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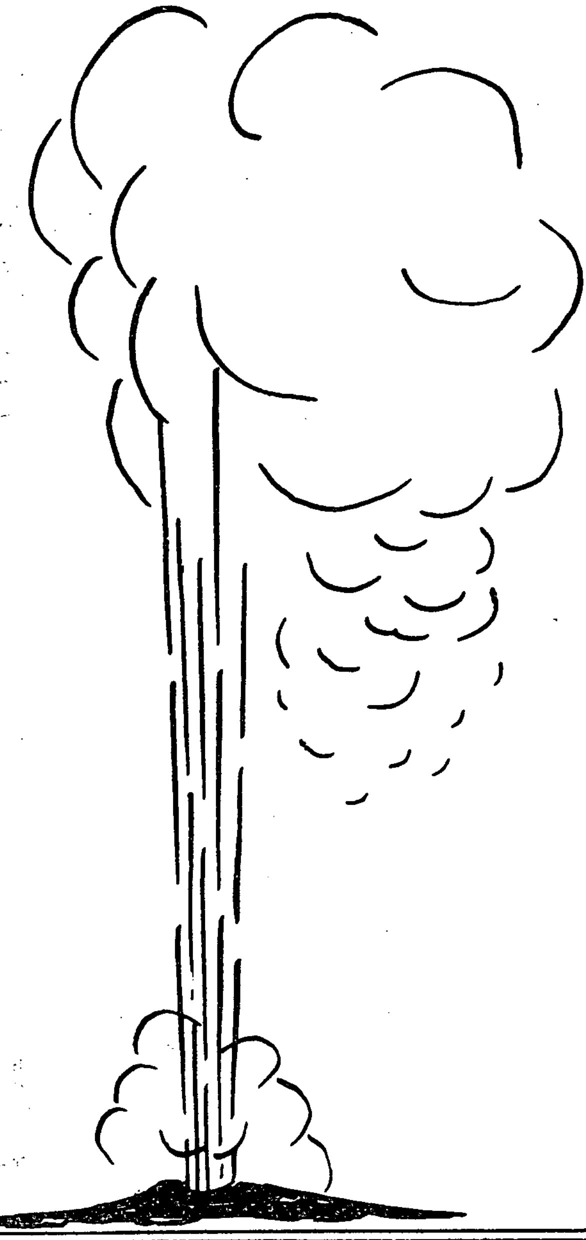

PRELIMINARY DEFINITION OF THE GEOTHERMAL RESOURCES POTENTIAL OF WEST VIRGINIA

By
J. L. Renner
Tracy L. Vaught

January 1979

Work Performed Under Contract No. ET-78-C-08-1558

Gruy Federal, Inc.
Arlington, Virginia

U. S. DEPARTMENT OF ENERGY

Geothermal Energy

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Foreword

This report is one in a series of analyses of the geothermal prospects in the Department of Energy-Division of Geothermal Energy Eastern Region. The work was performed under the Earth Sciences Task extension to contract ET-78-C-08-1558, Atlantic Coastal Plains Geothermal Drilling Program. These reports gather available geologic, geophysical, and geochemical data related to the possible occurrence of hydrothermal geothermal resources.

Abstract

Most of West Virginia is underlain by Paleozoic sedimentary rocks. Crystalline rocks are limited to two areas: a small area in the Harpers Ferry region and some basic intrusives and extrusives in Pendleton County.

In the Valley and Ridge province the rocks are folded and faulted. The deformation appears to be confined to the sediments overlying the crystalline basement.

The Appalachian Basin is characterized by moderately dipping sediments which may reach thicknesses of 7600 meters (25,000 feet) in eastern West Virginia.

The 38th parallel fracture zone may extend through West Virginia and serve to localize geothermal resources. Heat flow in West Virginia appears to be rather uniform and in the range of 1.12 to 1.26 heat flow units.

Bottomhole temperatures from oil and gas tests show no abnormally hot spots. Warm springs are limited to the eastern portion of West Virginia in the folded Appalachians and appear to be located on the flanks of anticlines at topographic lows. Geothermometry suggests subsurface temperatures in the 45 - 65°C (113 - 149°F) range.

The Appalachian Basin provides a thick sequence of rocks with normal geothermal gradient (18.2°C/kilometer, 1°F/100 feet). High temperatures are expected at great depths, but production rates are likely to be low.

Several oil and gas tests in West Virginia have encountered pressures about twice the normal pressure expected at the depth. However, the overpressured zones appear to be of small extent.

PRELIMINARY DEFINITION OF THE GEOTHERMAL RESOURCE POTENTIAL OF WEST VIRGINIA

Geology of West Virginia.

The major geologic divisions of West Virginia correspond closely to the two physiographic provinces shown on Figure 1. The linear valleys and ridges of the Valley and Ridge physiographic province are underlain by folded rocks with complex fault systems. Maturely dissected plateaus of the Appalachian Plateaus province are underlain by gently folded and relatively flat-lying Paleozoic sediments. The generalized geology of the state is shown on Plate 1.

Very few igneous or metamorphic rocks are exposed at the surface in West Virginia. Paleozoic metamorphic rocks--predominantly greenstones, quartzites, slates and phyllites--are exposed in the Harpers Ferry region at the extreme edge of the eastern panhandle. The only other crystalline rocks at the surface are dikes of diabase and other basic intrusives, found mostly in Pendleton County. These Mesozoic rocks are the youngest known igneous rocks in the state.

Most of West Virginia is underlain by thick deposits of sedimentary rocks. From the geologic and geophysical data available, their thickness ranges from near zero in the eastern panhandle region to more than 7600 meters (25,000 feet) in the deeper parts of the Appalachian Basin. A generalized stratigraphic column and description of the sedimentary rocks of West Virginia is shown in Table 1.

Structurally, the Valley and Ridge province is characterized by folds and thrust faults. Rich (1934) observed that although the area was broken by faulting, none of the faults brought basement to the surface. Sufficient data were not publicly available to document carefully this style of deformation until Gwinn (1964) published a summary of data generated by oil and gas exploration programs in the Central Appalachians.

