DIVISION OF MINERAL RESOURCES
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COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 36

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Thermal Springs of Virginia

BY

FRANK REEVES

SION OF MINERAL RESOURCES
O. Box 3667, University Station
Charlottesville, Virginia 22903

PREPARED IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

UNIVERSITY, VIRGINIA

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., October 20, 1931.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 36 of the Virginia Geological Survey series of reports the manuscript and illustrations of a report on the *Thermal Springs of Virginia,* by Dr. Frank Reeves.

This investigation was made in cooperation with the United States Geological Survey and the Virginia Hot Springs Company. It is a part of the comprehensive investigation carried on since December, 1927, between the divisions of Geological Survey and Water Resources and Power of the State Commission on Conservation and Development, and the geologic, topographic, and water resources branches of the United States Geological Survey. The Virginia Hot Springs Company has given considerable assistance to the general project.

This report treats mainly of the thermal springs in northwestern Virginia, especially in Alleghany, Augusta, Bath, Botetourt, Craig, Highland, Rockbridge, and Rockingham counties. It discusses the distribution, temperature, discharge, chemical character, gas content, geologic environment, and origin of these thermal springs.

As the thermal springs of these counties are of great interest to the many visitors and to the residents, and as these springs are an important economic resource, this report should be of value to many persons.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, November 25, 1931.
RICHARD A. GILLIAM, *Executive Secretary and Treasurer.*

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ABSTRACT

In the northwestern part of Virginia and adjacent parts of West Virginia there are 90 or more springs that have temperatures ranging from those slightly in excess of the mean annual air temperature to a temperature of 105° F. Most of these springs yield waters which are predominantly calcium carbonate in character. With the exception that the warmest springs have a slightly higher mineral content and are relatively richer in sulphates than most of the cold springs, the warm springs are very similar in mineral composition to the cold springs. The gases issuing from the warm springs are composed almost entirely of atmospheric gases, carbon dioxide being in greater percentage of the volume than in air. Nearly all the warm springs issue from the Oriskany sandstone, the Lowville limestone, and the Elbrook limestone, where these formations rise to the surface from considerable depths as a result of anticlinical folding. They invariably issue only at the lowest exposures of these rocks in the different anticlines, and are therefore commonly found in the valleys of the major streams where the streams have cut water gaps through anticlinal ridges. They are commonly found only in those anticlines in which the water-bearing formations are exposed at lower elevations than in adjacent anticlines.

The hypothesis as to the source of the heat and water supply of these warm springs that is most consistent with the facts of their chemical composition and geologic occurrence is that they are due to the artesian circulation of meteoric water through permeable beds, the water being taken in at a relatively high outcrop of the permeable bed in an anticline and discharged where the same bed is exposed at a lower level in an adjacent anticline. The temperature of the springs is an expression of the normal earth temperatures in the synclinal basins through which the water moves, as through great inverted siphons.

The condition for the occurrence of a warm spring having such an origin is a highly folded terrane with considerable relief, containing beds sufficiently permeable to act as aquifers, the continuity of which is not broken by faults. The unusual number of warm springs in the region under consideration and their absence or scarcity to the northeast and southwest may in part be due to the scarcity of thrust faults in this part of the Appalachian region.

Thermal Springs of Virginia[1]

By Frank Reeves

INTRODUCTION

NATURE OF THE INVESTIGATION[2]

The investigation on which this report is based is one of the units in a comprehensive investigation of the springs, especially the thermal springs, of Virginia. The project was initiated in December, 1927, by Wilbur A. Nelson, as State Geologist. The entire investigation of the springs has been carried on in cooperation between the State Commission on Conservation and Development, participating through the Virginia Geological Survey and the Division of Water Resources and Power, and the United States Geological Survey, participating through the geologic and topographic branches and the surface water, ground water, and quality of water divisions of the water resources branch. The Virginia Hot Springs Company has given material aid to the investigation.

On December 2 and 3, 1927, a visit to Hot Springs and a reconnaissance of the principal thermal springs in that vicinity were made by O. E. Meinzer and W. D. Collins, of the United States Geological Survey, in company with Mr. Nelson. Subsequently work of four kinds was begun: (1) Detailed topographic mapping of the Hot Springs area,[3] which includes the principal thermal springs of the State; (2) detailed study and mapping of the geology of the same area; (3) intensive investigation of the springs of the area, consisting chiefly of obtaining, during a period of years, accurate records of the discharge, temperature, chemical composition, gas content, and radioactivity of the springs; and (4) a survey of the springs of a much larger region, with special reference to correlating the springs, especially the thermal springs, with the rock structure. The investigation is still in progress, but two units of work have been completed and reports thereon have

[1] This report was prepared in cooperation with the United States Geological Survey and is published with the permission of the Director of that Survey.

[2] At the time the project was started the water resources investigations of Virginia were conducted, under the direction of J. J. Dirzulaitis, a district engineer in the United States Geological Survey, by the Geological Survey bureau of the State Commission on Conservation and Development. In 1928 the surface-water work was transferred to the newly created bureau of Water Resources and Power of the State Commission on Conservation and Development, with Mr. Dirzulaitis as chief engineer.

[3] Photolithographed advance sheets of the 7½-minute Falling Spring, Mountain Grove, and Warm Springs Run quadrangles have been issued on a scale of 1:24,000 and with a contour interval of 20 feet. Field work on the Healings Springs quadrangle has been completed.

