WELL CONSTRUCTION, LITHOLOGY, AND GEOPHYSICAL LOGS FOR BOREHOLES IN BEAR CREEK VALLEY NEAR OAK RIDGE, TENNESSEE

by Zelda Chapman Bailey and Dorothea Barrows Withington

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(in pocket)

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FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply	by	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
gallon per minute (gal/min)	3.785	liter per minute (L/min)

To convert degree Fahrenheit (°F) to degree Celsius (°C)

$$(0.556)(°F - 32) = °C$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

Twenty-four wells were constructed at nine sites in Bear Creek Valley to provide geologic and hydrologic information. Lithologic samples and suites of geophysical logs were obtained from the deepest boreholes at six of the sites. Two of these boreholes at the base of Chestnut Ridge were completed in the Maynardville Limestone and two were completed in the Nolichucky Shale. Two boreholes along Pine Ridge were completed in the Rome Formation.

Zones of similar lithology within a borehole were delineated from rock cuttings and refined by examination of geophysical logs. The contact between the Maynardville Limestone and Nolichucky Shale was identified in two of the boreholes. Fractures and cavities were readily identifiable on the acoustic-televiewer and caliper logs. Distinct water-bearing intervals were also identified from the temperature, fluid resistance, and resistivity logs. Depths at which the drilling encountered a thrust fault were identifed in two boreholes in the Rome Formation from both rock cuttings and from geophysical logs.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy (DOE), is conducting a hydrogeologic study of Bear Creek Valley in the Oak Ridge Reservation, Tennessee. The purpose of the study is to describe the ground-water flow system and determine the potential extent of contaminant migration. Observation wells were drilled at nine sites (fig. 1) around the perimeter of the valley to provide information on lithology, geologic structure, and hydrologic boundaries of the ground-water flow system. Wells at two of the sites were drilled by contractors to DOE; the remaining wells were drilled by the Geological Survey and the U.S. Army Corps of Engineers, Mobile District. Geophysical logs were obtained in six of the boreholes. Drilling began in October 1985 and drilling and logging were completed in May 1986.

The purpose of this report is to provide information on well locations and construction, and on interpretations made from lithologic samples and geophysical logs.

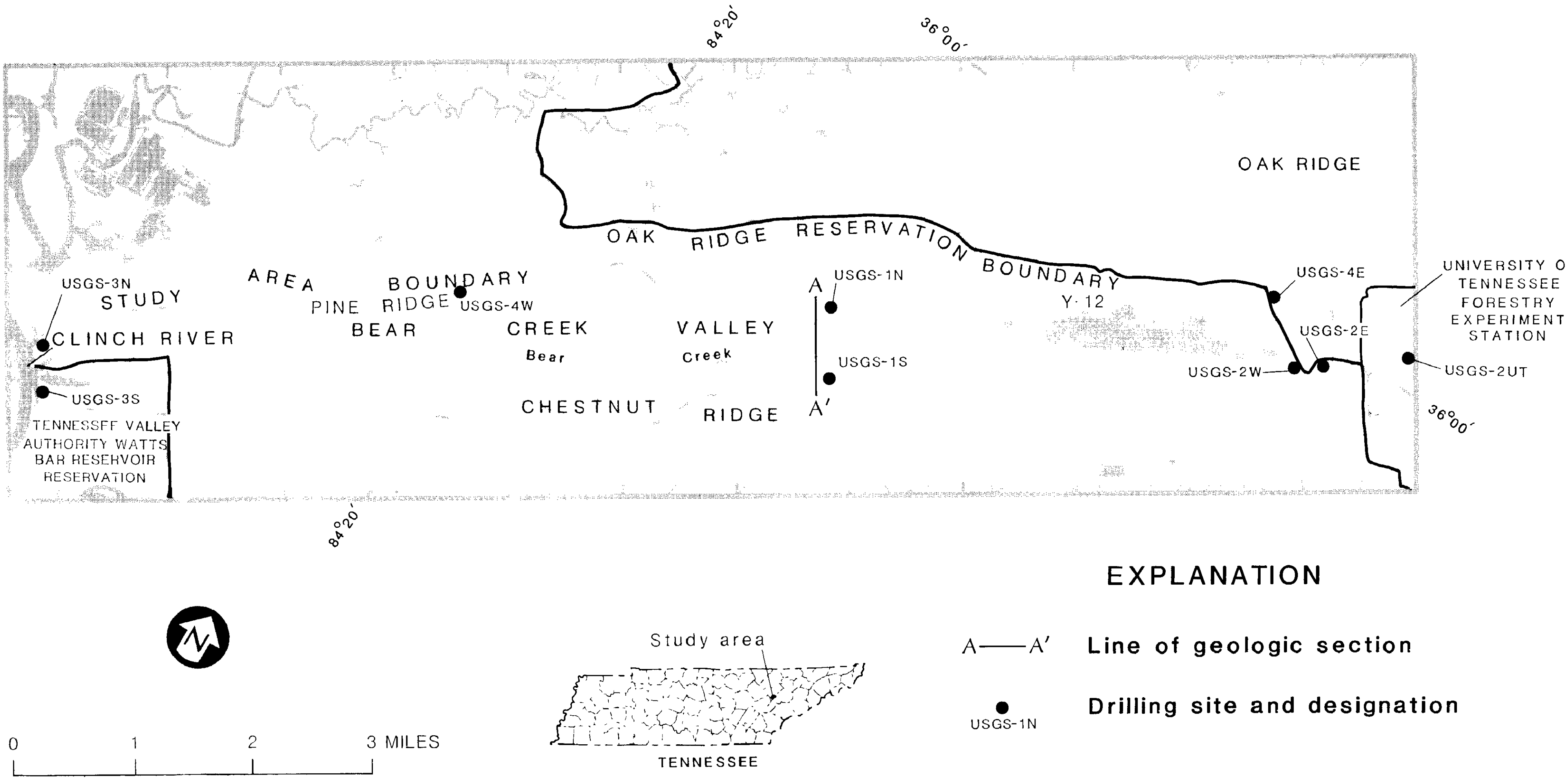


Figure 1.--Study area and drilling-site locations.