Regional seismic profiles and deep drilling, reported by Jacobeen and Kanes (1974), have confirmed Rich's original concept that deformation is confined to the sedimentary rocks overlying the basement. This style of deformation has been characterized as "thin skinned" (Rodgers, 1949).

Sheets of sediments sheared along relatively incompetent shales have been thrust to the northwest. In some areas the movement of the major thrust has been divided among several smaller faults near the surface. This has caused several sheets of sediments to be thrust one upon the other, resulting in repetition of the sedimentary section. The Ray Sponaugle well in Pendleton county, drilled to 3963 meters (13,000 feet) in 1960, shows such a repeat in section (Perry, 1964).

Most of the folding visible at the surface appears to result from the thrusting at depth. Harris and Milici (1977) envision that either sediments are emplaced as a series of thrust sheets beneath overlying competent rocks doming them upward (Figure 2a) or folds are caused by bending of rocks above a zone where the thrust moves upward from one horizon to another (Figure 2b). The thrusting and consequent repetition of section provide a thicker sedimentary section than would be expected if the folds involved basement uplift. Northwest of the folded Appalachians the compressive forces rapidly decreased, causing a rather sharp break between the highly folded and faulted rocks of the Valley and Ridge area and the gently deformed rocks of the Appalachian Plateaus. The Appalachian Plateaus province is characterized by moderately dipping Paleozoic rocks. The exposed rocks in the West Virginia segment of the Appalachian Plateaus are downwarped into the Allegheny synclinorium or Appalachian Basin. Figure 3 shows the postulated thickness of sediments in the basin.

Geothermal Resources.

Geothermal resources are not likely to be developed in West Virginia in the immediate future. Ultimate usage of geothermal resources in West Virginia will depend primarily on the economics of deep drilling and production. Two areas of the state having some potential for the utilization of geothermal resources are the warm springs area in eastern West Virginia and the deeper portions of the Appalachian Basin.

No major zones of crustal dislocation or recent igneous activity are definitely known in the state. The 38th parallel fracture zone (Dennison and Johnson, 1971; Heyl, 1972) is thought to pass through West Virginia. This hypothesized zone of tectonic and igneous activity could cause elevated temperatures and enhanced geothermal potential. As visualized by Heyl (1972), this zone runs through West Virginia from Wayne to Pocahontas County. Dennison and Johnson (1971) have compiled a list of geophysical and geologic features that coincide with this zone; among these are the hottest thermal springs in the Appalachians (Bath County, Virginia), Eocene and perhaps somewhat younger andesite dikes, and the maximum negative value of a simple Bouguer anomaly, which lies generally along the Virginia-West Virginia boundary. Review of geologic and topographic maps of Virginia also suggests east-west displacement of the folded Appalachians and the Blue Ridge at about the 38th parallel. This zone appears to have been sporadically active over a period of 800 million years and may still be a zone of deep crustal weakness.

Heat flow. Little is known about the heat flow characteristics of West Virginia. Sass and others (1976) show only four heat flow mesurements in West Virginia. The values, which range from 1.12 to 1.26 heat flow units are listed in Table 2 and shown on Figure 4. The same authors also report a heat flow measurement of 1.7 HFU in northern Buchanan County, Virginia, near the border with West Virginia. Heat flow data are too scarce to be useful in interpreting detailed heat flow characteristics in West Virginia or in interpreting the existence of the 38th parallel lineament.

The geothermal gradient map of North America (American Association of Petroleum Geologists and the U.S. Geological Survey, 1976), shows temperature gradients ranging from about 18.2 to 32.8°C/km (1.0 to 1.8°F/100 feet) in the state. The temperatures, obtained from electric logs run in oil and gas tests, were recorded by maximum-reading thermometers and do not necessarily represent the true bottomhole temperature at thermal equilibrium. Geothermal gradients in selected wells in West Virginia, calculated independently in the present investigation using the same methodology, are presented in Table 3.

We have no complete explanation for the differences in gradient from area to area within the state shown in our data and on the published geothermal gradient map. Some of the variation is probably caused by the methods used to record the data and some possibly by movement of ground water.

Warm springs. Surficial manifestiations of geothermal resources in West Virginia are limited to the warm springs that occur along the eastern border of the state, shown on Figure 4.

These warm springs occur along the flanks of anticlines where they are cut by water gaps. The hydrologic balance seems to be such that convective upwelling of waters and the consequent emergence as warm springs occur only where the upwelling waters can escape in topographic lows. Temperature profiles from existing wells and from one well specifically sited to avoid upwelling water indicate that vertical movement of water may not be important away from the hot springs themselves (Costain, 1976). Costain further suggests that the greatest geothermal potential occurs where the anticlines (and possible underlying thrust faults) are cut by near-vertical fault zones perpendicular to the trend of the anticlines.

Price and others (1936) list only four springs in West Virginia having temperatures greater than 18°C (65°F). Six springs with temperatures between 22 and 23°C (71 to 73.5°F) listed by Waring (1965) are listed in Table 4.

Modern geochemical interpretations have not been published for West Virginia springs. Hobba and others (1976) have reported some data on wells and springs in thermal areas of the Appalachians; their interpretative work will be published in the U.S. Geological Survey Professional Paper series during 1978 or early 1979. Price and others (1936) list chemical analyses of many springs in West Virginia. Possible reservoir temperatures calculated with the Na-K-Ca geothermometer (Fournier and Truesdell, 1973) and the SiO_2 geothermometer (Fournier and Rowe, 1966) from the data of Price and others (1936) and Hobba and others (1976) are given in Table 5.