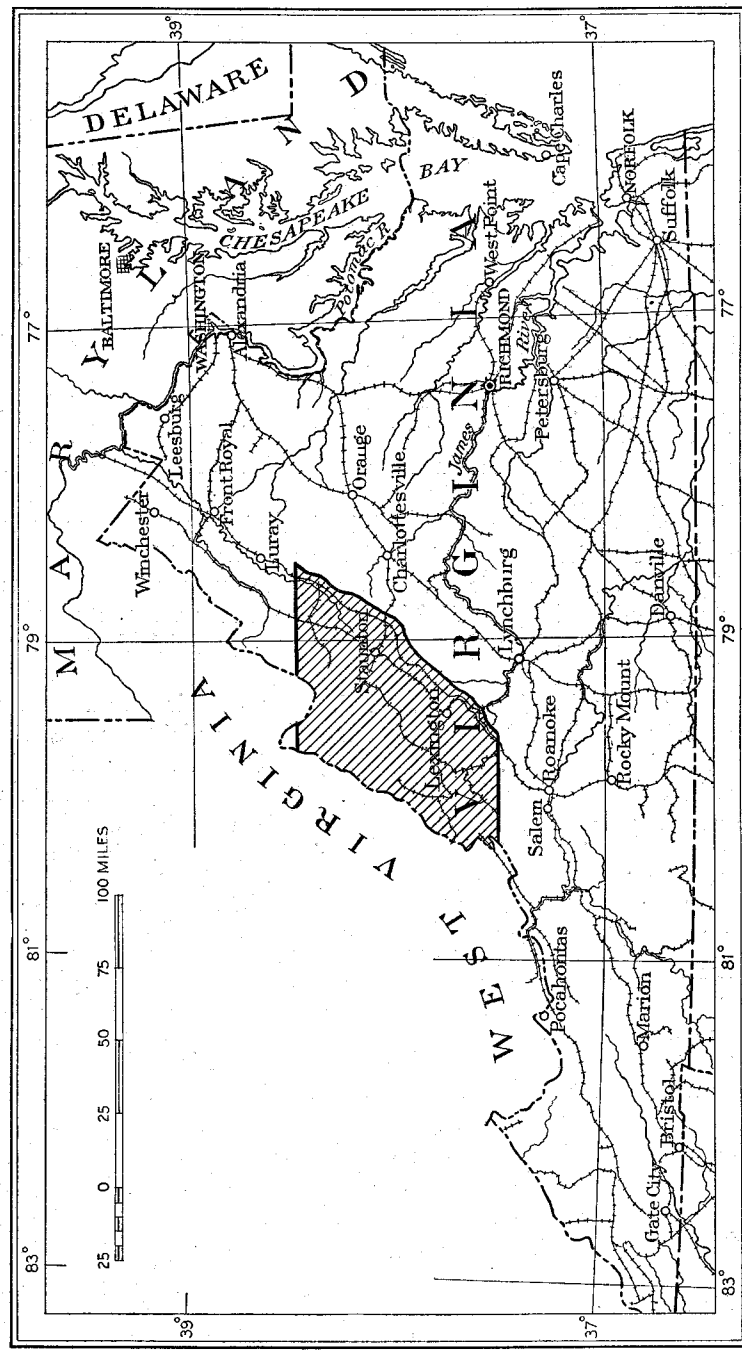


Figure 1.—Index map showing location of the thermal springs region of Virginia.

been prepared. The first of these units is the general report on springs of Virginia;[4] the second is the present report.

FIELD AND LABORATORY WORK

During February, March, and April, 1928, the writer made a field study of the principal springs in the region containing the Virginia warm springs, in order to acquire information as to the source of the heat and water of these springs. About 400 springs were visited in the counties of Alleghany, Augusta, Bath, Botetourt, Craig, Rockbridge, and Rockingham in Virginia, and in the adjacent counties of Greenbrier, Monroe, Pendleton, and Pocahontas in West Virginia. Observations were made as to the temperature, discharge, and geologic occurrence of these springs. Temperatures were taken with a maximum thermometer placed at the intake of the spring. The discharge was determined in various ways but chiefly by gaging the flow from the springs or by emptying the spring basin, measuring its capacity, and then determining the rate at which it filled. Samples of water were collected from many of the springs and analyzed by Margaret D. Foster in the water resources laboratory of the United States Geological Survey. Samples of the gases that bubble up in some of the springs were also collected and were analyzed by the United States Bureau of Mines. During the early part of September, 1928, many of the springs were revisited and their temperature again observed, for the purpose of determining to what extent the springs had been warmed during the summer. In November, another week of field work was given to geologic mapping in areas hitherto unmapped.

These field studies have furnished a satisfactory solution of the problem of the origin of the warm springs and have also yielded considerable information as to the occurrence, annual range in temperature, and chemical composition of the warm and ordinary springs of the region.

[4] Collins, W. D., Foster, M. D., Reeves, Frank, and Meacham, R. P., Springs of Virginia—a report on the discharge, temperature, and chemical character of springs in the southern part of the Great Valley: Virginia Commission on Conservation and Development, Water Resources and Power Div., Bull. 1, 1930.

