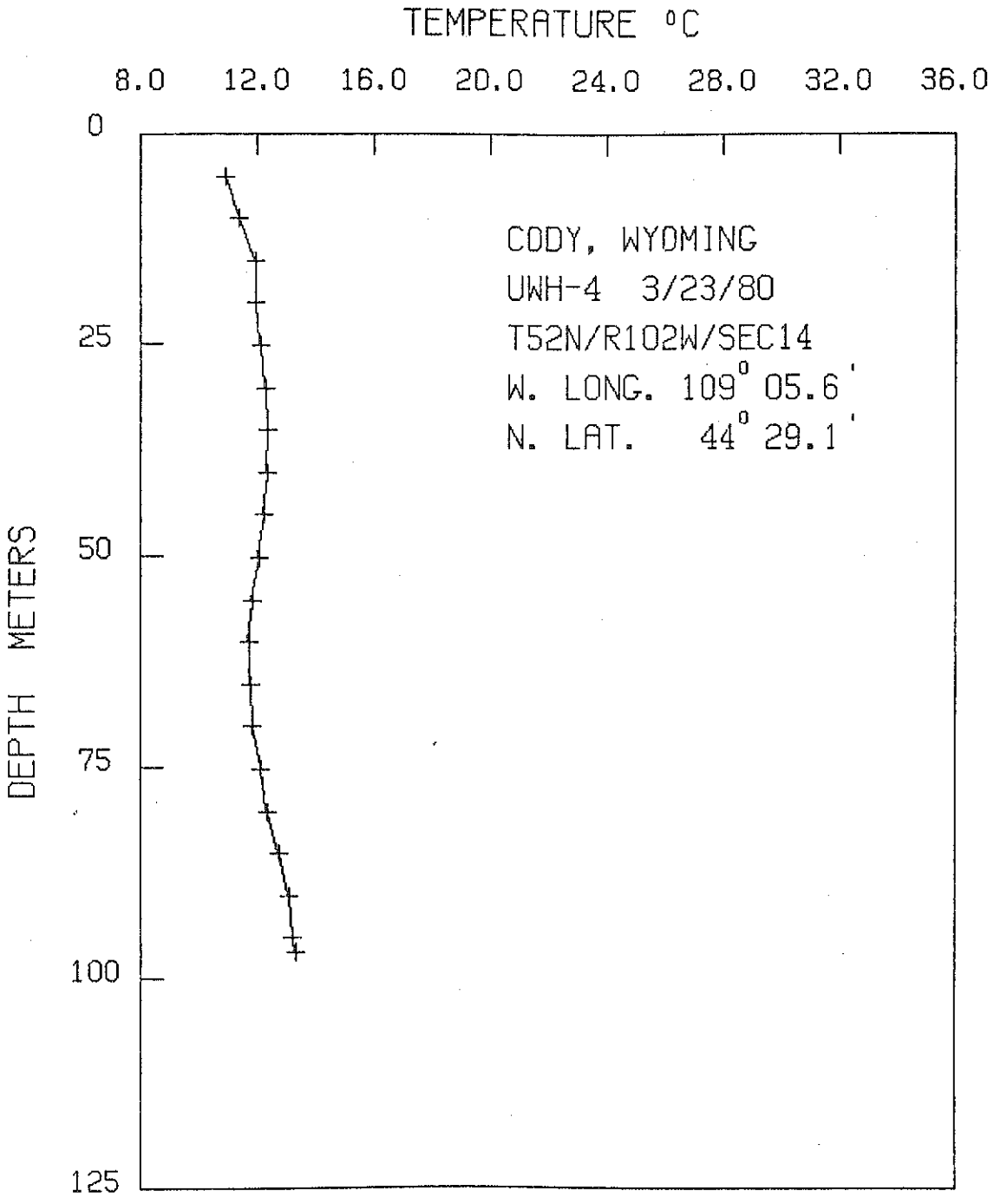

Figure 8. Temperatures as functions of depth in hole UWH-4 (3/23/80).