The geothermometry suggests that the West Virginia warm springs are not substantially hotter at depth than at the surface. Although silica geothermometry is probably the best guide to subsurface temperature, it is uncertain in this case whether quartz or chalcedony is the solution-controlling silica phase. Quartz has lower solubility at a given temperature than chalcedony, and geothermometry based on quartz solubility predicts higher temperatures. Temperatures calculated assuming quartz equilibrium are reported in Table 5; they can be regarded as maximum subsurface temperatures in the spring systems. With the exception of one set of analytical data from Minnehaha Springs, the Na-K-Ca results in West Virginia appear to be misleading. Equilibrium with calcite, deposition of calcite by the hot springs, or inaccurate analytical data might cause the poor results.

Geothermal potential. From the data collected through oil and gas exploration and limited geochemical sampling of warm springs in eastern West Virginia, tentative conclusions can be reached about the geothermal potential. The temperature gradient and heat flow in West Virginia appear to be relatively uniform and comparable to normal continental areas. Although Sass and others (1976) show a zone of low heat flow coincident with the folded Appalachians, it is likely that locally elevated temperatures will be found nearer to the surface here than elsewhere in the state because of vertical movement of water. The complex pattern of folding and faulting allows circulation and the consequent rise of heated water, which appears at the surface as warm springs.

Although it is likely that the 38th parallel lineament is a real geologic feature, there is no hard evidence for igneous activity more recent than Eocene in West Virginia. Costain (1976), Price and others (1936), Reeves (1932), and Rogers (1884), agree that the hot springs result from deep circulation of ground water along folds and faults. The relatively high surface temperatures in the Bath County, Virginia, area may simply be due to deeper than normal circulation caused by the intersection of the 38th parallel lineament with the folded Appalachians.

Warm spring areas. The most likely location for develoment of geothermal resources in the folded Appalachians would be areas of existing upwelling, i.e., hot spring locations. Secondary targets would be low topographic areas coincident with cross faults or transverse fracture zones. The combination of fracturing and sedimentary rocks should provide adequate production capacity for non-electric warm water applications.

Appalachian Basin. The largest area of potential geothermal development is the Appalachian Basin. This area does not appear to be abnormally hot at depth. However, the great thickness of sediments may produce sufficiently high temperatures at depth in rocks of sufficient permeability to be of interest.

The deepest wells in West Virginia have gradients between 16.4 and 20°C/kilometer (0.9 and 1.1°F/100 feet). If a mean ambient surface temperature of 10°C (50°F) is assumed, temperatures of 100°C will be reached at about 5.0 kilometers (212°F at 16,200 feet). The major constraint on development of geothermal resources appears to be the cost of drilling and production from such depths. If fluids from existing oil and gas wells could be used, drilling costs would be reduced; however, pumping costs would be quite high and probably make such fluids uneconomic.

If overpressures were present in the deep reservoirs, pumping costs could be reduced or possibly eliminated. Overpressures have recently been discovered at several locations in West Virginia in the process of drilling for oil and gas, but little is presently known about the extent of such pressures.

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GEOLOGIC MAP OF WEST VIRGINIA