GEOGRAPHIC DISTRIBUTION

The hottest and most widely known of the warm springs of the region are in Warm Springs Valley, Bath and Alleghany counties, in the northwestern part of Virginia. In this beautiful mountain valley (Pl. 4), which is about 18 miles long and 1 to 2 miles wide, there are four groups of springs, known as the Warm Springs, Hot Springs, Healing Springs, and Falling Springs. Warm Springs and Falling Springs are located, respectively, in the northeastern and southwestern extremities of the valley and Hot and Healing Springs in its middle part. (See Pl. 1.) Each group consists of three or more separate springs issuing from the ground in close proximity. The Warm Springs comprise four springs, three of which issue within less than 100 feet of one another, and the fourth is 800 feet to the southwest. At Hot Springs there are eight warm springs somewhat irregularly spaced in an area of about 1 acre. The Healing Springs consist of three separate springs less than 10 feet apart. Each of these groups of springs, except Falling Springs, is the site of a hotel. The Homestead Hotel, at Hot Springs, has long been a famous health and pleasure resort. The Falling Springs comprise a number of flows and seepages into a large artificial pond. They have a much lower temperature than the other warm springs of the valley but are notable for their large discharge, which is far greater than that of any other warm spring in the region.

There are many other springs of slightly lower temperature in the region. Among the warmest of these in Virginia are Bragg and Bolar Springs (Pl. 1 and Table 7, Nos. 76 and 78[a]), at Bolar, Highland County; Layton Spring (No. 142), on Jackson River, 2 miles south of Falling Spring P. O. (formerly Barber), Alleghany County; the Sweet Chalybeate Springs (No. 177), at Sweet Chalybeate, Alleghany County; Lithia Spring (No. 301), on Mill Creek, 3.2 miles east of Gala, Botetourt County; Lithia and Magnesia Springs (Nos. 267 and 268), at Rockbridge Baths, Rockbridge County; Panther Gap Springs (Nos. 252 and 253), in Panther Gap, 1.6 miles west of Goshen, Rockbridge County; Fitzgerald Spring (No. 202), on Middle River, 2.2 miles southwest of Fort Defiance, Augusta County; Dices Spring (No. 195), 1 mile southeast of Burketown, Augusta County; and Warm Springs (No. 189), 1 mile south of Bridgewater, Rockingham County. In the adjacent counties of West Virginia there are the Pritchard Spring (No. 2), near Dunmore, Minnehaha Springs (No. 6), at Minnehaha, and Curry Spring (No. 7), at Huntersville, all in Pocahontas County; Reed Springs (Nos. 13 and 14), 2 miles north of White Sulphur Springs; White Sulphur Spring (No. 17), at the Greenbrier

[a] Numbers of springs refer to Plate 1, showing the location, and to Table 7, giving the name and other data.

Hotel, White Sulphur Springs, Greenbrier County; and the Old Sweet Springs (Nos. 20 and 21), at Sweet Springs, Monroe County. Many of these springs are or have been the sites of hotels, such as the Greenbrier Hotel, at White Sulphur Springs, W. Va.

In addition to the springs mentioned above, which have a temperature of 60° F. or more, there are in the region many slightly cooler springs which, though not commonly regarded as warm, rightfully belong in the class of warm springs. Outside of the limits of the district here described there are few warm springs in the Appalachian region. In Virginia south of the area shown in Plate 1, not more than half a dozen warm springs have been noted, and these are only moderately warm, having temperatures of 55° to 65° F. South of Virginia, Watson[5] reports four warm springs: Hot Springs, Madison County, and Warm Springs, Meriwether County, N. C., and Thundering Spring, Pike County, and Lifsey Spring, Upson County, Ga. The temperatures of these springs are 104°, 87°, 76°, and 77° F., respectively.

North of the area under consideration in Virginia and West Virginia, the only springs known to the writer that have temperatures above 60° F. are the Fristoe and Davis springs, at Overall, in Page and Warren counties, Va., having summer temperatures of 61° and 65° F., respectively; the Capon Springs, at Capon Springs, Hampshire County, W. Va.,[6] with a temperature of 64° F., and the Berkley Springs, Morgan County, W. Va.,[7] with a temperature of 74° F.

[5] Watson, T. L., Thermal springs of the southeast Atlantic States: Jour. Geology, vol. 32, no. 5, pp. 373-384, 1924.

[6] Tilton, J. L., and others, Hampshire and Hardy counties: West Virginia Geol. Survey, [county reports], pp. 36-38, 1927.

[7] U. S. Geol. Survey Geol. Atlas, Pawpaw-Hancock folio (No. 179), pp. 23-24, 1912.

TEMPERATURE

All springs the mean annual temperature of which exceeds appreciably the mean annual temperature of the air at the mouth of the springs may be regarded as warm springs. The mean annual air temperature in this part of northwestern Virginia varies with the latitude and altitude of the surface above sea-level, ranging between 48° and 54° F. As specific information on the mean annual temperature at each spring is not at hand, it is not possible to draw a hard and fast line between the warm and cold springs, but it has been assumed that all springs in the area under consideration that have a mean annual temperature of 55° F. or more are warm springs. The total number of such springs noted by the writer in the area shown on Plate 1 is 85. Two of these have temperatures above 100° F., namely, the Spout and Boiler springs, at Hot Springs, Bath County, Va., which have maximum temperatures of approximately 105° F. Four other springs at Hot Springs and four at Warm Springs, have temperatures of 91° to 98.6°. Two springs at Healing Springs, 3 miles southwest of Hot Springs, have summer temperatures of about 85° F. The other warm springs have temperatures of less than 80° F. The range in temperature of all the warm springs, as well as of the cold springs, visited by the writer is presented in Table 1. The temperatures used in the grouping are those obtained late in winter, when the temperatures were somewhat below the mean annual temperatures. If all the springs had been revisited during late summer, so that their mean annual temperatures could have been determined, several of the cold springs as listed would have fallen into the group of slightly warm springs. Inasmuch as the grouping is based upon late winter temperatures, there can be no uncertainty as to the source of the heat in the springs that are classed as warm.