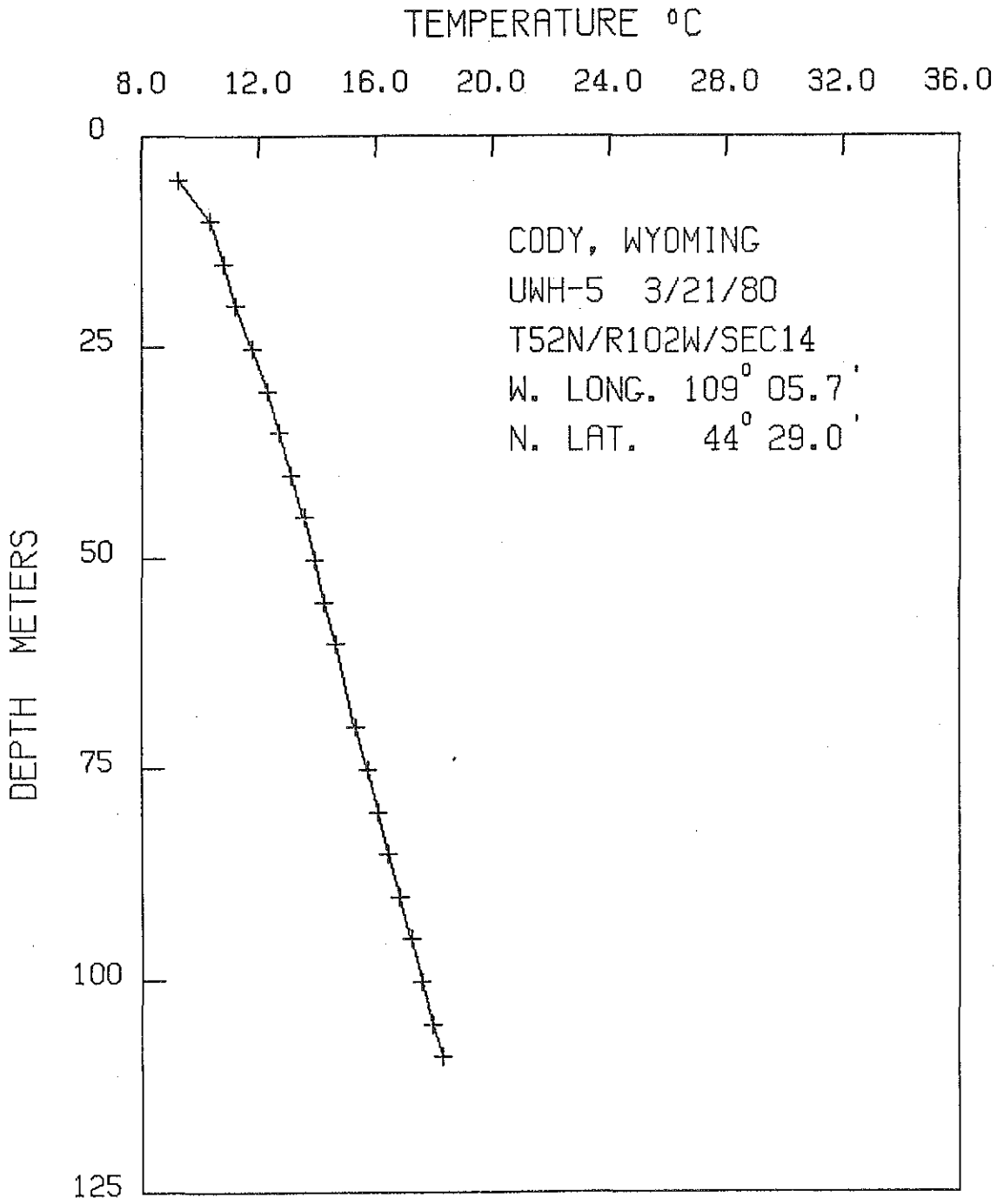

Figure 9. Temperatures as functions of depth in hole UWH-5 (3/21/80).

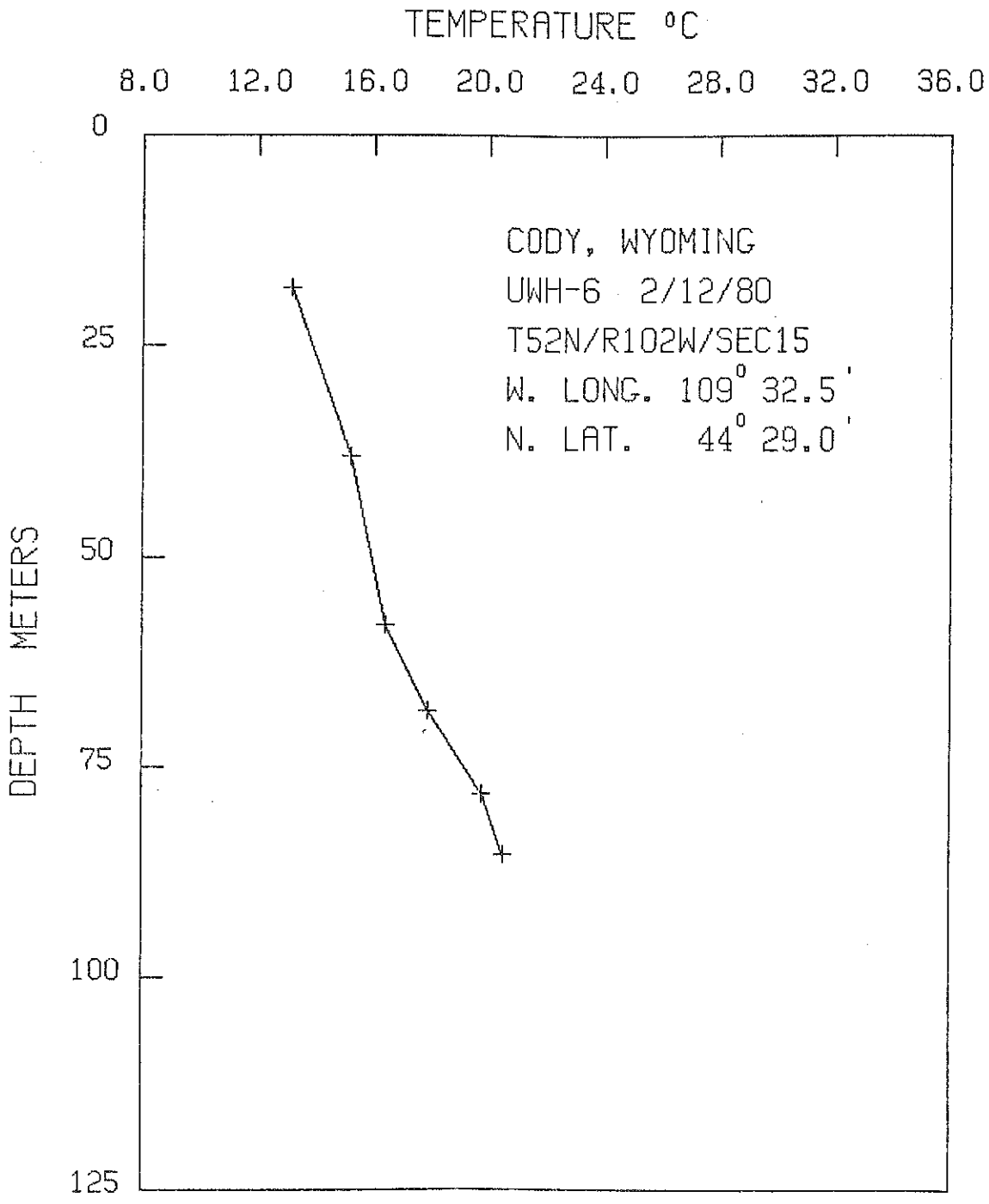

Figure 10. Temperatures as functions of depth in hole UWH-6 (2/12/80).