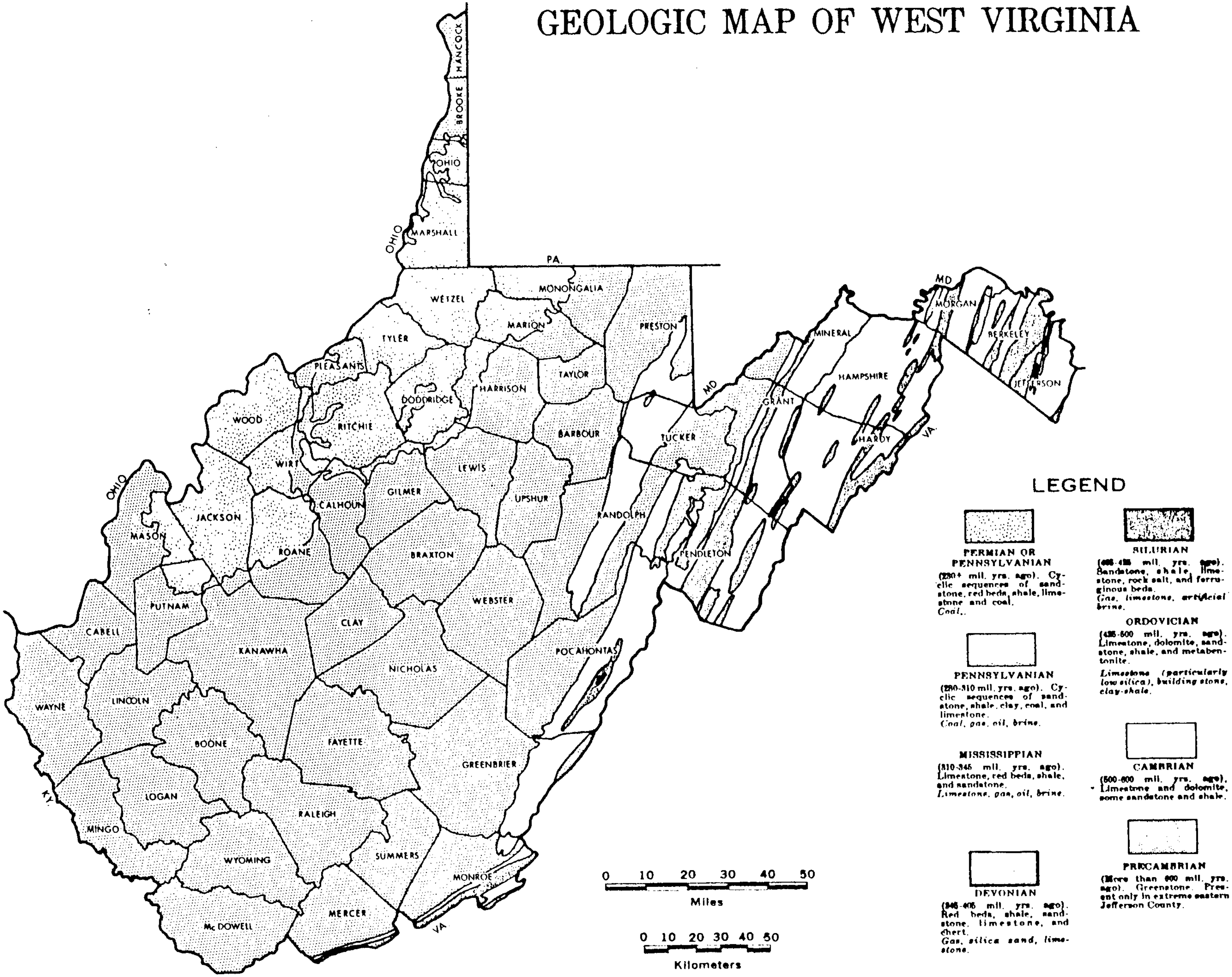

PLATE 1

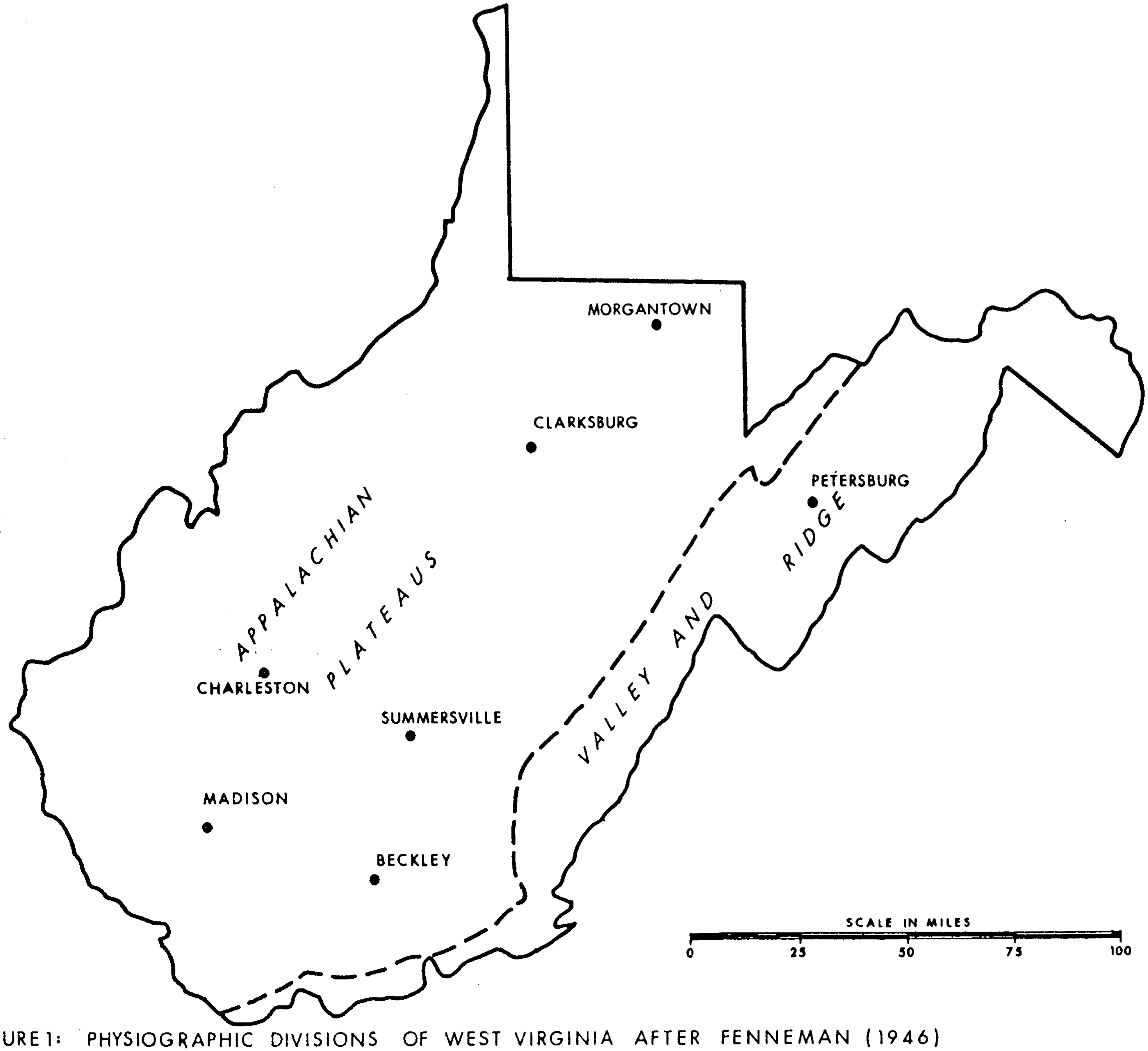

FIGURE 1: PHYSIOGRAPHIC DIVISIONS OF WEST VIRGINIA AFTER FENNEMAN (1946)

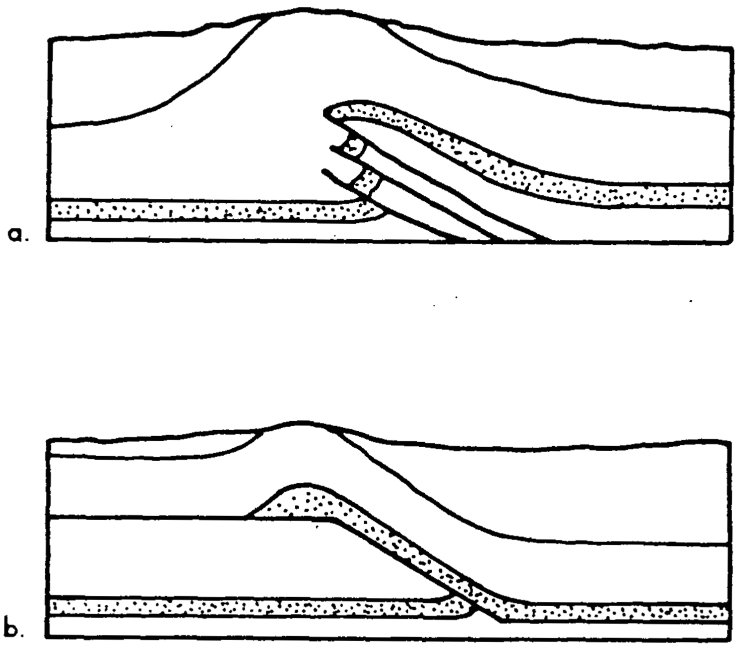

FIGURE 2: DIAGRAMS SHOWING TWO POSSIBLE METHODS OF THRUST INDUCED FOLDING. a. SUBSURFACE THICKENING OCCURS AS A RESULT OF REPETITION CAUSED BY SEVERAL THRUSTS. b. FOLDING OCCURS WHERE A SINGLE THRUST MOVES UPWARD THROUGH SECTION TO ANOTHER LEVEL.