TABLE 1.—*Springs of the Virginia thermal springs area grouped according to their temperature*

	Number
Warm springs:	
100 —105.8° F.	2
90 — 98.6	8
77.2— 86	3
60 — 75	27
55 — 59.5	45
Cold springs:	
50 — 54.9° F.	120
35 — 49.5	116

SEASONAL FLUCTUATION IN GROUND TEMPERATURE

The seasonal fluctuation in temperature of springs is related partly to the seasonal fluctuations in ground temperature. The discussion of

the annual range in temperature of the springs is therefore prefaced by some of the data pertaining to seasonal changes in ground temperature. The accompanying graph (Fig. 2) prepared by W. D. Collins and based upon observations of ground temperature by Oishi[8] at Tokyo, Forbes[9] and Heath[10] at Edinburgh, Rambaut[11] at Oxford, and Spence[12] at the University of North Dakota, shows the annual range in ground temperature in the upper 20 feet of the earth's crust in the temperate zone. At the surface the range is evidently closely equivalent to the mean annual range in air temperature and therefore varies widely in the different localities, being greatest at the University of North Dakota, where it is 110° F., and least at Edinburgh, where it is 30° F. From the surface downward the annual range decreases rapidly, being between 6° and 16° F. at a depth of 10 feet, and slightly less than 2° F. at a depth of 20 feet. The curves indicate that at a depth of about 30 feet earth temperatures are approximately constant throughout the year.

SEASONAL CHANGES IN TEMPERATURE OF SPRINGS

In view of the data given above, it is to be expected that springs fed by water circulating in the upper 30 feet of the earth's crust will reflect to some degree the seasonal fluctuation in earth temperature that exists in this part of the crust and that the springs fed by shallow circulating waters will show the greatest annual variation in temperature. Springs fed by waters issuing from depths below 30 feet will presumably also show some change in temperature throughout the year, because the water, in order to reach the surface, must flow upward through the shallow part of the crust which is affected by seasonal changes in temperature. The extent that the temperature of the water of a deep spring is modified during its flow through the shallow part of the crust depends largely upon its volume of discharge and the character of the channel of flow. The greatest modification is possible where the discharge is small and the channel of flow is such that much of the water comes into contact with the rocks.

The question next arises as to when the springs will reach their lowest and highest annual temperatures. Springs fed by waters that have remained in the ground for any length of time will not attain their lowest and highest temperatures in midsummer and midwinter, for the

[8] Oishi, W., Observations of earth temperatures in Japan: Monthly Weather Review, vol. 33, no. 7, p. 300, 1905.

[9] Forbes, J. D., Account of some experiments on the temperature of the earth at different depths and in different soils near Edinburgh: Royal Soc. Edinburgh Trans., vol. 16, pp. 189-236, 1849.

[10] Heath, Thomas, Observations of the Edinburgh rock thermometers: Royal Soc. Edinburgh Trans., vol. 40, pp. 157-186, 1906.

[11] Rambaut, A. A., Underground temperatures at Oxford in the year 1899 as determined by five platinum-resistance thermometers: Royal Philos. Soc. London Trans., vol. 195, pp. 235-258, 1900.

[12] Spence, B. J., Underground temperatures at the University of North Dakota: North Dakota Univ. Quart. Jour., vol. 8, pp. 233-238, 1918.