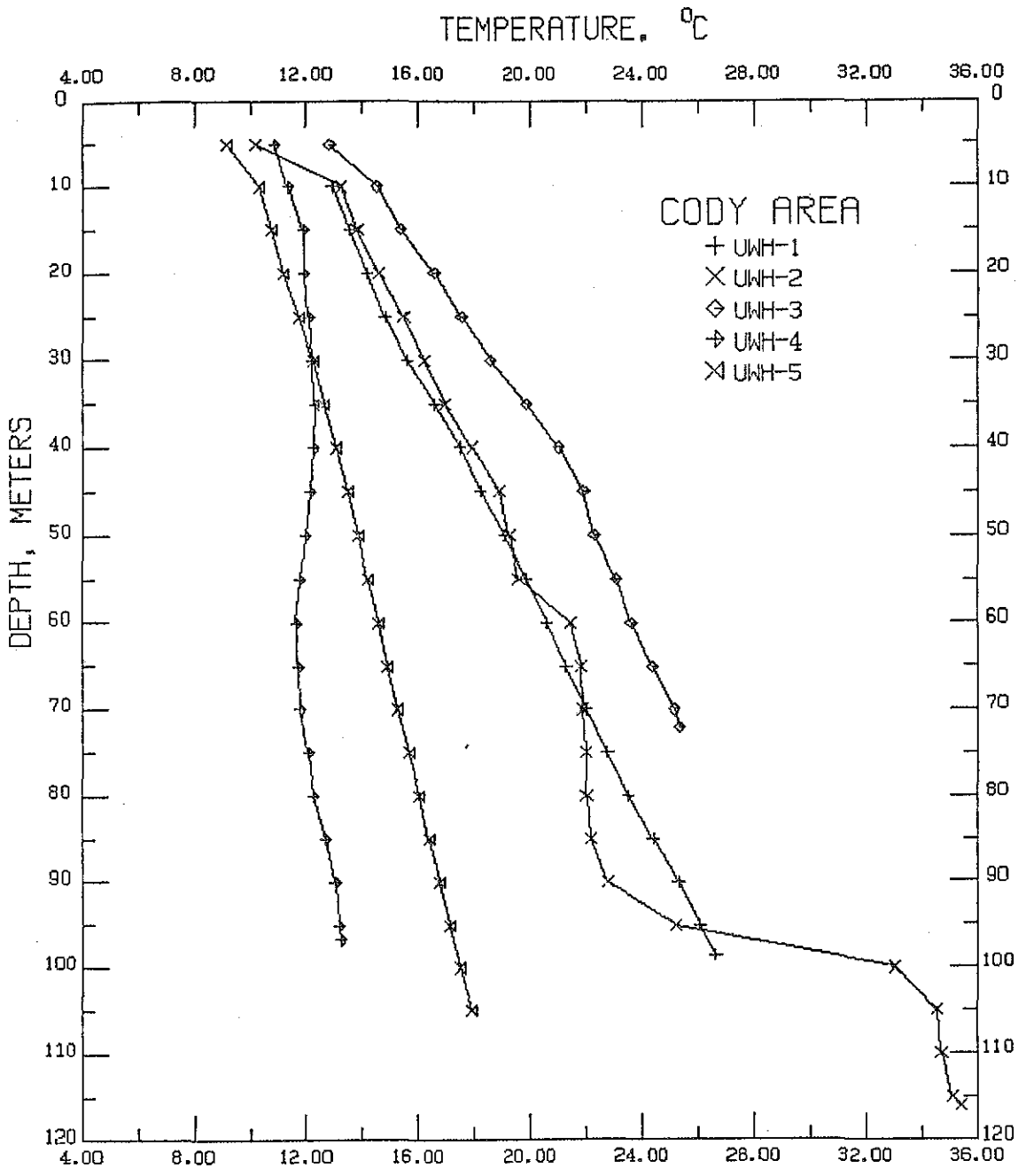

Figure 11. Temperatures as functions of depth in UWH drill holes.