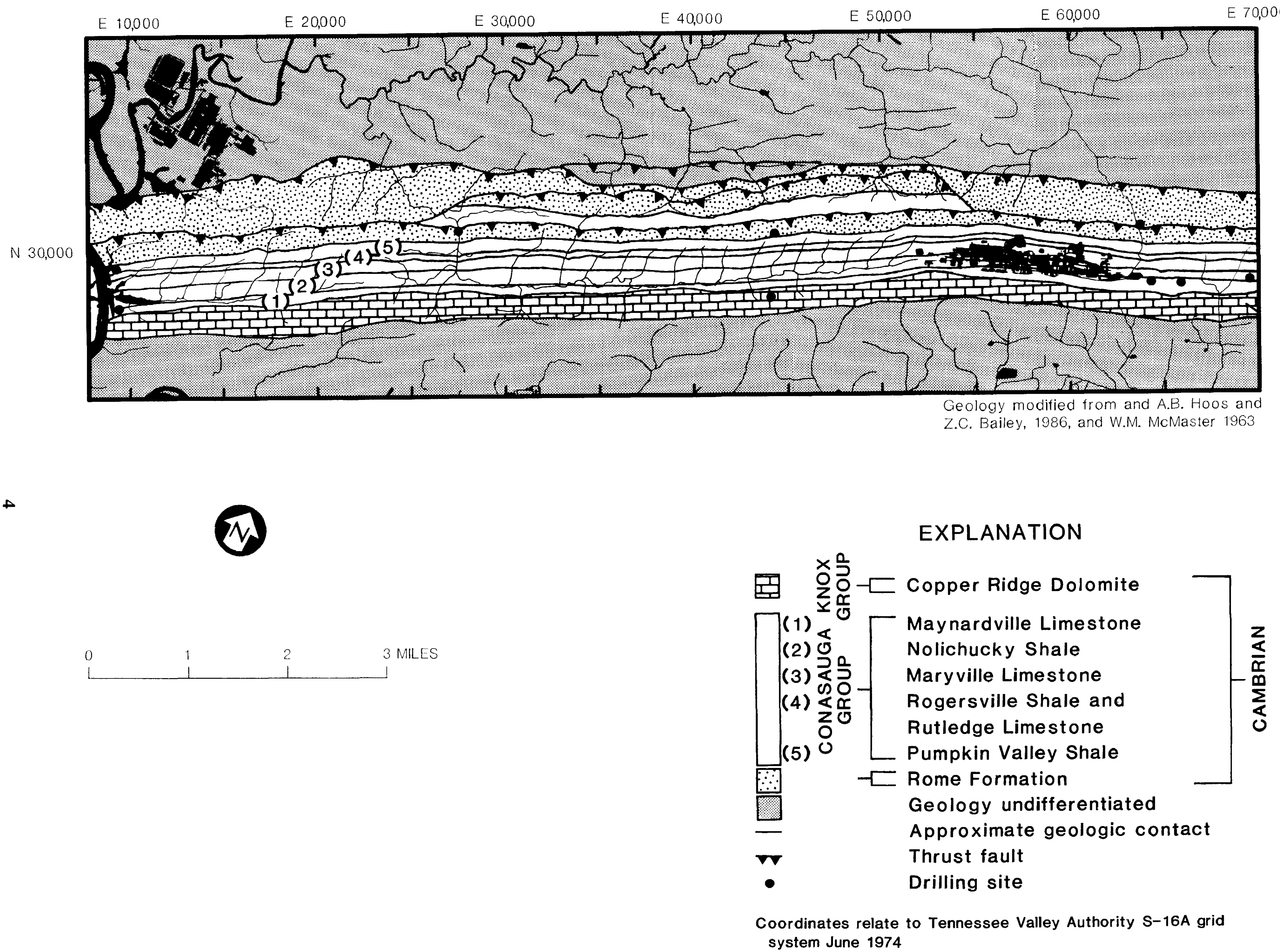


Figure 2.--Bedrock geology of study area.

Geologic Setting

Bear Creek Valley and adjacent ridges are underlain by rocks of Cambrian age (fig. 2) that strike approximately north 55 degrees east. The dip of the rock varies from 30 to 70 degrees to the southeast, but the average dip is about 45 degrees (fig. 3). A series of thrust faults, also dipping southeast, intersect the northwest flank of Pine Ridge. Pine Ridge is underlain by interbedded sandstone, siltstone, and shale of the Rome Formation. Bear Creek Valley is underlain by six formations that compose the Conasauga Group. From oldest to youngest these formations are: Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. The Maynardville Limestone contains solution cavities. Chestnut Ridge is underlain by massive, siliceous dolomite of the Knox Group and contains solution and karst features. The Copper Ridge Dolomite is the oldest formation in the Knox Group and overlies the Maynardville Limestone. Regolith, consisting of soil and weathered rock, overlies the bedrock and ranges from 0 to 80 feet thick.

Acknowledgments

The assistance and contributions of several people were particularly valuable to the project and are greatly appreciated. Dr. C. Stephen Haase and George Gillis, Martin Marietta Energy Systems, Inc. (MMES), provided the drilling for five wells at two of the drilling sites, logistical support during the Geological Survey drilling, and surveying for grid coordinates and elevations of the wells. In addition to drilling on DOE property, permission was granted by Tennessee Valley Authority and University of Tennessee to drill and collect data on their properties. Geophysical logging was conducted by Gerald E. Idler, U.S. Geological Survey, who provides logging services for the Southeastern Region. Assistance during logging and supervision of drilling operations was provided by David A. Webster, and assistance in geophysical log interpretation by Patrick Tucci, both of the U.S. Geological Survey.

WELL CONSTRUCTION

Nine sites (fig. 1) were selected and three wells were to be drilled at each site to provide vertical hydraulic-potential data: one shallow well in the regolith, and two wells in bedrock at about 100 and 400 feet in depth. Problems encountered during drilling resulted in one site having only one well and two sites having boreholes drilled that had to be abandoned. A total of 24 wells were constructed and an additional 3 boreholes were drilled but wells were not installed. Drilling-site names and well names were assigned from a naming system used by MMES staff for wells in Bear Creek Valley. Following are general descriptions of drilling, casing, and grouting procedures. Location coordinates and specific construction information for each well and test hole are summarized in table 1.

Holes for the shallow wells were augered to the top of bedrock. A 2-inch PVC casing with 5 feet of slotted PVC screen at the bottom was installed in each hole. Sand was poured into the annulus around the screen to about 1 foot above the top of the screen, and a 1-foot deep layer of bentonite pellets was poured into the annulus to form a seal. A Portland Type 1 cement slurry was then poured into the annulus around the casing to form a seal from the top of the bentonite to ground surface.

Holes for the deeper wells were first augered to the top of bedrock and 8-inch diameter PVC surface casing was grouted into the holes to seal water and surface material out of the borehole during drilling. The underlying bedrock was then drilled by either air hammer or mud-rotary drilling methods. Casing, generally

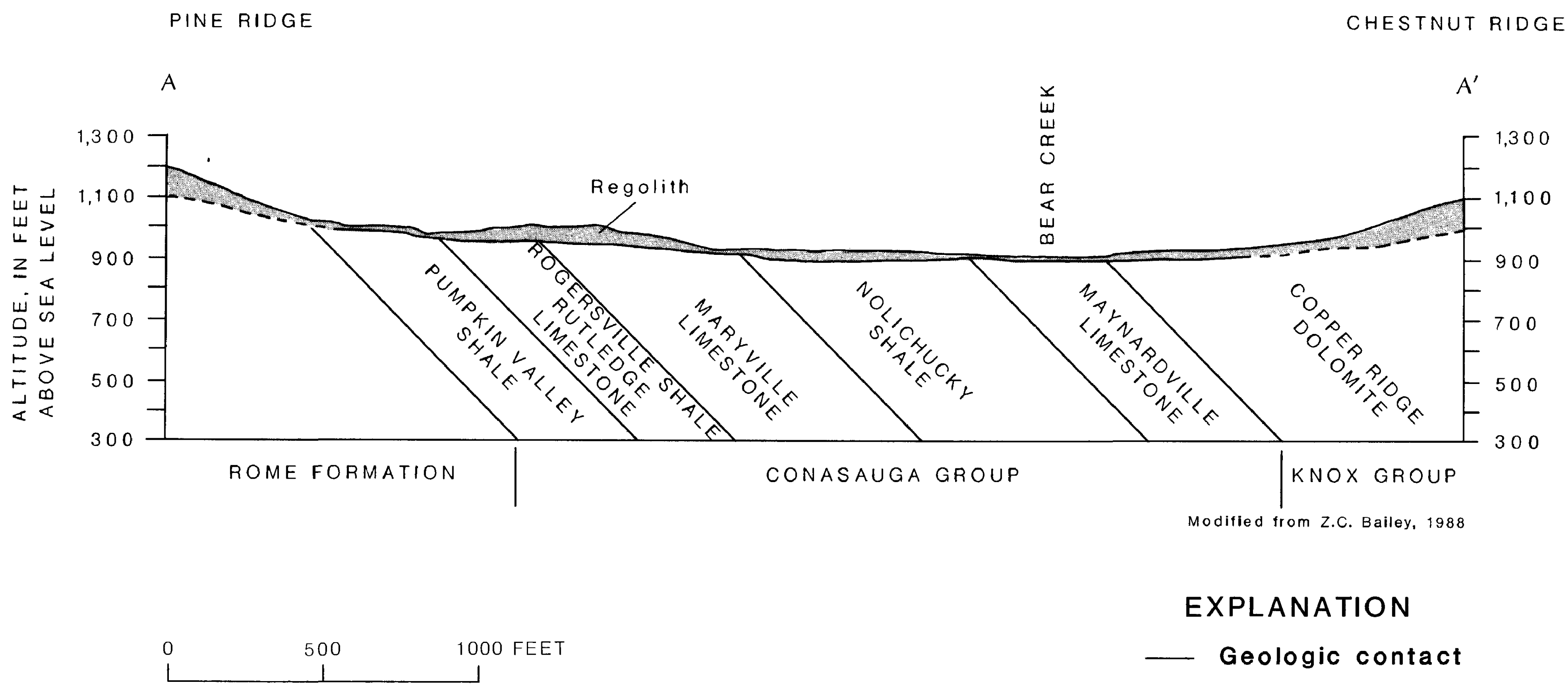


Figure 3.--Generalized geologic section through Bear Creek Valley.