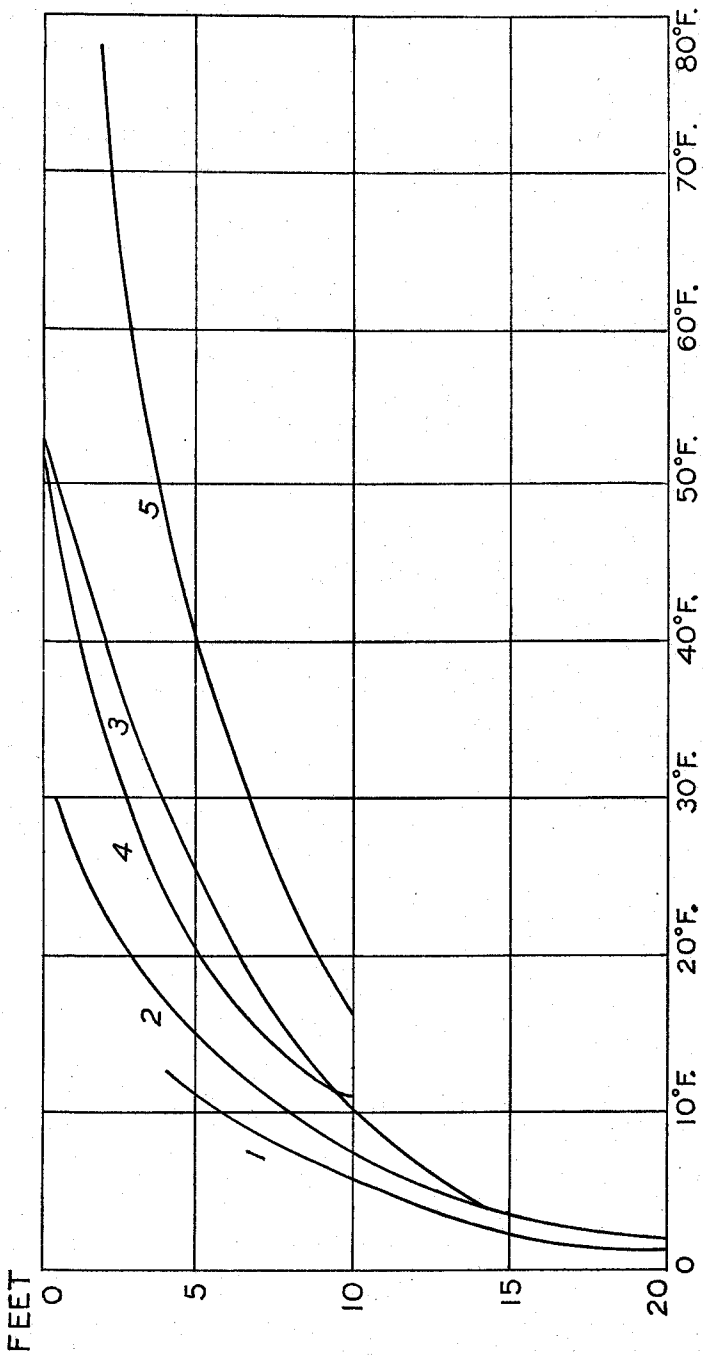


Figure 2.—Annual range in earth temperature due to seasonal climatic changes. (1) Oishi, Tokyo; (2) Forbes, Edinburgh; (3) Heath, Edinburgh; (4) Rambaut, Oxford; (5) Spence, University of North Dakota.

reason that the earth heats up and cools off very slowly. Information as to the lag in earth temperature as recorded by Oishi[13] at Tokyo is given in Table 2.

TABLE 2.—*Seasonal lag in ground temperature*

DEPTH (FEET)	ANNUAL RANGE (°F.)	HIGHEST TEMPERATURE		LOWEST TEMPERATURE	
		DATE	LAG	DATE	LAG
0	50.7	August 11	None	January 23	None
1	40.8	August 16	5 days	January 28	5 days
1.0	33.6	August 21	10 days	January 31	8 days
3.9	25.2	September 15	35 days	February 27	35 days
9.8	9.4	November 6	87 days	May 3	100 days
16.4	2.3	February 2	175 days	July 30	188 days
22.9	0.7	April 30	236 days	October 30	280 days

From these data and those obtained by other observers in the temperate zone in other parts of the world, it is recognized that at a depth of 10 feet maximum and minimum earth temperatures are attained about three months after the maximum and minimum air temperatures, and that at a depth of 16 feet the lag is about six months. As a result of this lag, the effect of ground temperature in modifying the temperature of spring waters rising to the surface is somewhat neutralized. Inasmuch as the temperature changes are not of great magnitude below a depth of 10 feet the modifying effects of earth temperature below this depth are probably not sufficiently great to offset to any extent the temperature changes in the shallow zone. Even in this zone, however, the effects are not concordant. An examination of the graph prepared by Spence[14] (Fig. 3) leads to the conclusion that the greatest temperature effects will be attained in the early part of September, when practically the entire upper 10 feet of the earth is still warming up, and that shortly after this period the upper part begins to cool off and to neutralize the continued slight rise in temperature at lower depths. The graph also indicates that the minimum temperature effects will be attained in late February and early March. It is reasonable, therefore, to assume that springs fed by waters whose source is 10 feet or more beneath the surface will attain their maximum and minimum temperatures about the first of September and the first of March, respectively. Shallower springs, of which there are few, will attain their maximum and minimum temperatures in July and February, respectively. Springs of very small discharge will probably be warmest and coolest nearer the period of maximum and minimum air temperatures, for the temperature variations of these springs are due more to the direct effect of air temperature than to earth temperature. Springs that are fed by streams which have been

[13] Oishi, W., Observations of earth temperatures in Japan: Monthly Weather Review, vol. 33, no. 7, p. 300, 1905.
[14] Op. cit., p. 236.