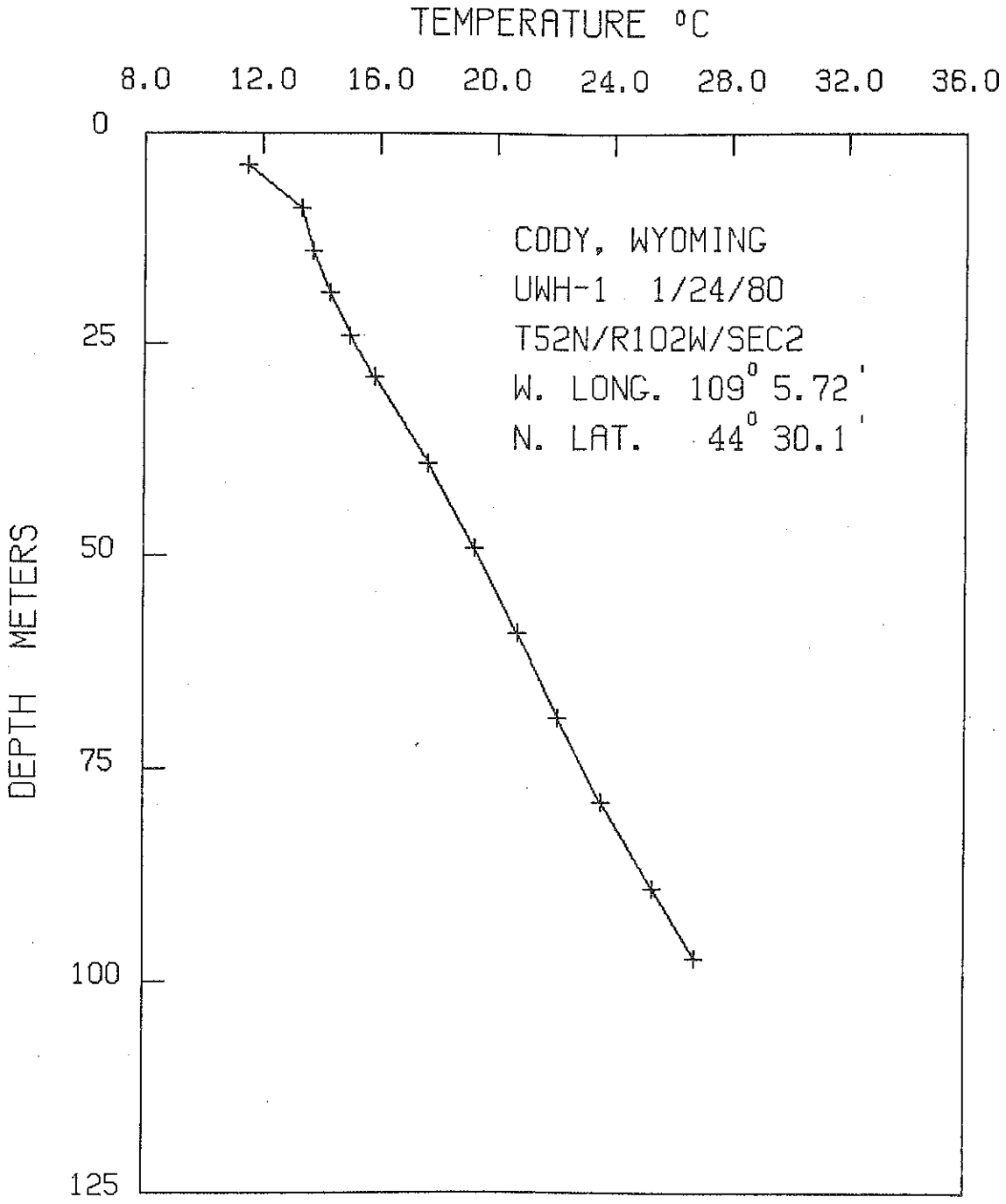

Figure 12. Temperatures as functions of depth in hole UWH-1 (1/24/80).

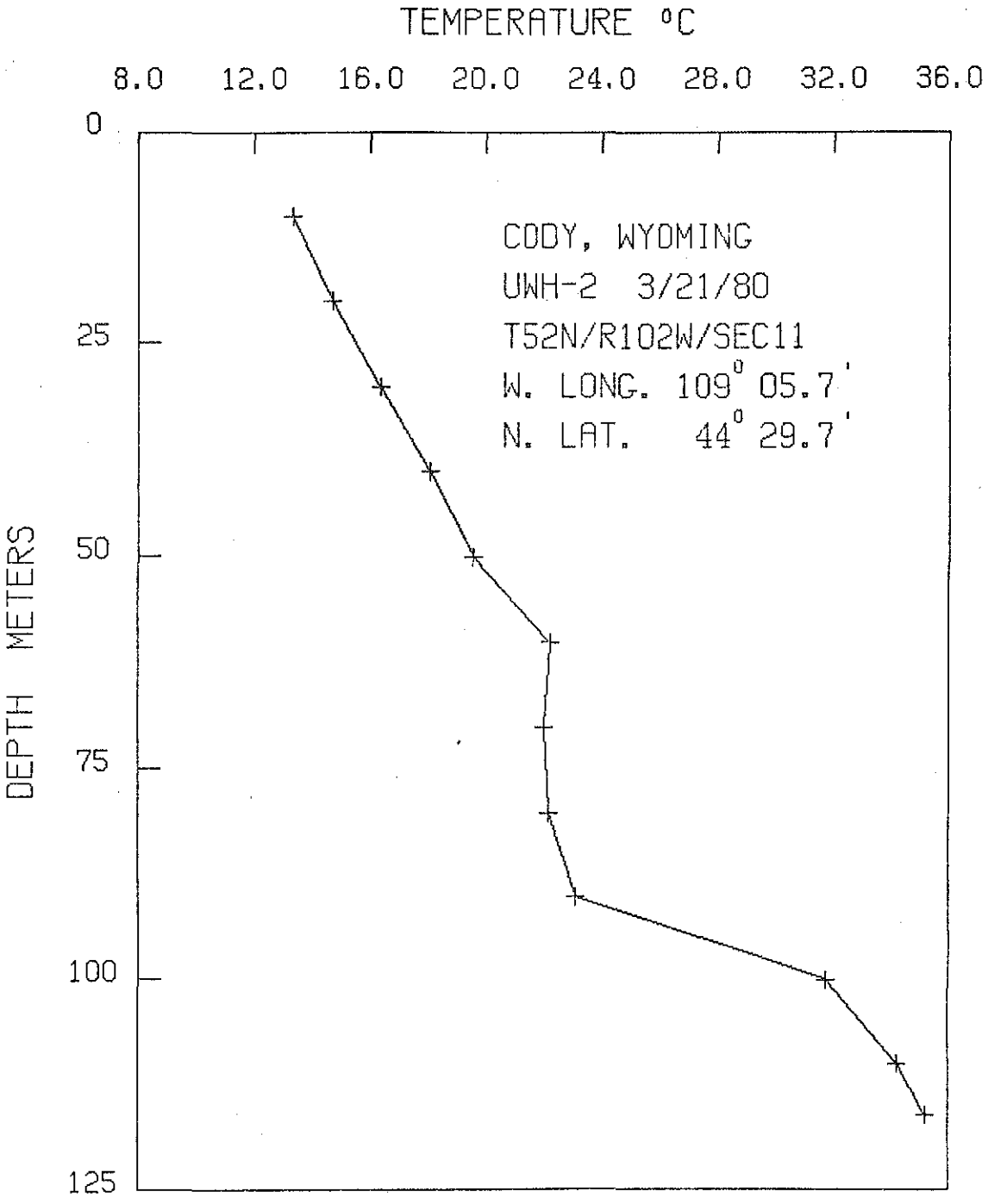

Figure 13. Temperatures as functions of depth in hole UWH-2 (3/21/80).