Table 1.--*Construction and locations of wells and test holes*

Site USGS	Well name	Coordinates North (feet)*	Coordinates East (feet)*	Depth (feet)	Ground elevation (feet above sea level)	Measuring point (feet above sea level)	Open interval (feet below land surface)	Screened interval (feet below land surface)	Casing material	Casing diameter (inches)	Drilling method A = auger M = mud rotary H = air hammer
1N	GW-162	31331	44481	125.0	1,036.4	1,037.6	92.0 - 125.0		Steel	6.00	M
	GW-163	31334	44483	225.0	1,037.0	1,039.6	208.0 - 225.0		Steel	6.00	M
	GW-164	31328	44470	405.0	1,036.4	1,038.5	378.0 - 405.0		Steel	6.00	M
1S	GW-165	27807	44547	325.0	1,090.4	1,091.4	276.0 - 325.0		Steel	6.00	M
	GW-166	27835	44531	385.0	1,092.0	1,093.3	380.0 - 385.0		Steel	6.00	M
2W	GW-167	28703	65146	30.1	929.7	931.4	25.0 - 30.1	26.0 - 30.1	PVC	2.00	A
	GW-168	28698	65167	135.5	929.4	930.9	104.0 - 135.4		Steel	4.00	H
	GW-239	28715	65089	433.3	928.8	930.5	404.0 - 433.0		Steel	4.00	H
2E	GW-169	28545	66854	34.8	929.9	931.5[a]	28.7 - 34.8	29.7 - 34.8	PVC	2.00	A
	GW-170	28545	66843	157.0	930.7	932.4	104.0 - 156.9		Steel	4.00	H
	GW-232	28546	66863	411.7	929.5	931.2	401.0 - 411.7		Steel	4.00	H
2UT	GW-171	28403	69654	31.2	918.5	920.1	25.8 - 31.2	26.8 - 31.2	PVC	2.00	A
	GW-172	28359	69579	133.9	923.1	924.8	105.0 - 133.8		Steel	4.00	H
	GW-230	28389	69617	406.4	919.8	920.8	341.0 - 406.4		Steel	4.00	H
	GW-235	28416	69712	68.0	920.0	--	hole abandoned				H
4E	GW-206	31603	64019	16.9	894.6	894.6[b]	10.8 - 16.9	11.8 - 16.9	PVC	2.00	A
	GW-207	31596	64023	109.7	894.7	898.8[c]	100.0 - 109.7		PVC	4.00	M
	GW-208	31612	64007	412.8	894.5	901.3	404.0 - 412.8		Steel	4.00	H
4W	GW-209	31775	27699	48.1	793.0	799.4	42.0 - 48.1	43.0 - 48.1	PVC	2.00	A
	GW-210	31765	27700	124.0	792.9	799.1	104.0 - 124.0		Steel	4.00	H
	GW-211	31799	27698	410.0	793.1	796.3	404.0 - 410.0		Steel	4.00	H
3S	GW-212	27787	9119	13.9	750.9	751.1	8.4 - 13.9	9.4 - 13.9	PVC	2.00	A
	GW-213	27746	9119	128.0	751.0	--	hole abandoned				H
	GW-238	27838	9116	129.0	751.0	752.1	100.0 - 129.0		Steel	4.00	H
	GW-260	27773	9121	134.0	750.9	--	hole abandoned				H
	GW-214	27802	9119	430.0	750.8	753.9	414.6 - 430.0		Steel	4.00	H
3N	GW-215	29468	9204	15.2	754.5	754.8	9.6 - 15.2	10.6 - 15.2	PVC	2.00	A

* Coordinates relate to the S-16A grid system.
[a] Measuring point was 931.9 prior to May 26, 1987.
[b] Measuring point was 895.0 prior to November 2. 1987.
[c] Measuring point was 901.81 prior to October 20, 1986.

steel, was set in the hole and the annulus was pressure grouted with Portland cement to ground surface. The grout used in wells GW-165, GW-166, and GW-230 also contained Haliburton Flo Seal and calcium chloride to prevent the grout from flowing out of the annulus through fractures and solution cavities. After the grout hardened, an open interval was drilled below the cased interval. Cuttings were cleared from the hole by using compressed air.

WELL LOCATIONS AND GENERAL LITHOLOGY

Drilling sites, selected to supplement data from wells already drilled in the valley by other investigators, are primarily located where data were lacking for the hydrologic boundaries at each end of the valley and along the ridges.

Wells at site 1S, on Chestnut Ridge, were drilled in the Copper Ridge Dolomite (fig. 4) by MMES contractors, and the open intervals in each of the two wells intersect cavities or large fractures. The wells at site 1N (fig. 4) on Pine Ridge were also drilled by MMES contractors. The shallow well at site 1N (GW-162) is open to the lower member of the Pumpkin Valley Shale; the two deeper wells (GW-163 and GW-164) are in the Rome Formation (Haase and others, 1986, p. 39). No geophysical logs were obtained from the wells at these sites. Lithologic descriptions of these wells are included in Haase and others, 1987.

All wells at four sites (3S, 2W, 2E, and 2UT) along the base of Chestnut Ridge are completed in the Maynardville Limestone (figs. 5-7) except for the deepest wells at sites 3S (GW-214, fig. 5) and 2W (GW-239, fig. 6), which were completed in the underlying Nolichucky Shale. Three boreholes, one at site 2UT (GW-235, fig. 7) and two at site 3S (GW-213 and GW-260), were abandoned either because of large cavities that could not be sealed off from the well casing or because casing could not be installed through the cavities. Cavities in borehole GW-235, at site 2UT, were encountered between 5 and 14 feet below land surface, between 24 and 27 feet, between 34 and 42 feet, and between 50 and 52 feet. The cavity encountered from 5 to 14 feet below land surface also extended horizontally several feet from the borehole, which made grouting infeasible. The cavity and borehole were filled with rock and gravel to prevent collapse and were abandoned.

The well drilled at site 3N (GW-215, fig. 5) is in regolith, probably formed from the Rogersville Shale. No wells were drilled in bedrock at this site.

Wells at sites 4E and 4W (figs. 6 and 8) were drilled in water gaps in Pine Ridge near the mapped trace of a thrust fault (McMaster, 1963). The wells at site 4E are completed in the Rome Formation, because the Rome is present on both sides of the fault. Wells at site 4W probably intersect the fault and possibly a block of Conasauga Group. The structure in this area has been interpreted differently by several investigators (summarized in Exxon Nuclear Company, Inc., 1978, p. 3.6-27 through 33), but there is general agreement that a fault exists and that a block of Conasauga Group (formations not identified) on the northwest side of the fault contacts the Rome Formation.

LITHOLOGY

Rock cuttings were collected at about 10-foot intervals from the deep boreholes at six of the sites; cuttings were not collected at sites 1N, 1S, and 3N. The amount of sample collected was generally adequate for description, and the size of the chips ranged from powder to 0.4 inch. Lithologic descriptions included in the following sections are generalized to support grouping the rock into consistent zones delineated by changes