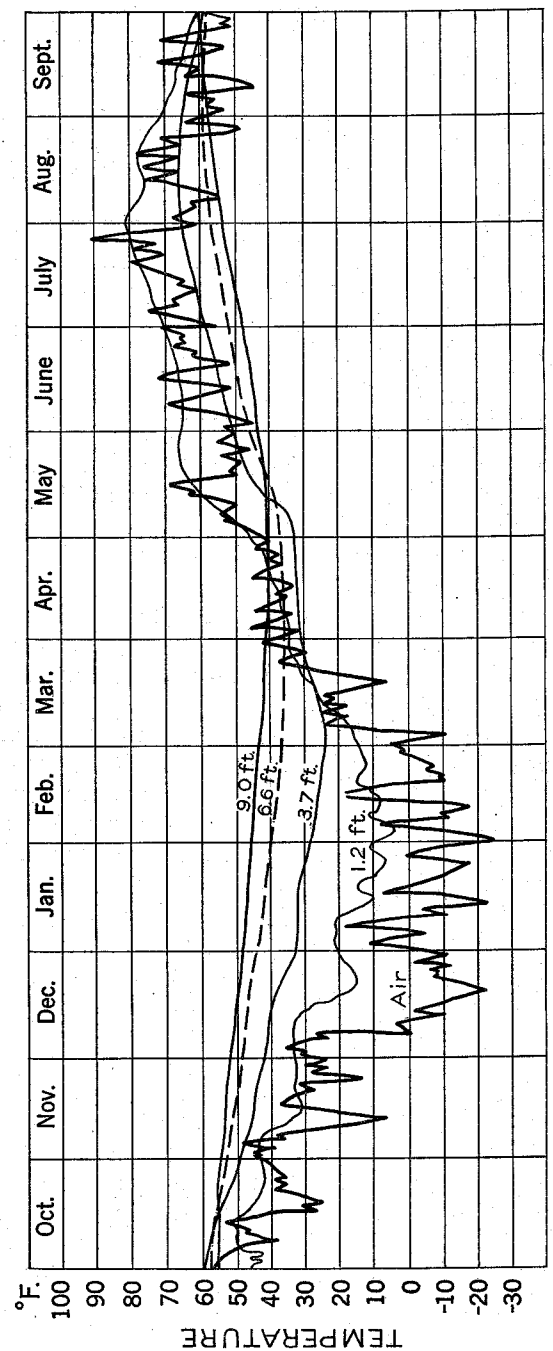


Figure 3.—Seasonal changes in ground temperature at the University of North Dakota. Depths shown are 1.2, 3.7, 6.6, and 9.0 feet. (After Spence.)

underground for too short a distance to attain the temperature of the ground reflect, to a considerable extent, changes in air temperature. In all springs, except those of very small discharge, the direct effect of air temperature can be eliminated by taking with a maximum thermometer the temperature of the water where it first enters the spring basin.

The data obtained on the annual range in temperature of the springs under investigation are presented below. It is probable that at the time the springs were first visited, during February and March, most of them were at about their lowest yearly temperature, and that during the second visit, in September, they were approximately at their highest temperature. The difference in the temperature on the two visits therefore probably represents with fair accuracy the annual range in the temperature of the springs. The temperature observations are recorded in Table 7, and the differences between the late winter and late summer temperatures are shown graphically in Plate 2. Of the 106 springs whose temperature was observed during the two periods, all but two showed higher temperatures in September than in late winter. The two that showed lower temperatures are Nos. 189 and 268, in which the summer temperatures were, respectively, 0.6° and 0.2° F. less than the winter temperatures. A study of the diagram reveals, as was to be expected, that the cold springs, because of their shallow source, have a greater range in temperature than the warm springs. The average range of the 49 springs having temperatures below 55° is 5.7°, whereas for the 57 springs having temperatures above 55° the range is 2.2°. It is evident also that the springs of small discharge, because of the fact that they are readily affected by air temperatures generally show a greater range than those of large discharge. The cold springs of large discharge that show a range distinctly above the average, such as Nos. 15, 79, and 137, are the outlets of streams that have gone underground. The considerable range of spring No. 8 is attributable to the fact that the water has flowed a mile through pipe buried a few feet beneath the surface.

The cause of the considerable range in temperature of some of the warm springs of large discharge, such as Nos. 78 and 134, is discussed in the following paragraphs.

DAILY AND OTHER CHANGES IN TEMPERATURE OF SPRINGS

Although there are not sufficient consecutive records of the temperature of the springs to furnish a basis for a thorough discussion of the daily range in their temperature, it appears probable that only very small springs and those fed by underground streams vary much in temperature throughout the day, for only such springs could be affected to any appreciable extent by daily change in air temperature. The records made by the thermograph installed by W. D. Collins on Spout

and Boiler springs, at the Homestead Hotel, Hot Springs, Virginia, show practically no variation in daily temperature for Boiler Spring. Spout Spring, however, declined in temperature 3° to 5° during periods when water was pumped from the spring. This was due probably to seepages of cold water into the spring resulting from the lowering of head during pumping. Because of other marked changes in the temperature of this spring, the hotel managers have recognized for some time that cold water was entering this spring. It appears possible, therefore, to recognize the warm springs that are being mixed with cold water from shallow depths, for such springs will probably show variations in temperature that other warm springs do not show. Presumably the temperature of a warm spring of mixed waters will rise during dry periods and fall during wet periods, or at least as soon thereafter as the rainfall is reflected in the discharge of the springs. Pronounced fluctuation in the discharge of warm springs is therefore itself an indication of the mixed source of the water. From the information at hand it appears that most warm springs show very slight variation in discharge. This evidence, together with the fact that the temperature of practically all the springs in which observations were made was higher in late summer than in late winter, leads the writer to conclude that few of the warm springs are being mixed with cold water from shallow sources. Springs Nos. 78, 126, and 134 of Table 7, however, show pronounced variation in temperature as well as in discharge and are probably fed by waters of mixed source.