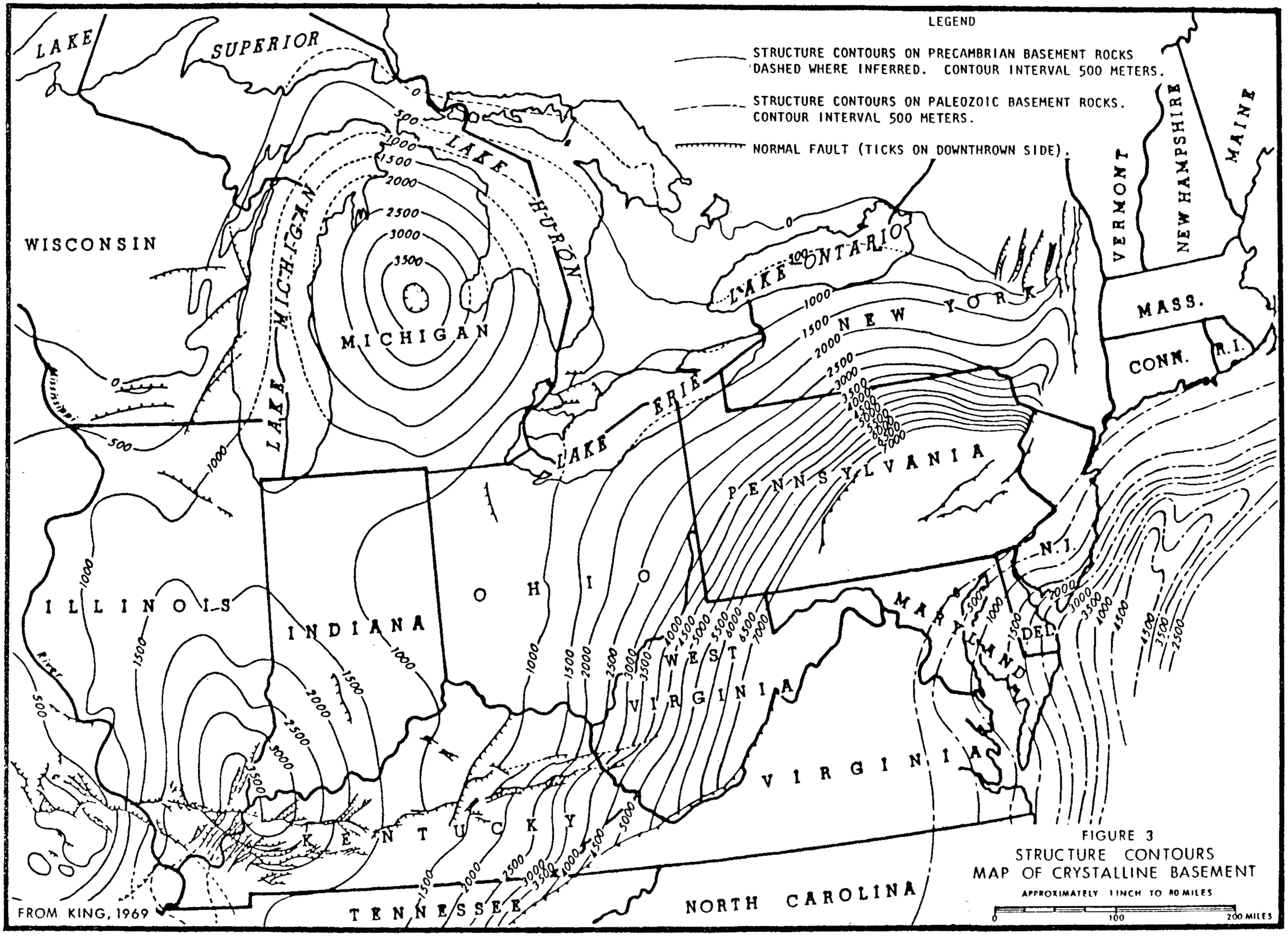

FIGURE 3
STRUCTURE CONTOURS
MAP OF CRYSTALLINE BASEMENT

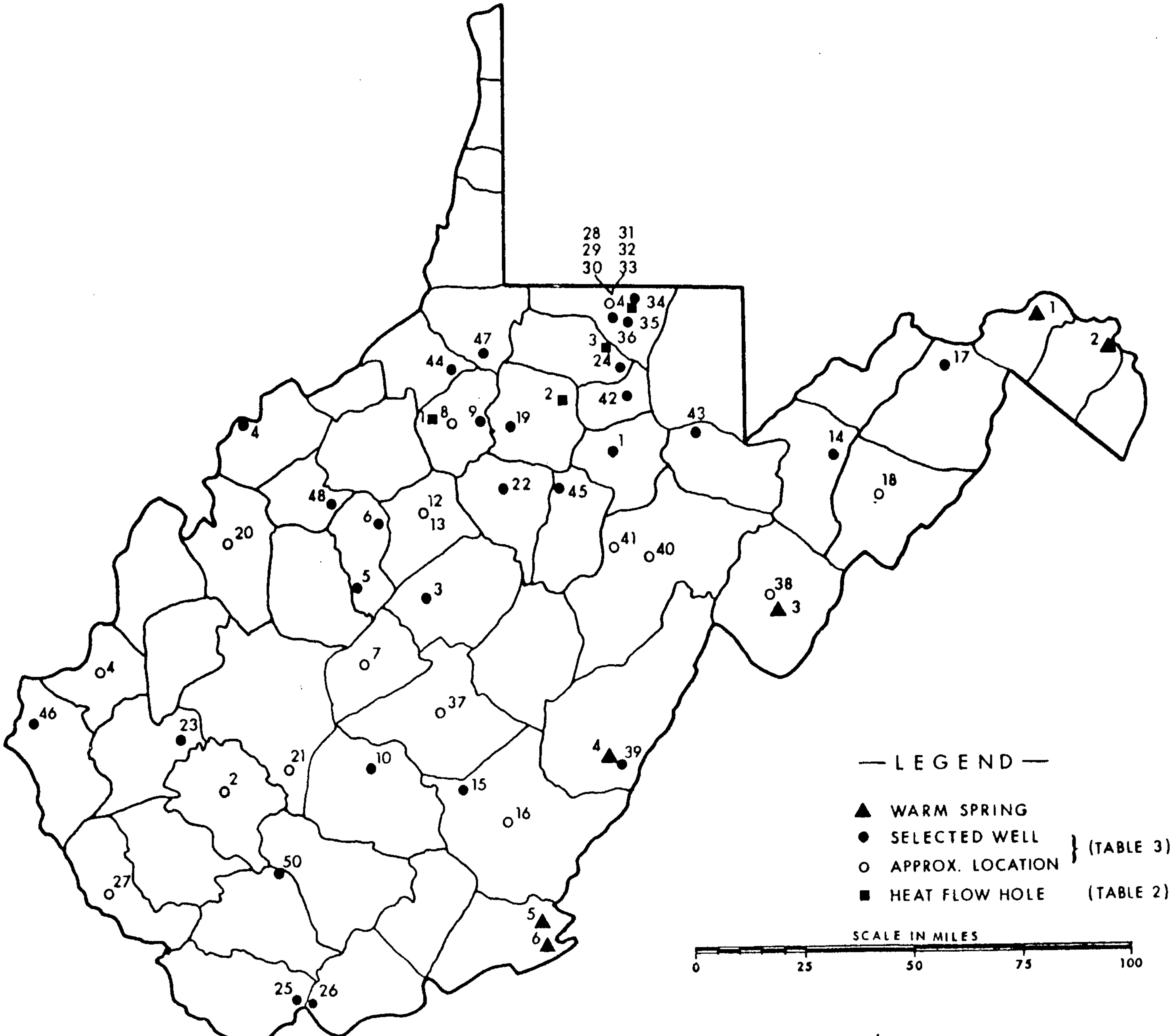

FIGURE 4: WARM SPRINGS, DEEP WELLS & HEAT FLOW HOLES IN WEST VIRGINIA

TABLE 1

GENERALIZED STRATIGRAPHIC COLUMN OF WEST VIRGINIA

ERA	PERIOD		GROUP	FORMATION	DESCRIPTION
Cenozoic					Alluvial deposits of sand, gravel, and clay
Mesozoic	Triassic				Nonmarine, igneous bodies, diabase dikes
Paleozoic	Permian		Dunkard Group		Sandstone, siltstone, red shales, coal seams, nonmarine fossils
	Pennsylvanian	[Upper]	Monongahela Group		Extensive deposits of Pittsburgh coal
			Conemaugh Group		Red beds, coal seams
		[Mid]	Allegheny Fm.		Some sandstone, coal seams
		[..Lower..]	Pottsville Group	Kanawha Fm.	Sandstone, siltstone, shale, coal, conglomeratic with a few limestone layers
				New River Fm.	Same
				Pocohontas Fm.	Same
	Mississippian	[Upper]	Mauch Chunk Group		Nonmarine, shale and sandstone, red beds near top
		[Mid]	Greenbrier Group		Mostly limestone, layers of dark calcareous shale with sandy zones; some parts of the limestone are oölitic; cherty layers near the base
		[Lower]		Maccrady Fm.	Red shale and mudstone, partly calcareous
			Pocono Group		Nonmarine sandstone, siltstone, shale and sandy shale, coal seams, thin limestone layers, fossiliferous