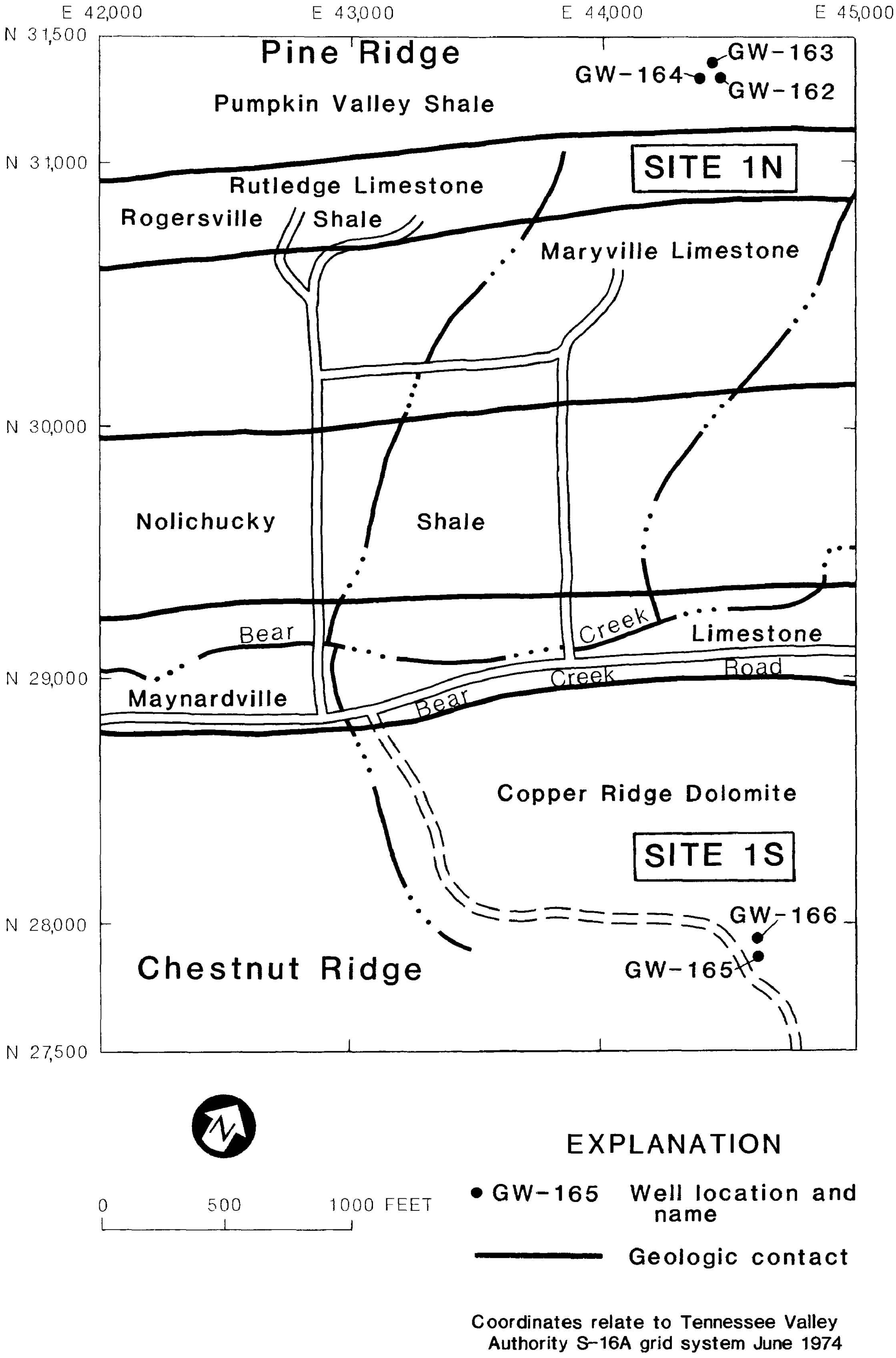


Figure 4.--Well locations and geology at sites 1N and 1S.

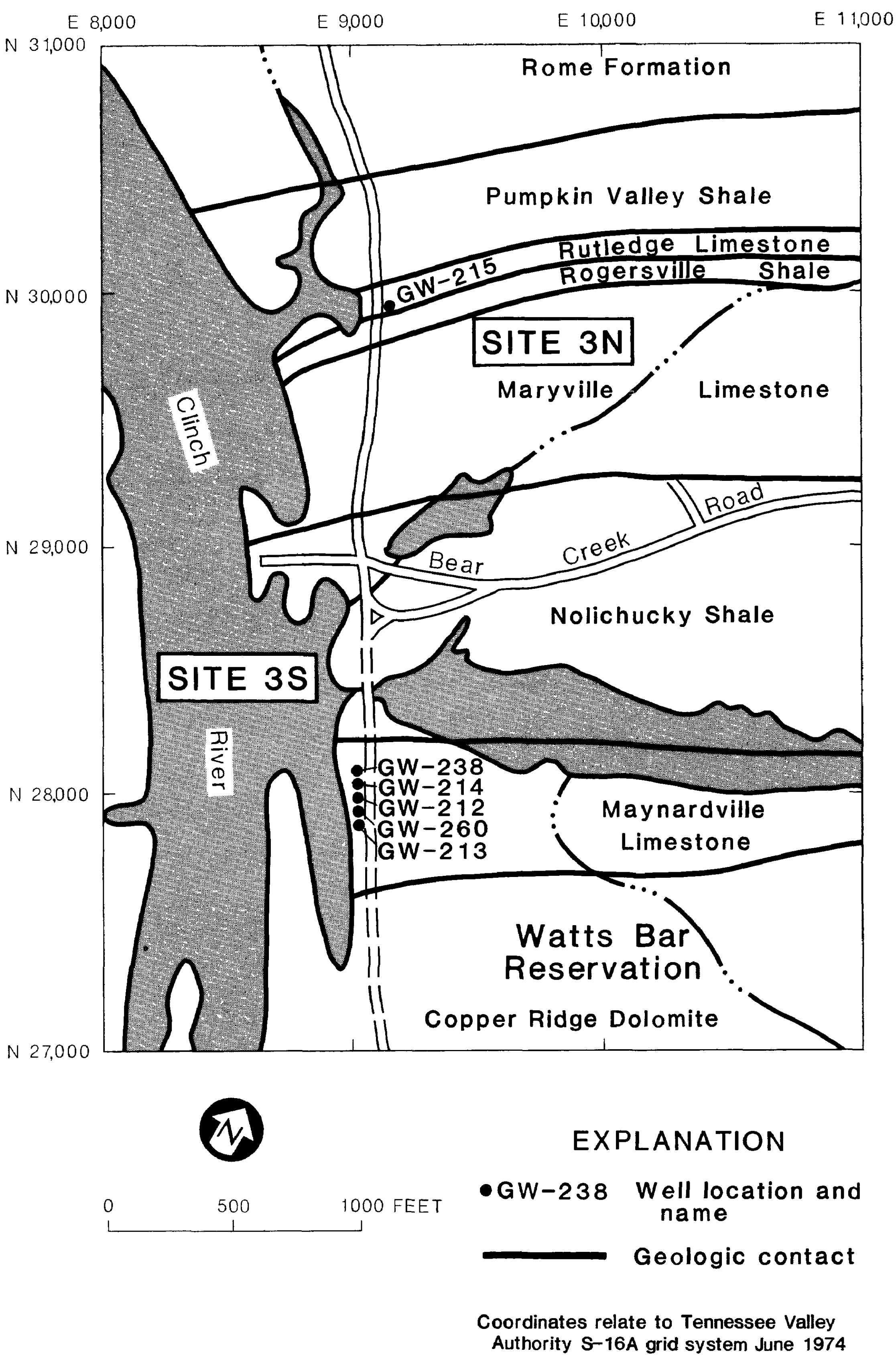


Figure 5.--Well locations and geology at sites 3N and 3S.

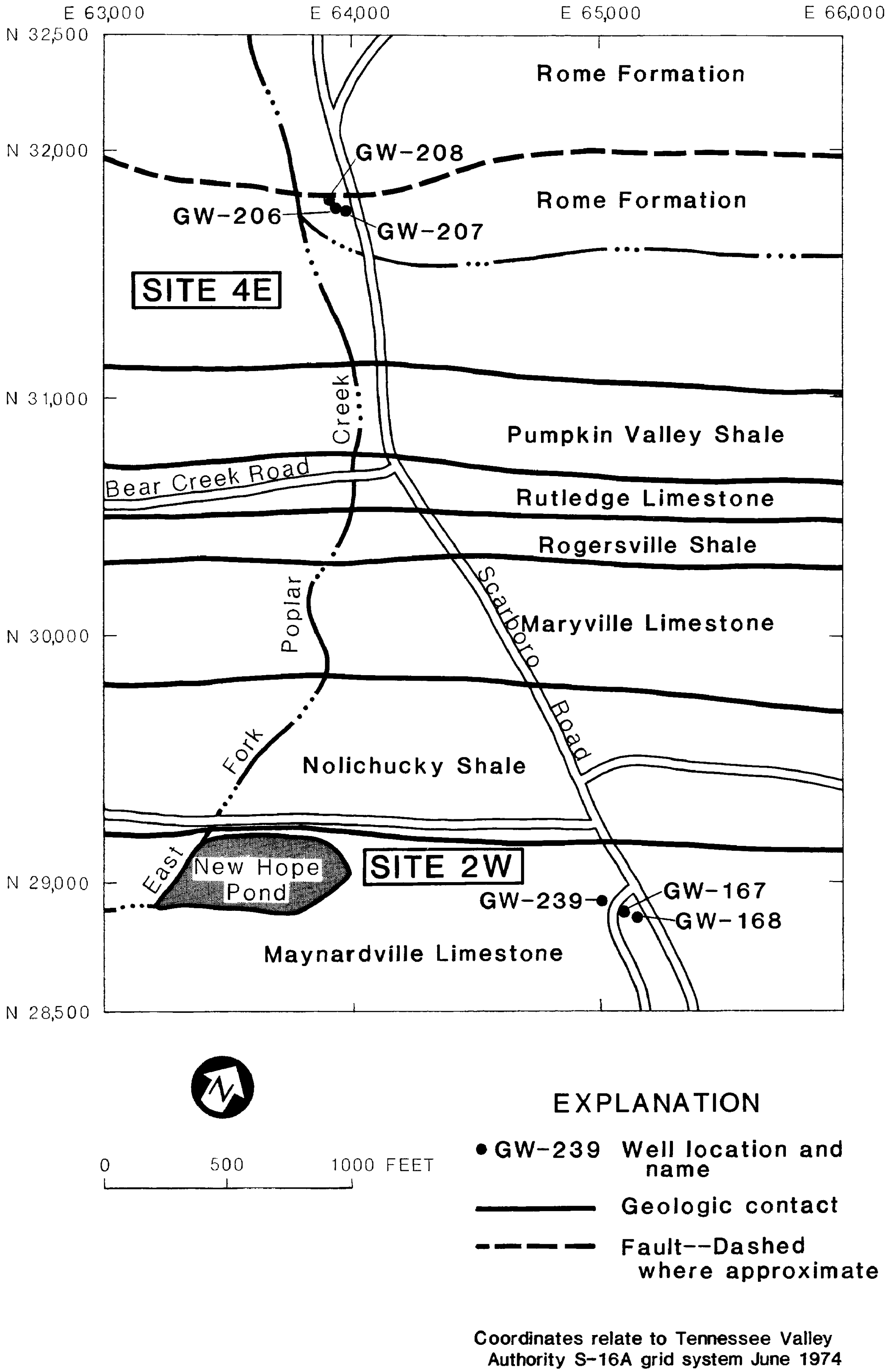


Figure 6.--Well locations and geology at sites 4E and 2W.