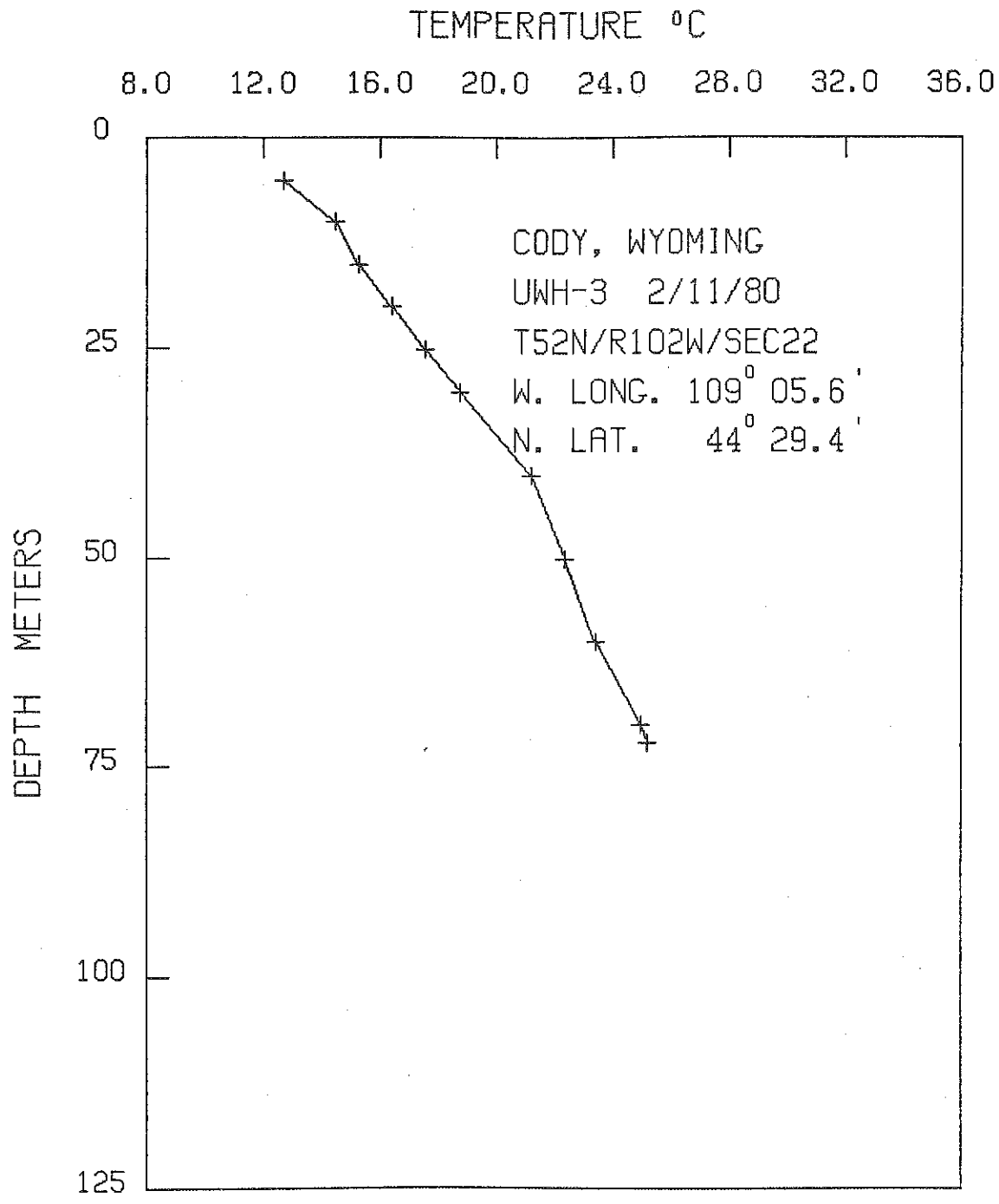

Figure 14. Temperatures as functions of depth in hole UWH-3 (2/11/80).