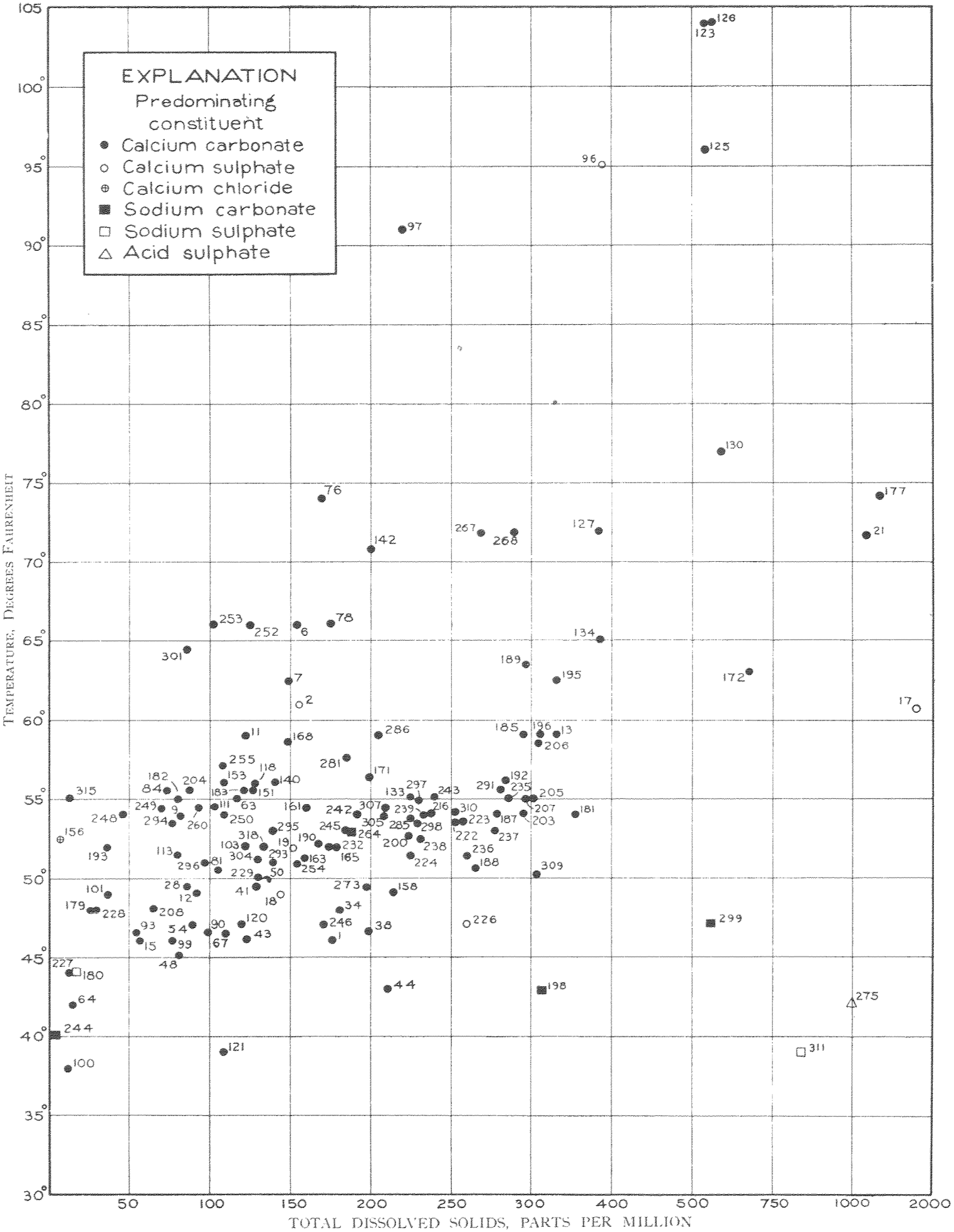
Another factor which theoretically may result in slight fluctuations in the temperature of both cold and warm springs is the rate of evaporation of the water at the outlet of the spring. This factor probably has no effect except in small springs that issue as diffuse seepages. The cooling effect of evaporation in such seepages may be considerable on hot, dry, windy days and may be more than sufficient to offset the heating effect of the air on such days.

CHANGES IN TEMPERATURE OF SPRINGS DURING MANY YEARS

The question whether the warm springs are slowly cooling can not be definitely answered, but the data at hand indicate that there has been no marked change during the last 100 years. Observations of the temperature of some of the principal warm springs here under consideration were made by Rogers[15] in 1834 to 1838 and by Watson[16] in 1923. These observations, together with those made at the same springs by the writer, are recorded in Table 3. The temperature readings of the

[15] Rogers, W. B., On the connection of thermal springs in Virginia with anticlinal axes and faults: Assoc. Am. Geologists and Naturalists, Report of 1st, 2d, and 3d meetings, pp. 328-330, 1840-42. A reprint . . . . geology of the Virginias, pp. 577-597, New York, 1884.

[16] Watson, T. L., Thermal springs of the southeast Atlantic States: Jour. Geology, vol. 32, no. 5, p. 378, 1924.



Relation between mineral content, chemical character, and temperature of springs in the Virginia thermal springs region. Numbers refer to springs in Table 7 and on Plate 1.

warm springs in Bath County, made by Watson during the summer of 1923, vary but slightly from those made by the writer in the late summer of 1928. Likewise, the temperature observations made by Rogers nearly 100 years ago show no differences other than those attributable to seasonable changes and to the use in the earlier reading of unstandardized thermometers.