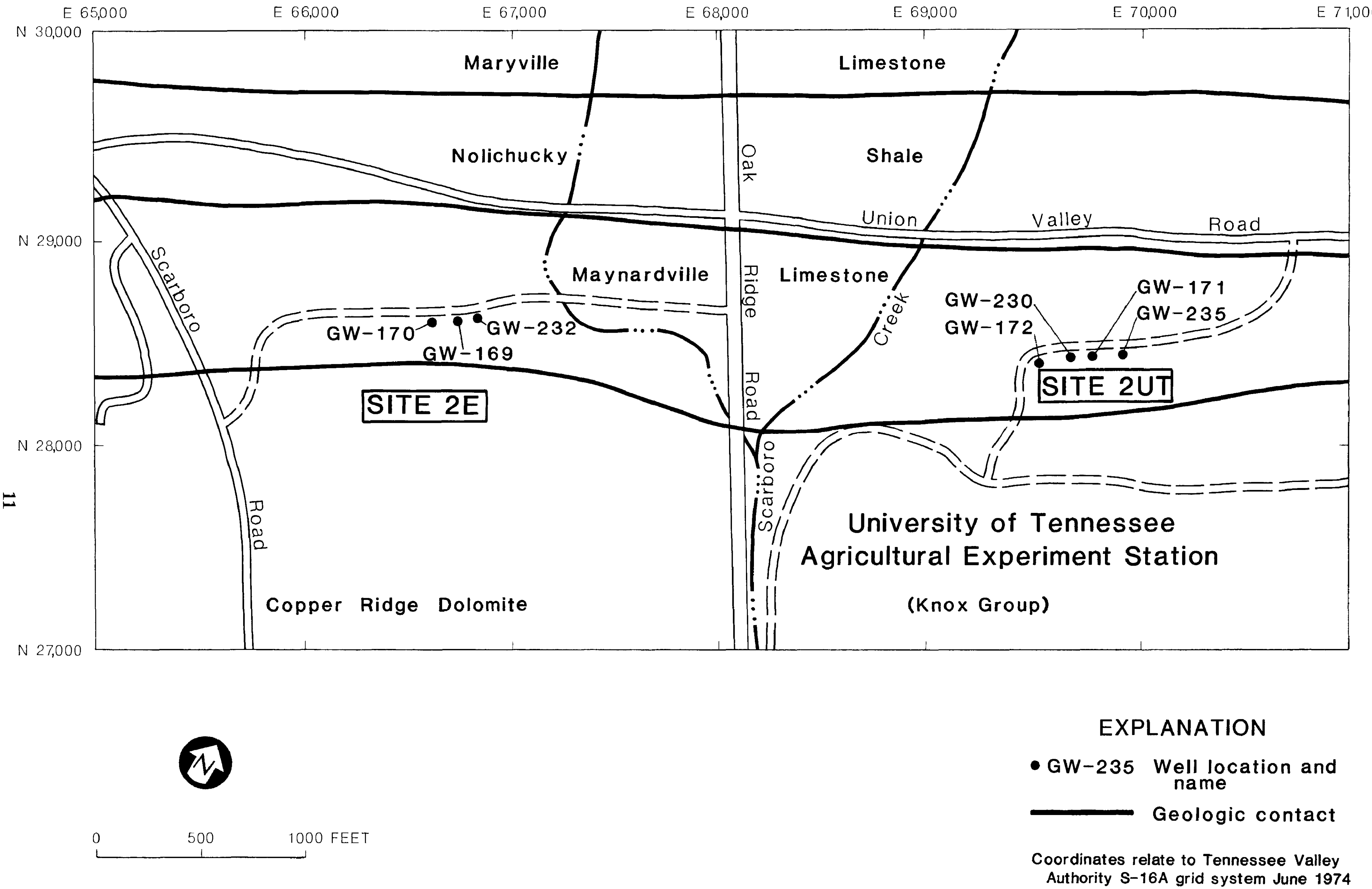


Figure 7.--Well locations and geology at sites 2E and 2UT.

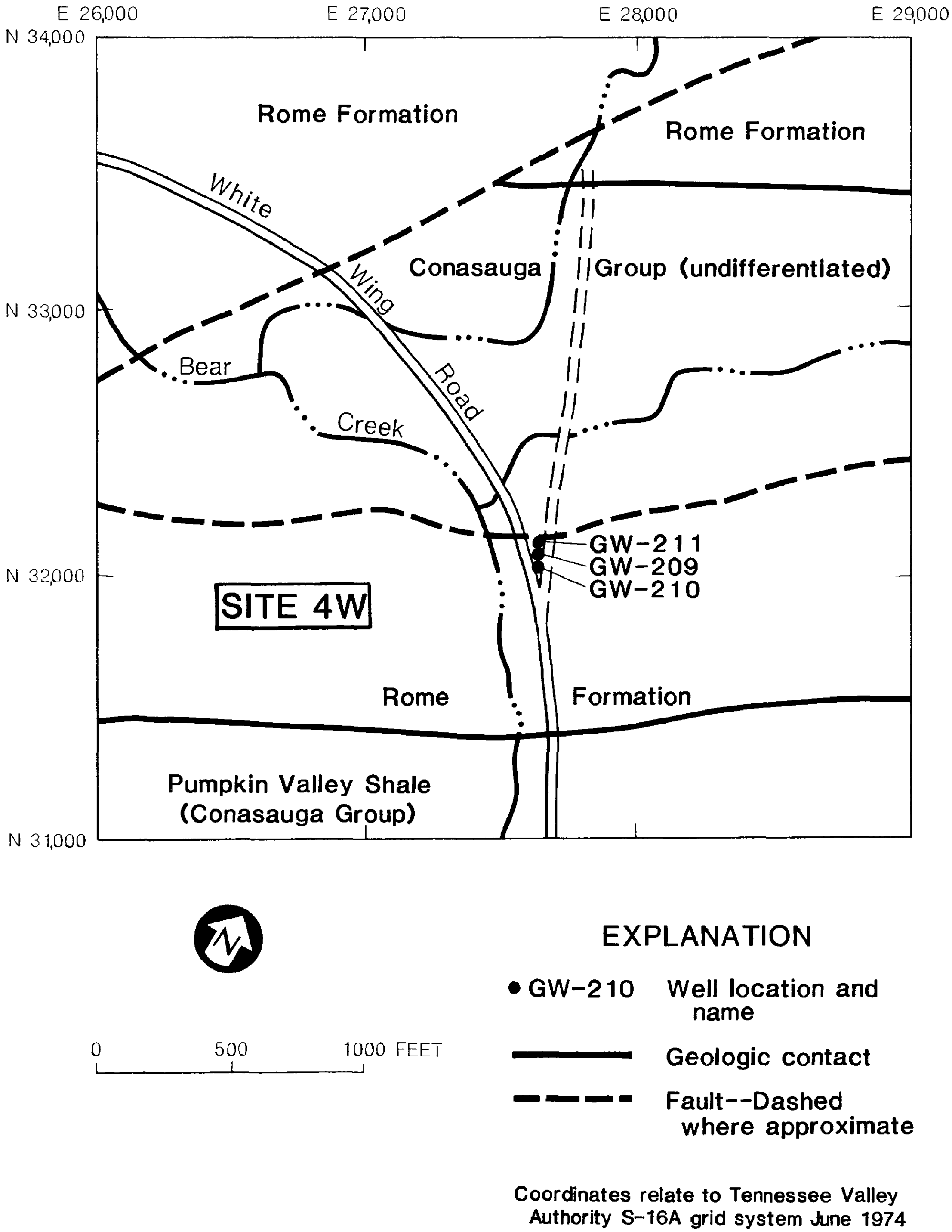


Figure 8.--Well locations and geology at site 4W.

in lithology, texture, cementation, or color (pl. 1). Depth intervals of zones are approximate due to the lack of continuous sampling.