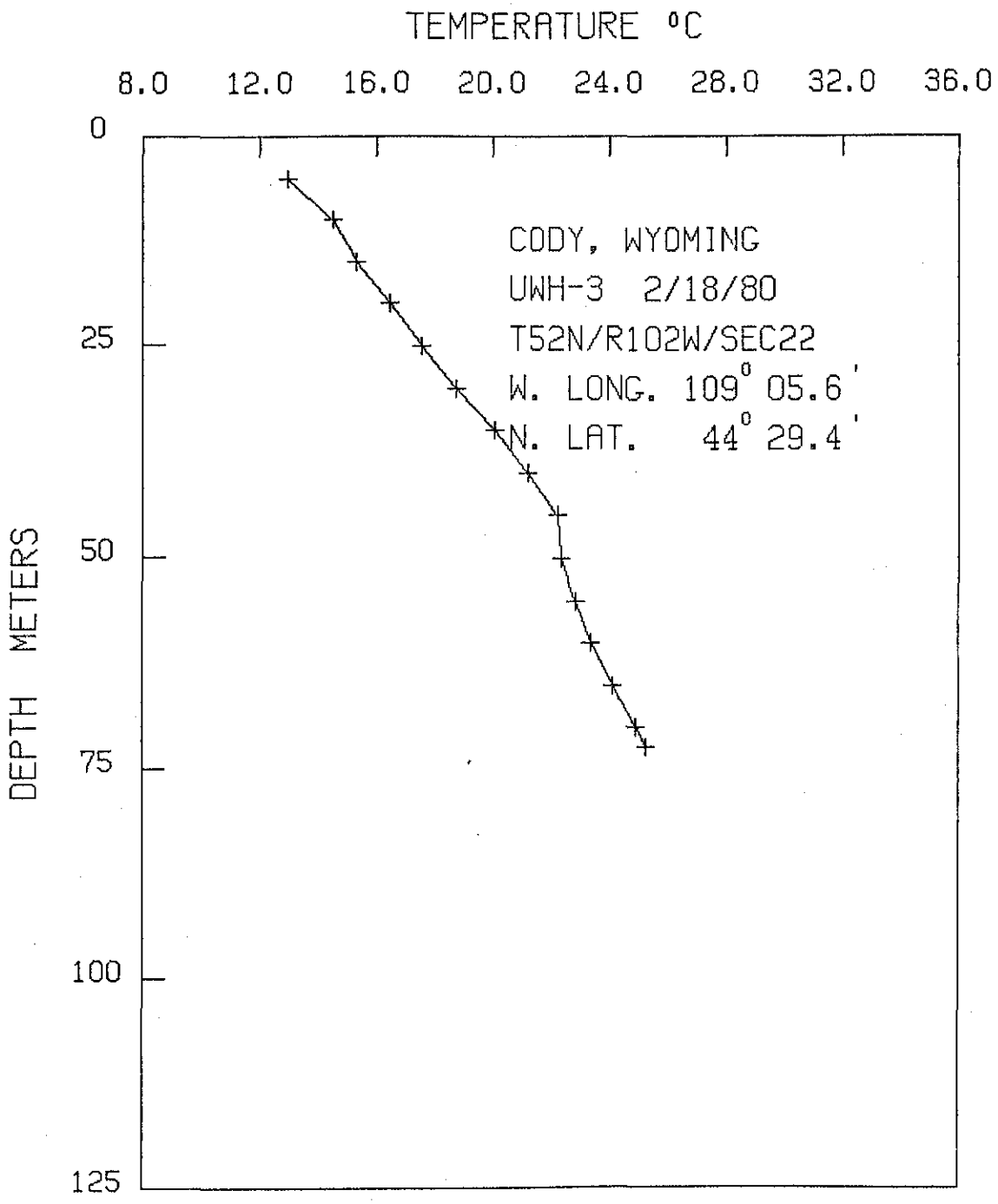

Figure 15. Temperatures as functions of depth in hole UWH-3 (2/18/80).

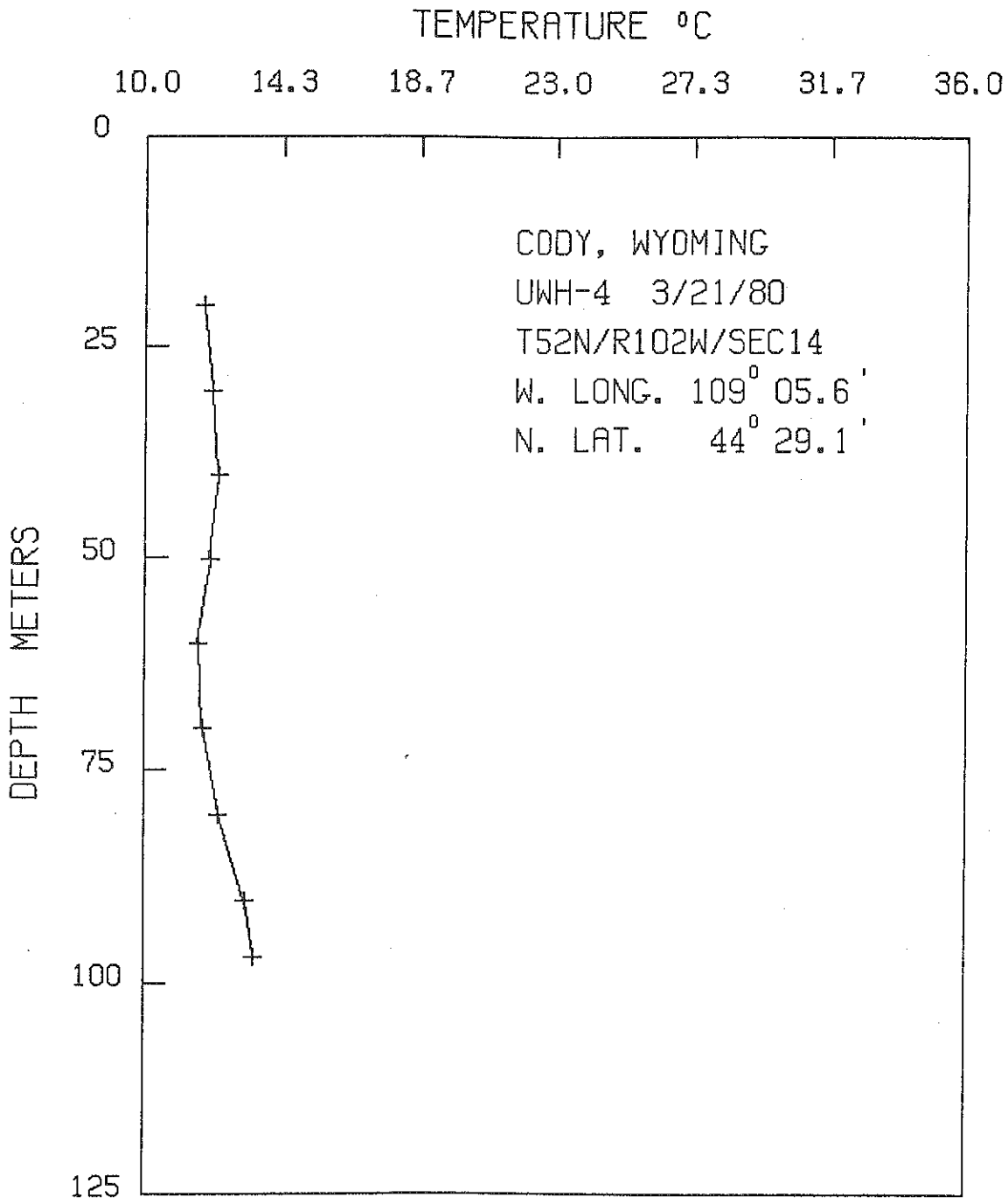

Figure 16. Temperatures as functions of depth in hole UWH-4 (3/21/80).