Table 1 continued

GENERALIZED STRATIGRAPHIC COLUMN OF WEST VIRGINIA

ERA	PERIOD		GROUP	FORMATION	DESCRIPTION
Paleozoic	Devonian			Hampshire Fm.	Nonmarine, red and green shales, sandstones
		Upper	Chemung Gr.		Grey shale with siltstone layers, sandstone and some conglomerate
		Upper		Brallier Fm.	Olive grey to dark shale with siltstone and sandstone lenses
		Middle		Harrell Shale	Black shale, calcareous zone near base
		Middle		Mahantango Fm.	Dark grey shale, sandstone lenses
		Middle		Marcellus Fm.	Black fissile shale
		Middle		Tioga Bentonite	"Brown break," altered ash
		Middle		Orondaga Limestone	Argillaceous and cherty limestone, high colloidal silica content (west)
		Middle		Hunterville Chert	Highly silicified black shale, brecciated, re-cemented with amorphous silica (SE)
		Middle		Needmore Shale	Very dark shale (NE)
		Lower		Oriskany Sandstone	Clean, porous, blanket sandstone
		Lower	Helderberg		Limestone, some sandstone and shale units, locally cherty
	Silurian	Upper		Tonoloway Fm.	Thinly laminated, interbedded, argillaceous limestone and calcareous shale
		Upper		Wills Creek Fm.	Shale with sandstone interbeds; carbonates predominate to SW and contain sandy zones
		Upper		Williamsport Fm.	Sandstone, shallow marine