Boreholes at the Base of Chestnut Ridge

The deepest boreholes at sites 2UT and 2E (wells GW-230 and GW-232) were completed in the Maynardville Limestone (fig. 7). Wells GW-214 at site 3S and GW-239 at site 2W (figs. 5 and 6) were completed in the Nolichucky Shale. The limestone in all four wells is interbedded pelletal-oolitic wackestone and micrite. Minor fossil fragments, such as trilobite shell fragments and fossil hash, are found in the finer crystalline lithologies. Recrystallization in the coarser lithologies gives some of the limestone a sparry appearance. The Nolichucky Shale in GW-214 and GW-239 is typically interbedded, very fine-grained, and greenish-gray or fine-grained and dusky yellowish-brown shale and siltstone.

Lithologic samples for GW-230, at site 2UT, began at 20 feet and ended at about 405 feet below land surface (pl. 1). The sampling interval was irregular for the first 100 feet, although the sampling interval throughout the borehole approximates 10 feet. The borehole is entirely within the Maynardville Limestone, which consists predominantly of pelletal-oolitic limestone with interbeds of micritic limestone. Regolith overlies the bedrock from land surface to a depth of 30 feet. Between land surface and 110 feet, micrite is the predominant lithology. The upper 55 feet of this zone has numerous cavities or solution openings. A major lithologic change at about 110 feet may correspond to a fracture along a bedding plane. The predominant lithologic type between 110 and 375 feet is oosparite, although the interval between 205 and 225 feet consists of a coarse crystalline sparry limestone. The open-hole interval, between 375 and 405 feet, consists of a coarser crystalline micrite.

GW-232, at site 2E, was sampled at intervals approximating 20 feet from 34 to 415 feet (pl. 1). Regolith overlies the bedrock from land surface to a depth of 33 feet. From 33 to 94 feet, the lithology consists of pelletal limestone and minor fossil fragments. Fractures or cavities are indicated by the presence of weathered rock fragments. There is a distinct lithologic break at 94 feet; between 94 and 140 feet, the predominant lithology is fossiliferous limestone. From 140 to 204 feet, there is a color change within the fossiliferous limestone, from dusky yellow brown to light olive gray. The lithology between 204 and 250 feet is a cryptocrystalline limestone matrix supporting pellets up to 0.005 inch in diameter. The lower limit of this interval is not exact, perhaps indicating a gradational contact. From about 250 feet to the bottom of the hole (415 feet), the rocks are micrites that display no structure.

Samples in GW-239, at site 2W, begin at 40 feet and continue at approximately 20-foot intervals to 400 feet (pl. 1). Regolith overlies the bedrock from land surface to a depth of 30 feet. The limestone from 30 to 320 feet consists of pelletal-oolitic limestone interbedded with micrite. The limestone between 100 and 150 feet is a denser cryptocrystalline micrite. Near 150 feet, the sample consists predominantly of mud and minor amounts of limestone chips, which is evidence of a cavity. Shale and siltstone of the Maynardville Limestone contacts the Nolichucky Shale at 320 feet. The contact between the limestone and the shale-siltstone is gradational. The sample collected at 320 feet contains both limestone and shale chips, but shale predominates below 340 feet. The lithology below 340 feet is interbeded fine to very fine-grained shale and siltstone.

Samples were collected from GW-214, at site 3S, at 10-foot intervals from 75 to 380 feet (pl. 1). Regolith overlies the bedrock from land surface to a depth of 18 feet. The limestone, which consists of micrite, probably begins at the bottom of the regolith and continues to about 189 feet. Numerous cavities within this interval are evident from samples that consist primarily of mud and weathered chips. At approximately 189 feet, there is a change in lithology; from 189 to 240 feet, the samples are predominantly mud mixed with chips of both limestone and minor quantities of shale. From 240 to approximately 320 feet, shale is more abundant in the samples, and below 320 feet, the samples are exclusively shale. The Maynardville Limestone contacts the shale and siltstone of the Nolichucky Shale at 320 feet.

Boreholes Along Pine Ridge

The boreholes at site 4E (fig. 6), located adjacent to East Fork Poplar Creek in a gap in Pine Ridge, were drilled in the Rome Formation near the mapped trace of a thrust fault (McMaster, 1963). The boreholes at site 4W (fig. 8) were drilled in a gap in Pine Ridge near Bear Creek and near the trace of the same thrust fault. The lithologies of the two sites are significantly different from each other and from those drilled along Chestnut Ridge. Rock cuttings from the deep wells at sites 4E and 4W show distinct lithologic sequences. The lithology of each borehole probably represents a different stratigraphic section of the Rome Formation, however, lithologic evidence is too tenuous to identify their exact locations in the section.

GW-208, at site 4E, was sampled at 10-foot intervals from 60 to about 404 feet (pl. 1). Lithology is interbedded shale, siltstone, and fine-grained sandstone having little or no carbonate cement. Regolith overlies the bedrock from land surface to a depth of 24 feet. Samples were not collected between 24 and 60 feet. Between 60 and 112 feet, the rocks are composed of a very fine- to fine-grained shale and minor amounts of very fine-grained sandstone. Within this interval there is interstitial glauconite at 92 feet, and all the samples contain carbonate cement. The lithology from 112 to 245 feet is interbedded fine-grained shale and fine-grained sandstone, and there is no carbonate reaction in the rock. At 245 feet, faulting is evident from the mylanitic texture of the shale. Between 245 and 404 feet, the section consists of fine-grained shale. Within this interval, the shale is grayish-red between 245 and 270 feet and blackish red below 270 feet.

GW-211, at site 4W, was sampled at approximately 10-foot intervals from 10 to 404 feet (pl. 1). Lithology consists of interbedded shale, siltstone, and minor amounts of fine-grained sandstone. The interbedding makes exact locations of changes in lithology difficult to identify. Regolith overlies the bedrock from land surface to a depth of 37 feet. Underlying the regolith to a depth of 100 feet, the section consists of fine- to medium-grained siltstone and sandstone and silica cement. At 100 feet, there is evidence of faulting similar to that found in samples from GW-208. Shale is the predominant lithology below 100 feet. Type of cement is the major distinction throughout this interval, and color also changes. Between 100 and 170 feet, the rock is cemented with carbonate and consists of interbedded blackish-red and grayish-red shale. There is no evidence of carbonate cement from 170 to 240 feet. Carbonate cement is present in the grayish-brown and dark-red very fine-grained shale between 240 and 340 feet. From 340 feet to the bottom of the open-hole interval (410 feet), the noncarbonate rock is interbedded grayish-black and olive-black shale.

GEOPHYSICAL LOGS

Geophysical logs were obtained in the same deep boreholes (table 2) for which lithology was described. All boreholes were logged in the open hole prior to installation of casing, except for well GW-239, which was logged after casing was set and the open interval below the casing had been drilled. Logs were obtained in

Table 2.--*Geophysical logs made in boreholes in Bear Creek Valley*

Well name	Depth of logging (feet)	Borehole geophysical log (indicated by X)										
		Temperature (degrees Celsius)	Fluid resistance (ohms)	Caliper (inches)	Gamma (counts per second)	Neutron (counts per second)	Gamma-gamma (density, in grams per cubic centimeter)	Electric 16 (ohm-meters)	Electric 64 (ohm-meters)	Spontaneous potential (millivolts)	Acoustic velocity (micro-seconds per foot)	Acoustic televiewer
GW-208	404	X	X	X	X	X	X	X	X	X	X	X
GW-211	404	X	X	X	X	X	X	X	X	X	X	X
GW-214	414.6			X	X	X		X	X	X		X
GW-230	341	X	X	X	X	X	X	X	X	X	X	X
GW-232	401	X	X	X	X	X	X	X	X	X	X	X
GW-239 [a]	433			X	X	X	X					

[a] Logged through steel casing from land surface to depth of 404 feet.

air-rotary drilled boreholes, therefore, no drilling mud was present to affect log interpretation. Logs were not obtained for some wells because of equipment malfunctions at the time of logging, or, in the case of GW-239, because some types of logs are not applicable in cased wells. The logs, shown on plates 2 through 7, were used to refine the lithologic zones delineated by sample descriptions and allowed additional interpretations based on continuous lithologic and hydrologic information in the borehole (pl. 1).

In general, interpretations of geophysical logs can be made as follows: deflections to the right for caliper logs indicate increasing wellbore diameter, which is frequently caused by fractures; for temperature logs, increasing water temperature; for fluid-resistance logs, fresher water; for gamma and spontaneous-potential logs, increasing shale-clay content; for neutron logs, decreasing porosity; for gamma-gamma and acoustic velocity logs, increasing density; and for long- and short-normal resistivity logs, fresher water or limestone-sandstone as opposed to shale.