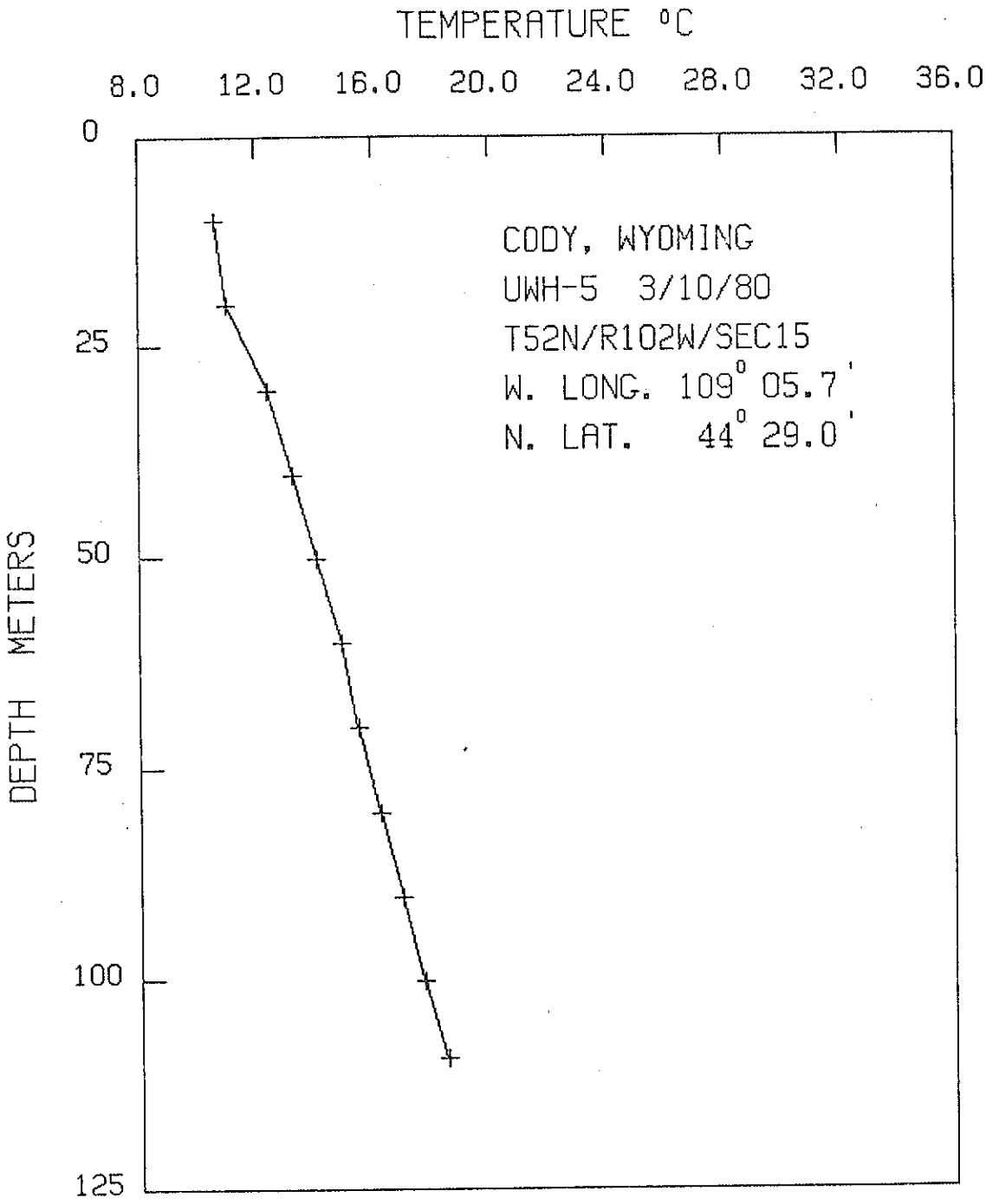

Figure 17. Temperatures as functions of depth in hole UWH-5 (3/10/80).

SELECTED BIBLIOGRAPY

Andrews, D. A., Pierce, W. G., and Eargle, D. H., 1947, Geologic Map of the Big Horn Basin, Wyoming and Montana, Showing Terrace Deposits and Physiographic Features: U.S. Geol. Survey Oil and Gas Investigations Preliminary Map 71.

Breckenridge, R. M., and Hinckley, B. S., 1978, Thermal Springs of Wyoming: Geological Survey of Wyoming Bull. 60, 104 p.

Crawford, J. G., 1940, Oil-field waters of Wyoming and their relation to geologic formations: Amer. Assoc. Petrol. Geol. Bull., v. 24, p. 1214-1329.

Decker, E. R., 1976, Geothermal resources, present and future demand for power and legislation in the State of Wyoming: Wyoming Geological Survey, Public Information Series-1, 21 p.

Eldridge, G. H., 1894, A geological reconnaissance in northwest Wyoming with special reference to its economic resources: U.S. Geol. Survey Bull. 119, 72 p.

Fisher, C. A., 1906, Geology and water resources of the Bighorn Basin, Wyoming: U.S. Geol. Survey Prof. Paper 53, 72 p.

Hague, Arnold, 1904, Atlas to accompany Monography 32 on the geology of Yellowstone National Park: U.S. Geol. Survey, 15 sheets.

_____, 1899, Description of the Absaroka quadrangle (Crandall and Ishawooa quadrangles, Wyoming): U.S. Geol. Survey Geol. Atlas, Folio 52, 6 p.

Hale, B., 1976, Temperature gradients during electrical logging conditions, State of Wyoming: Dept. of Petrol. Engineering, University of Wyoming, 2 maps.

Hayden, F. V., 1883, Twelfth annual report of the United States Geological and Geographical Survey of the Territories; a report of progess of the exploration in Wyoming and Idaho for the year 1878, Part 1: Washington, U.S. Govt. Printing Office, 809 p.

Heasler, H. P., 1978, Heat flow in the Elk Basin Oil Field, northwestern Wyoming, M.S. Thesis, University of Wyoming, 168 p.