Table 1 continued

GENERALIZED STRATIGRAPHIC COLUMN OF WEST VIRGINIA

ERA	PERIOD	GROUP		FORMATION	DESCRIPTION
Paleozoic	Silurian		Middle	McKenzie Fm.	Dark calcareous shales and thin bedded fossiliferous limestones
				Rochester shale	Dark grey shale, contains several thin limestone beds
				Keefer Sandstone	Sandstone (sheet)
				Rose Hill Fm.	Shale with thin sandstone layers, high in iron oxide
			Lower	Tuscarora Sand-stone	Clean white sandstone, resistant
			Upper	Juniata Fm.	Nonmarine, red-brown sandstone with some shale, noncalcareous
				Oswego Fm.	Grey to grey-brown, nonfossiliferous arkosic sandstone
				Reedsville Shale	
		Trenton	Middle	Martinsburg Fm.	
				Nealmont Limestone	Dark grey limestone with dark grey shale lenses, deposits of bentonite
		Black River			Limestone; some dolomite and chert
		St. Paul			Limestone and some dolomite and chert
	Ordovician	KNOX [Lower] Beekmantown			Dolomite with some limestone
	Cambrian	KNOX	Upper	Conococheaque Fm.	Limestone and dolomite with some sandstone and shale layers

Table 1 continued

GENERALIZED STRATIGRAPHIC COLUMN OF WEST VIRGINIA

ERA	PERIOD	GROUP		FORMATION	DESCRIPTION
Paleozoic	Cambrian	[KNOX]	[Upper]	Copper Ridge Dolomite (west)	Same as above, but sandstone gets more coarse to the west
			[Mid]	Elbrook Fm.	Mostly limestone with a purple shale near its base
			[Lower]	Waynesboro Fm.	Green shale with streaks of impure sandstone; dolomite is also present
				Tomstown Dol.	Dolomite; upper portion is very pure
		Chilhowee		Antietam Fm.	Quartz sandstone
	Anticambrian			Harpers Fm.	Metamorphosed sandy shale has formed phyllite or micaceous schist with sericitic sandstone streaks
				Weaverton-Loudon Fm.	Arkosic, coarse grained sandstone; some shale and fragments of epidote are present
				Catoctin Fm.	Basalt altered to greenstone and schist (contains chlorite and epidote)
				Crystalline rocks	Schist, quartzite, slate and gneiss
Precambrian					

(From Cardwell, 1975)

TABLE 2

HEAT FLOW MEASUREMENTS AND LOCATIONS
FOR DISTRICT OF COLUMBIA, PENNSYLVANIA, VIRGINIA, AND WEST VIRGINIA

	Latitude	Longitude	Heat Flow (HFU)	Location (Fig. 4)
District of Columbia				
	39°00'	77°00'	1.12	
Pennsylvania				
	40°06'	77°11'	0.57	
	40°22'	75°50'	0.70	
	40°34'	75°12'	0.89	
	40°59'	80°08'	1.20	
	41°12'	78°39'	1.31	
	41°52'	78°00'	1.31	
	41°56'	77°51'	1.47	
Virginia				
	36°49'	81°06'	1.03	
	36°52'	77°54'	1.40	
	37°20'	82°00'	1.70	
	36°49'45"	77°19'15"	1.24	
	37°45'56"	78°05'37"	0.97	
West Virginia				
	39°17'	80°46'	1.22	4
	39°18'	80°14'	1.26	3
	39°25'	80°05'	1.20	2
	39°40'	79°59'	1.12	1

SOURCES: Sass and others (1976); Costain and others (1978).

TABLE 3

GEOTHERMAL GRADIENTS FOR SELECTED WELLS IN WEST VIRGINIA

DATE	NO.*	COUNTY	WELL NO.	TEMP (°C)	TEMP (°F)	DEPTH (M)	DEPTH (FT)	GRADIENT (°C/km)	GRADIENT (°F/100 FT)
9-11-64	1	Barbour 173	Popperfield #10,647	44	112	1401	4,596	25.5	1.4
6-13-76	2	Boone 1059	A.C. Canterbury #12191	49	120	1354	4,443	29.1	1.6
9-17-75	3	Braxton 1126		72	162	2065	6,774	32.8	1.8
11-24-68	4	Cabell 532	H.L. Perry #1	48	118	1430	4,693	27.3	1.5
12-29-75	5	Calhoun 2548	Denver-Brannon #12104	50	122	1798	5,900	21.8	1.2
6-11-74	6	Calhoun 2503	Garner Lee et al #1	74	165	3338	10,950	20.0	1.1
10-22-75	7	Clay 1110	James Reed #20,315	26	79	608	1,996	27.3	1.5
8-5-63	8	Doddridge 1019	Downs #A-207	30	86	648	2,125	30.9	1.7
5-18-78	9	Doddridge 1807	Mt. Williams #12117	41	105	1608	5,274	18.2	1.0
4-22-62	10	Fayette 123	Faulke Estate #1	25	77	1189	3,900	12.7	0.7
7-6-66	11	Garrett	Turney #2	58	137	2202	7,225	21.8	1.2
9-23-66	12	Gilmer 7-F	W.H. Frost #746	25	77	650	2,134	23.7	1.3
9-2-69	13	Gilmer 2010	Elizabeth Lee #1	39	103	1171	3,842	25.5	1.4
9-9-65	14	Grant 2	Greenland Lodge #1	87	189	3961	12,994	20.0	1.1
1-27-68	15	Greenbriar 18	Myrtle Haynes #10,960	72	161	2664	8,741	23.7	1.3
1-20-76	16	Greenbriar 22	West Vaco #200-59-T	94	202	3084	10,118	27.3	1.5
3-10-64	17	Hampsire 12	Duckworth #1	82	180	4267	13,999	16.4	0.9
8-27-65	18	Hardy	Orr et al #9321	60	140	2286	7,499	21.8	1.2
7-30-70	19	Harrison 10-F	D.C. Hael 1945	27	81	807	2,649	21.8	1.2
5-27-70	20	Jackson 1203	Addre B. Thomas et al #1-795	48	118	1682	5,517	21.8	1.2
10-13-62	21	Kanawha 1911	Bedford Land Co. #7	26	78	921	3,002	16.4	0.9
10-15-73	22	Lewis 1937	Wm. J. Ross 11682	42	108	1453	4,766	21.8	1.2
6-3-74	23	Lincoln 1469	Doug McCormick	123	253	5824	19,106	20.0	1.1

*See Fig. 4.