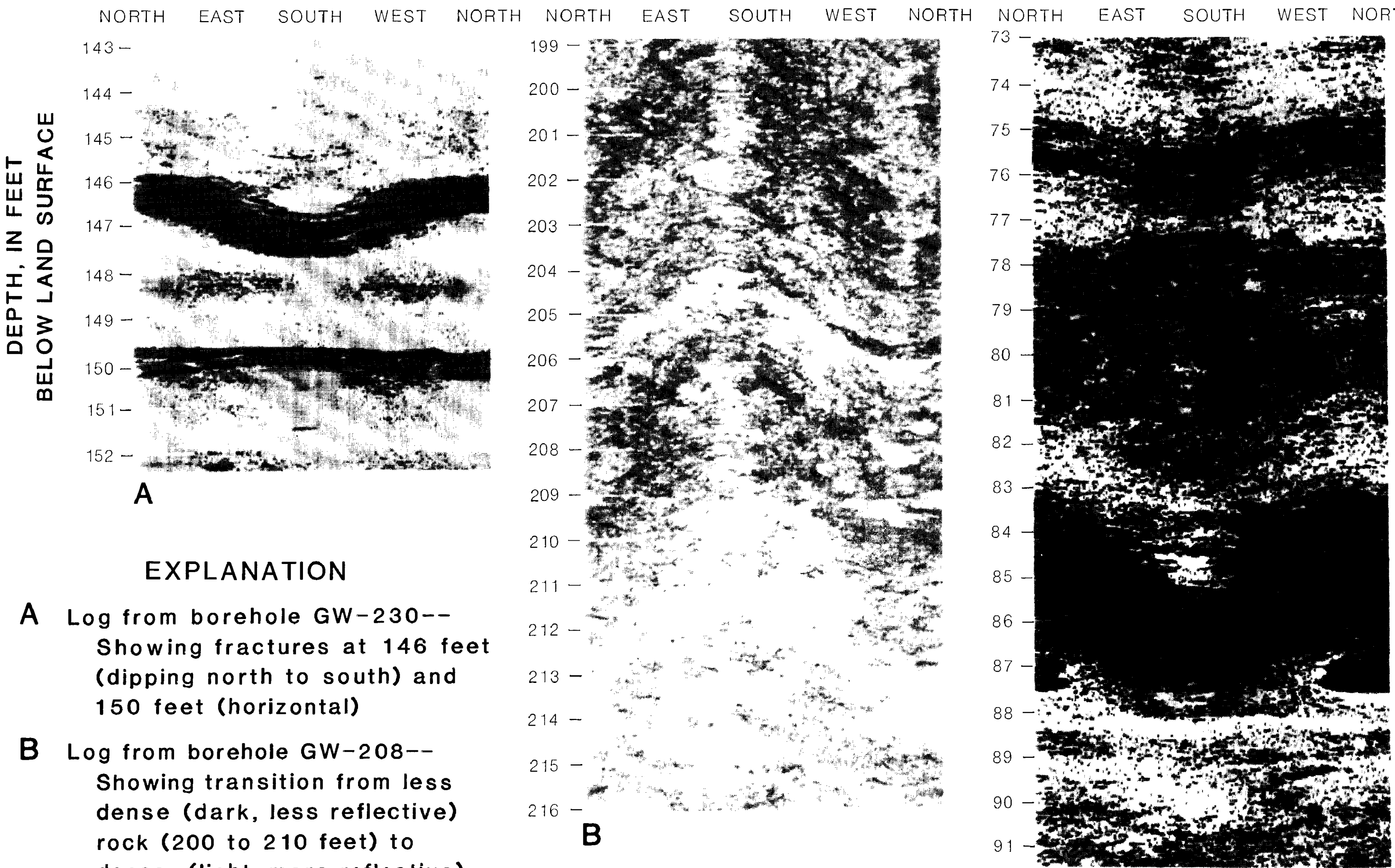
The acoustic borehole televiewer produces a photographic image representing the pattern of acoustic reflectivity on the borehole wall. Fractures are represented on the acoustic-televiewer (ATV) log by black lines that result from almost no reflectance of the acoustic signal back to the receiver (fig. 9 A). Bedding-plane orientation can also be seen in the closely spaced, curved striations on the logs. Because magnetic north is at each side of the log and south is in the center, a curved line that peaks at the middle axis of the log represents beds that dip from south to north (fig. 9 B). Massive and generally unfractured rock is represented by white areas on the log, which are produced by an almost complete reflectance of the acoustic signal off the borehole wall (fig. 9 B).

Identical scales and positioning of logs on plates 2 through 7 facilitates direct comparisons between plates. Zones designated on the plates are a combination of lithologic and geophysical zones for each borehole.

Boreholes at the Base of Chestnut Ridge

The geophysical logs for the four deep boreholes drilled at the base of Chestnut Ridge (pl. 2-5) indicate numerous fracture zones in the Maynardville Limestone, and, for two of the wells (GW-214 and GW-239), the contact with the Nolichucky Shale. Geophysical zones designated on plate 1 primarily represent sections of the ATV log that were either intensely fractured or massive and generally unfractured. These zones, which represent changes in geologic or hydrologic properties, correlate well with significant deflections on the other geophysical logs and with most changes in lithology identified from the rock cuttings. The generally low counts per second on the natural gamma logs are indicative of limestone, and are typical of all the boreholes logged in the Maynardville Limestone.

GW-230, drilled entirely in the Maynardville Limestone, was logged from land surface to a depth of 341 feet. The upper 55 feet of the logs are affected by the steel surface casings. Three major zones and a minor zone within the second zone were identified from lithologic descriptions. These same zone boundaries are identifiable as geophysical zones (pl. 1), but additional zones were also identified from patterns in the ATV log and deflections in the other geophysical logs (pl. 2). Mud-filled fractures to a depth of 110 feet are indicated primarily by the gamma and neutron logs. Rock between 110 and 145 feet is denser and less fractured. An influx of water below 145 feet is indicated by changes in water temperature, fluid resistance, and resistivity, and an intensely fractured interval is seen on the ATV log at this depth (fig. 9 A). Fractures continue to characterize the rock to a depth of 225 feet. Fractures are primarily horizontal between 145 and 183



EXPLANATION

A Log from borehole GW-230--Showing fractures at 146 feet (dipping north to south) and 150 feet (horizontal)

B Log from borehole GW-208--Showing transition from less dense (dark, less reflective) rock (200 to 210 feet) to denser (light, more reflective) rock (210 to 215 feet). Section also shows dip of beds from northeast to southwest

C Log from borehole GW-211--Showing possible thrust-fault zone (dark), (83 to 87 feet)

Figure 9.--Examples of structure observed on acoustic-televiewer logs.

feet, and dip from north to south between 183 and 220 feet. Increased porosity due to fractures between 145 and 183 feet is indicated by the neutron log, and clay filling in the fractures is indicated by the gamma and resistivity logs. Uniform fluid resistance indicates a more uniform mixing of water between 183 and 250 feet, and fractures are also identifiable on the gamma-gamma (decreased density) and acoustic-velocity (decreased velocity) logs. Below 220 feet, the rocks are again dense and only one fracture is identified on the ATV log at 270 feet. Temperature increases and fluid resistance decreases sharply below the fracture. The three lithologic and five geophysical zones (pl. 1) can be combined into three major zones (pl. 2) based on lithology and degree of fracturing. There are at least three and possibly four distinct changes in the fluid-resistance log that are associated with major fractures and may represent distinct water-bearing zones. Some of the major deflections on the geophysical logs not accounted for by zone changes can be correlated to specific fractures within the zones.

GW-232, drilled entirely in the Maynardville Limestone, was logged from land surface to a depth of 401 feet. The upper 33 feet of the logs are affected by surface casing. Lithologic descriptions identified five zones (pl. 1). The first three zones (33 to 94, 94 to 204, and 204 to 250 feet) and a subzone boundary at 140 feet are identifiable on the geophysical logs (pl. 3). The bottom of the third zone (250 feet) is near a fracture within dense rock, although the bottom of the corresponding fourth geophysical zone is at 275 feet. Uniform water temperature and generally uniform fluid resistance to a depth of about 280 feet indicate circulation and mixing of water. There is a pure, dense limestone from about 204 to 240 feet that is clearly indicated by the low counts per second on the gamma log, decreased porosity on the neutron log, and increased resistivity on the long- and short-normal log. This limestone is bounded on the top and bottom by fractures (ATV log) and corresponds to a gradual increase in temperature and fluid resistance. The fractures between 275 and 280 feet corresponds to a sharp decrease in fluid resistance that continues to the bottom of the hole. This change in fluid resistance and water temperature indicates an influx of water from a different water-bearing zone below 280 feet. Between 275 and 401 feet, the fracture density increases, and, although the change was not enough to delineate a separate lithologic zone, the color of the rock samples also changes at about 275 feet. There is a dense, unfractured subzone from 310 to 325 feet, and below this interval the fluid resistance decreases sharply. The four lithologic zones (and one subzone) and five geophysical zones (and one subzone) were combined into five zones (pl. 3) based on lithology and degree of fracturing.