Hewett, D. F., 1914, Sulphur deposits in Park County, Wyoming: U.S. Geol. Survey Bull., 540-R, p. 477-480.

_____, 1914, The Shoshone River section: U.S. Geol. Survey Bull. 541-C, p. 43-67.

_____, 1926, Geology and oil and coal resources of the Oregon Basin, Meeteetsee, and Grass Creek Basin Quadrangles Wyoming: U.S. Geol. Survey Prof. Paper 145, 111 p.

Hem, J. D., 1959, Study and interpretation of the Chemical Characteristics of Natural Water: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Hill, C., Southerland, W., and Tierney, L., 1976, Caves of Wyoming: Wyoming Geological Survey Bull. 59, 230 p.

Johnson, J. G., 1934, Geology of the mountain uplift transected by the Shoshone Canyon, Wyoming: Journal of Geology, v. 42, no. 8, p. 809-838.

Jones, W. A., 1874, Report upon the reconnaissance of northwestern Wyoming made in the summer of 1873: House of Representatives, 43rd Congress, 1st Session, Executive Document No. 285, 210 p., 49 plates.

Love, J. D., and Good, J. M., 1970, Hydrocarbons in thermal areas, northwestern Wyoming: U.S. Geol. Survey Prof. Paper 644B, 23 p.

Lowry, M. E., and Lines, G. C., 1972, Chemical analysis of groundwater in the Bighorn Basin: Wyo. Dept. of Economic Planning and Development report, 15 p.

Lowry, M. E., Lowham, H. W., and Lines, G. C., 1976, Water resources of the Bighorn Basin, northwestern Wyoming: U.S. Geol. Survey Hdrologic Atlas 512.

Mackin, J. H., 1937, Erosional history of the Big Horn Basin, Wyoming: Geol. Soc. America Bull., v. 48, p. 812-893.

Mears, B., Jr., 1974, The evolution of the Rocky Mountain glacial model in Coates, D., (ed.), Glacial Geomorphology: Binghamton, N.Y., Publications in Geomorphology, p. 11-40.

Moses, T. H., Jr., and Sass, J. H., 1979, Drilling techniques presently in use by the geothermal studies project, U. S. Geological Survey: U. S. Geol. Survey Open-File Report 79-763, 26 p.

Moss, J. H., 1974, The relation of river terrace formation to glaciation in the Shoshone River Basin, western Wyoming, in Coates, D., (ed.), Glacial Geomorphology: Binghamton, N. Y., Publications in Geomorphology, p. 293-314.

Moss, J. H., and Bonini, W. E., 1961, Seismic evidence supporting a new interpretation of the Cody terrace near Cody, Wyoming: Geol. Soc. America Bull., v. 72, p. 547-555.

Pierce, W. G., 1966, Geologic map of the Cody quadrangle, Park County, Wyoming: U. S. Geol. Survey Geol. Quad Map GQ-542.

_____, 1968, The Carter Mountain landslide area, northwest Wyoming, in Geological Survey Research 1968, Chap. D: U.S. Geol. Survey Prof. Paper 600-D, p. 235-241.

Pierce, W. G., 1970, Geologic map of the Devils Tooth quadrangle, Park County, Wyoming: U.S. Geol. Survey Geol. Quad Map GQ-817.

_____, 1978, Geologic map of the Cody 1^{o} by 2^{o} quadrangle, Wyoming: U. S. Geol. Survey Miscellaneous Field Studies Map MF-963.

Pierce, W. G., and Andrews, D. A., 1941, Geology and oil and coal resources of the region south of Cody, Park County, Wyoming: U. S. Geol. Survey Bull. 921-B, 180 p.

Pierce, W. G., Andrews, D. A., and Keroher, J. K., 1947 Structure Contour Map of the Big Horn Basin, Wyoming and Montana: U. S. Geol. Survey Oil and Gas Inv. Map OM-74.

Pierce, W. G., and Nelson, W. H., 1968, Geologic map of the Pat O'Hara quadrangle, Park County, Wyoming: U. S. Geol. Survey Geol. Quad Map GQ-755.

_____, 1968, Geologic map of the Wapiti quadrangle, Park County, Wyoming: U.S. Geol. Survey Geol. Quad Map GQ-778.

Ritter, D. F., 1975, New information concerning the geomorphic evolution of the Big Horn Basin: Wyoming Geol. Assoc. Guidebook, 27th Annual Field Conference, p. 34-44.

Stearns, D. W., 1975, Laramide basement deformation in the Big Horn Basin, the controlling factor for structures in the layered rocks: Wyo. Geol. Assoc. Guidebook, 27th Ann. Field Conf., p. 149-158.

Stone, D. V., 1967, Theory of Paleozoic oil and gas acculation in Big Horn Basin Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 10, p. 2056-2114.

Swenson, F. A., 1947, Geology and groundwater, Heart Mountain and Chapman Bench Divisions, Shoshone irrigation project, Wyoming: U.S. Geol. Survey Water Supply Paper 1418, 55 p.

Wenger, W. J., and Lanum, W. J., 1954, Characteristics of crude oils from Big Horn Basin fields: Petroleum Engineer, v. 26, no. 2, p. A52-A60.

Wideman, F. L., 1957, A Reconnaissance of Sulphur Resources in Wyoming, Colorado, Utah, New Mexico, and Arizona: U.S. Bureau of Mines Information Circular 7770, 61 p.

Wilson, W. H., 1964, Geologic notes, Greybull-Wood River areas Southern Absaroka Mountains, Wyoming: Guidebook on structures and origin of volcanic rocks Montana, Wyoming, Idaho: A summer conference sponsored by Wayne State University, p. 28-33.

Woodruff, E. G., 1908, Sulphur deposits at Cody, Wyoming: U. S. Geol. Survey Bull. 340-L, p. 451-456.

Zapp, A. D., 1956, Structure contour map of the Tensleep sandstone in the Big Horn Basin, Wyoming and Montana: U. S. Geol. Survey Oil and Gas Inv. Map OM-182.