Table 3 continued

GEOTHERMAL GRADIENTS FOR SELECTED WELLS IN WEST VIRGINIA

DATE	NO.*	COUNTY	WELL NO.	TEMP(°C)	TEMP(°F)	DEPTH(M)	DEPTH(FT)	GRADIENT(°C/km)	GRADIENT(°F/100ft)
7-7-77	24	Marion 321	Barth #A-1	58	137	2360	7,744	20.0	1.1
10-21-77	25	McDowell 730	Pocohontas LD Corp 12405	36	96	1267	4,158	20.0	1.1
10-5-73	26	Mercer 23	Pocohontas LD Corp #11611	42	108	1412	4,633	23.7	1.3
2-8-73	27	Mingo 805	Mineral Tract #10	126	258	5954	19,534	20.0	1.1
4-17-78	28	Monongalia	Merc #1	63	145	2287	7,502	23.7	1.3
12-11-75	29	Monongalia 347	L.W. McMillian #11731	72	162	2493	8,179	25.5	1.4
3-20-78	30	Monongalia 367	M. Miller 12478	70	158	2383	7,819	25.5	1.4
12-5-66	31	Monongalia 302	Giles C #1	67	152	2482	8,143	23.7	1.3
10-25-66	32	Monongalia 301	Giles R #1	72	161	2438	7,998	25.5	1.4
11-12-67	33	Monongalia 308	J.R. Wetsell A #1	71	159	2590	8,497	23.7	1.3
10-19-70	34	Monongalia 364	W. Sarah Hart #11730	68	154	2454	8,056	23.7	1.3
8-22-73	35	Monongalia 332	Greer Steel Co. #11,646	89	192	3226	11,567	21.8	1.2
11-27-77	36	Monongalia 323	O'Hare B #1 10.963	79	175	2543	8,344	27.3	1.5
12-8-71	37	Nicholas 293	R.A. Summers #1	76	168	2326	7,632	27.3	1.5
4-6-64	38	Pendleton 6	Sponangle #1 T8800	78	172	3961	12,996	16.4	0.9
8-14-63	39	Pocohontas 21	USA Tract 357 #1	78	172	3605	11,826	18.2	1.0
7-20-76	40	Randolph 103	W. Va. Med Security Prison Farm #10,228	119	246	3999	13,121	27.3	1.5
7-20-76	41	Randolph 178	E. Hutton #A-600	79	174	2415	7,922	29.1	1.6
9-9-74	42	Taylor 104	Richard K. Barlett #11,822	41	105	1393	4,571	21.8	1.2
4-24-70	43	Tucker 36	W.W. Nestor 11196	76	169	2651	8,696	25.5	1.4
4-21-77	44	Tyler 481	M. Geo. #12274	46	114	1517	4,976	23.7	1.3

*See Fig. 4.

Table 3 continued

GEOTHERMAL GRADIENTS FOR SELECTED WELLS IN WEST VIRGINIA

DATE	NO.*	COUNTY	WELL NO.	TEMP(°C)	TEMP(°F)	DEPTH(M)	DEPTH(FT)	GRADIENT(°C/km)	GRADIENT(°F/100ft)
6-11-73	45	Upshur 1491	L.E. Bond #11,657	61	142	2195	7,203	23.7	1.3
8-6-75	46	Wayne 1572	Jay P. Smith #1	77	170	4016	13,176	16.4	0.9
2-14-76	47	Wetzel 604	Mills Wetzel Lds.	36	96	975	3,199	25.5	1.4
6-1-73	48	Wirt 628	P.L. Depue et al #1	29	84	670	2,198	29.1	1.6
10-31-76	49	Wood 755	Borg Warner Corp. #4	49	121	1797	5,895	21.8	1.2
3-10-70	50	Wyoming 688	Low Creek Colliery	53	128	2032	6,668	21.8	1.2

*See Fig. 4.

TABLE 4

WARM SPRINGS OF WEST VIRGINIA

NAME	LOCATION	FLOW, gpm	ASSOCIATED ROCKS	TEMPERATURE
Berkeley Springs	Berkeley Springs, W. Va.	1000-1230	Oriskany Sandstone	73.5°F
Sevan Pond Spring	5 miles east of Martinsbury, W. Va.	100	Ordovician strata	72°F
Near mouth of Thorn Creek	2 miles south of Franklin, W. Va.	7700	Devonian strata	71°F
Minnehaha Spring	Camp Minnehaha, 4 miles southeast of Huntersville, W. Va.	550-660	Marcellus Shale	72°F
Old Sweet Springs	Sweet Springs, W. Va.	large	Stones River Limestone	73°F
Upstream from Erwin Run Spring	7 miles southeast of Gap Mills, W. Va.	66	Ordovician strata	72°F

(From Waring, 1965)

TABLE 5

ESTIMATED RESERVOIR TEMPERATURES

Reservoir temperatures are calculated using the silica (SiO_2) geothermometer of Fournier and Rowe (1966) and the Na-K-Ca geothermometer of Fournier and Truesdell (1973). Analyses are in parts per million.

SPRING NAME	SURFACE TEMPERATURE	SiO_2 ppm	T_{SiO_2}	PPM Na	K	Ca	$T_{Na-K-Ca}$
Berkeley (1)	23°C	12	53°C	5.4	1.5	49	166°C
Berkeley (2)	22°C	9.5	46°C	4.1	1.0	45	156°C
Minnehaha (1)	22°C	10	47°C	5.6	3.5	40	27°C
Minnehaha (2)	20°C	8.4	42°C	2.2	0.8	39	166°C
Old Sweet (1)	22°C	18	65°C	36	---	298	---
Shannondale Blue (1)	18°C	36	90°C	16	---	605	---

(1) Analysis from Price and others (1936)
(2) Analysis from Hobba and others (1976)

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