GW-239 was logged after the steel well casing was set from land surface to a depth of 404 feet, and the open interval was drilled from 404 to 433 feet below land surface. Only nuclear logs, which are essentially unaffected by the steel casing, were obtained. Deflections in the logs at 405 feet result from the probe moving from cased to uncased borehole (pl. 4). The ATV log was not obtained at this borehole, but deflections in the logs that were obtained delineate fractured and unfractured zones that correspond almost exactly to the four lithologic zones (pl. 1). Lithologic descriptions combined with the low counts per second on the gamma log provide evidence that the upper 320 feet are drilled in the Maynardville Limestone. Low density and clay-filled fractures in the uppermost zone, from 30 to 105 feet, are indicated on the gamma-gamma and neutron logs. The same logs show very dense rock and low porosity for the zone from 105 to 160 feet. Although density (gamma-gamma log) gradually increases in the zone from 160 to 320 feet, there are individual spikes on the gamma and neutron logs that indicate clay-filled fractures. The lithologic samples and higher gamma counts, increased porosity (neutron log), and lower density (gamma-gamma log), indicate that the remainder of the borehole is in the Nolichucky Shale. The four zones on plate 4 are the same as the geophysical zones, and are nearly identical to the lithologic zones.

GW-214, was logged from land surface to a depth of 410 feet. Some logs were not obtained for this borehole because of equipment malfunctions. Lithologic samples and the geophysical logs indicate that the upper 320 feet are drilled in the Maynardville Limestone and the remainder of the borehole is in the Nolichucky Shale. A PVC surface casing was set to a depth of 13 feet, but further drilling indicated that the top of unweathered bedrock is at a depth of 18 feet. An estimated water yield of 450 gal/min was produced from the uncased interval, from 13 to 18 feet, during drilling. Four zones are identified by both lithology and geophysics (pl. 1), but only two boundaries correspond. The first zone, identified from lithologic samples to a depth of 189 feet, can be divided into two geophysical zones. The first geophysical zone, from 24 to 110 feet, is dense limestone, although some individual fractures show on the ATV and caliper logs (pl. 5). These fractures are clay filled (from gamma and neutron logs). The second geophysical zone, from 110 to about 190 feet has an increased number of mud-filled fractures, as indicated on the ATV and caliper logs, and from higher counts per second on the gamma log, increased porosity on the neutron logs, and lower resistivity on the long- and short-normal log. Mud filled fractures were inferred from the lithologic samples within an otherwise uniform lithology. Although there are lithologic changes below 190 feet, they are not detected by the long- and short-normal logs; the resistivity indicates uniform water quality. The third geophysical zone, from 190 to 320 feet, corresponds to two lithologic zones; however, if the bottom of the second lithologic zone (240 feet) is projected on the geophysical logs, slight deflections are notable. The interbedded nature of this zone is evident in the alternating deflections on the gamma and neutron logs, and in a "gouged" appearance on the ATV log, which may result from incompetent shale layers caving into the borehole. The change to Nolichucky Shale at 320 feet is indicated by the higher counts per second on the gamma log and increased porosity on the neutron log. The four zones identified by geophysical logs were the zones selected to represent the major zones on plate 5. The lithologic zone at 240 feet was not included.

Boreholes Along Pine Ridge

Logs for each deep borehole drilled along Pine Ridge (pl. 6-7) show significantly different lithologic sequences from the wells on the opposite side of the valley, and from each other. Both wells were drilled near the mapped trace of a thrust fault, and the lithologic samples and geophysical logs were used to identify the fault in the subsurface. Geophysical zones (pl. 1) generally represent sections of the ATV logs that were either light or dark in tone (fig. 9 **B**). Few fractures were seen on these logs in comparison with the logs of wells in the Maynardville Limestone. In addition, the gamma logs generally show higher ranges of counts per second, which indicates a different lithology than that seen on logs for the Maynardville Limestone.

GW-208 was logged from land surface to a depth of 404 feet. The upper 24 feet of the logs are affected by PVC surface casing. The well constructed in this borehole and the shallower bedrock well at this site (GW-207) are flowing wells. The mixing of water throughout this borehole is apparent from the logs of fluid resistance and water temperature (pl. 6). A few fractures are evident, but the majority of dark lines on the ATV log show dip of bedding. The four zones delineated from the geophysical logs correspond almost exactly to zones identified by lithology (pl. 1). Bedding in the zone that extends to a depth of 110 feet below land surface dips from north to south, and the interbedded nature of rocks in this zone is indicated on the gamma and neutron logs. Bedding in the second zone (110 to 245 feet), observed on the ATV log, dips from northeast to southwest (fig. 9 B), which is normal to regional dip. Within this zone, all the logs show relatively uniform lithology except for a more porous shale from 170 to 215 feet, which is observed on the neutron and gamma logs. Evidence found in the lithologic samples indicates a possible fault at about 245 feet, and the major deflections on the geophysical logs corroborate the lithologic evidence. The interval from 245 to 280 feet, possibly the thrust fault, has a generally gouged and irregular appearance on the ATV log, and contains intervals of bedding that dip north to south. An increase in water yield from this zone was detected during drilling, and therefore, most of the inflow in the borehole is probably from this zone. From 280 to 360 feet, the dip continues to be from north to south. Within this interval the fluid resistance continues to decrease, which may indicate that the thrust fault impedes the flow of water from below the thrust to the upper zones. There is a return to uniformity in the geophysical logs from 360 to 404 feet and no pattern of dip is apparent on the ATV log; however, these differences relative to the preceeding zones are not great enough to designate a separate zone. The four zones on plate 6 are the same as the major geophysical zones and generally correspond to the lithologic zones.

GW-211 was logged from land surface to a depth of 404 feet. The upper 37 feet of the logs are affected by a steel surface casing. Five zones were identified from the lithologic samples and the geophysical logs, but only three of the zone boundaries are in general agreement (pl. 1). More fractures are indicated on the logs for this well than for GW-208, and water-bearing intervals are indicated by sharper deflections and changes in slope on the water temperature and fluid resistance logs (pl. 7). The dark areas on the ATV log show bedding that dips primarily from north to south. Examination of the rock cuttings indicate that the thrust fault may be at about 90 to 100 feet below land surface. In addition, the ATV and caliper logs show a large fracture from 83 to 88 feet (fig. 9 C), and most of the other logs also show significant deflections at this depth. Increased flow of water during drilling was associated with several of the fractures indicated on the logs at 116, 166, 220, 295, 345 to 355, and 385 to 395 feet below land surface. Temperature and fluid resistance logs indicate an influx of warmer, more conductive water at 50, 145, 220, 240, 275, and 300 feet. Although the shallow and intermediate depth wells at this site flow, the well installed in this borehole does not flow, possibly because the water-bearing zone was cased. Deflections on the gamma log from 295 to 310 feet and from 320 to 340 feet look representative of limestone, but lithologic samples show shale and carbonate cement. Within these intervals, the water quality is significantly different than in the upper zones, as seen on the resistivity and fluid resistance logs. From 340 to 404 feet, the fluid resistance log remains unchanged, but the other logs are indicative of the fractured shale described from the lithologic samples. A combination of the lithologic and geophysical zones produced the six zones on plate 7.

SUMMARY

Twenty-four wells were constructed at nine sites in Bear Creek Valley to provide geologic and hydrologic information. Lithologic samples and suites of geophysical logs were obtained from the deepest boreholes at six of the sites. The lithologic samples and geophysical logs provided significant information on structure, stratigraphy, and water-bearing intervals.

Two of the logged boreholes at the base of Chestnut Ridge were completed in the Maynardville Limestone, and in two other boreholes the contact between the Maynardville Limestone and Nolichucky Shale was identified. The two boreholes along Pine Ridge were completed in the Rome Formation, and the probable

location of a thrust fault was identified in each borehole.

Zones of similar lithology within a borehole were delineated from rock cuttings and refined by examination of geophysical logs. There was generally a good correspondence between the zones identified from lithologic samples and those independently identified from the geophysical logs. Fractures and cavities in the Maynardville Limestone were identified on the acoustic-televiewer and caliper logs, and orientation of bedding in the Rome Formation was determined from the acoustic-televiewer logs. Different water-bearing intervals within a borehole were distinguished from the water temperature, fluid resistance, and resistivity logs, and these intervals often correlated to fractures.

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