TABLE 3.—*Temperatures of warm springs in Virginia and West Virginia observed at different periods*

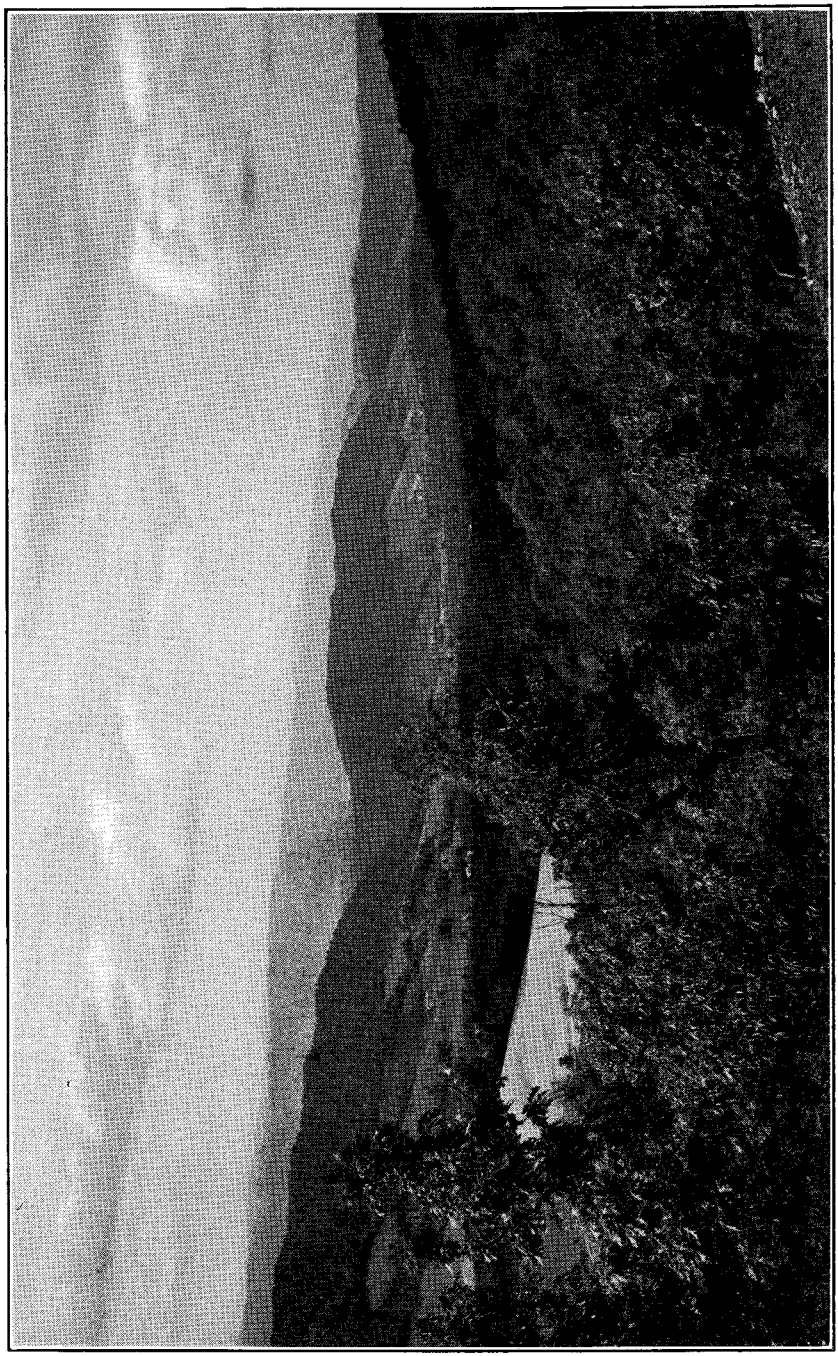
No. [a]	NAME	LOCATION	TEMPERATURE (°F.)				
			1834-38 (Rogers)	Summer 1923 (Watson)	1928 (REEVES)		
					Winter	Summer	Autumn
7	Curry	Huntersville, Pocahontas County, W. Va	61.5	.....	62.5	64.2	63
17	White Sulphur	White Sulphur Springs, Greenbrier County, W. Va	65	.....	60.5	63.5	.....
21	Old Sweet	Sweet Springs, Monroe County, W. Va	74	.....	71.8	73.4	.....
78	Bolar	Bolar, Highland County, Va	71	.....	66	68.8	71.8
94	Ladies' pool	Warm Springs, Bath County, Va	.....	95	94	95.3	.....
95	Drinking fountain	Warm Springs, Bath County, Va	96	95.5	95	95.3	95.5
96	Gentlemen's pool	Warm Springs, Bath County, Va	97.5	95.9	95.2	96.2	96
122	Octagon	Hot Springs, Bath County, Va	.....	98.6	95.1	98.6	98.6
123	Boiler	Hot Springs, Bath County, Va	106	104.9	104	104.9	104.5
124	Hot Sulphur	Hot Springs, Bath County, Va	.....	98.6	97.3	98.5	97
125	Magnesia	Hot Springs, Bath County, Va	.....	95.9	95.8	96.5	95.9
126	Spout	Hot Springs, Bath County, Va	108	105.8	100	105	105.8
130	Drinking	Healing Springs, Bath County, Va	83	83.3	77.2	84.2	83
131	Bathing pool	Healing Springs, Bath County, Va	74	81.9	.....	84.2	78
132	Bottling	Healing Springs, Bath County, Va	85	86	.....	86	85
134	Falling	Southwest end of Warm Springs Valley, Alleghany County, Va	62	.....	65	66.7	74
177	Sweet Chalybeate	Sweet Chalybeate, Alleghany County, Va	78	.....	74.2	76.1	.....
252	Panther Gap	Panther Gap, 2½ miles west of Goshen, Rockbridge County, Va	62	.....	66	66.2	66
267	Lithia	Rockbridge Baths, Rockbridge County, Va	70	.....	71.8	72.1	.....

[a] Numbers of springs refer to designation in Table 7.

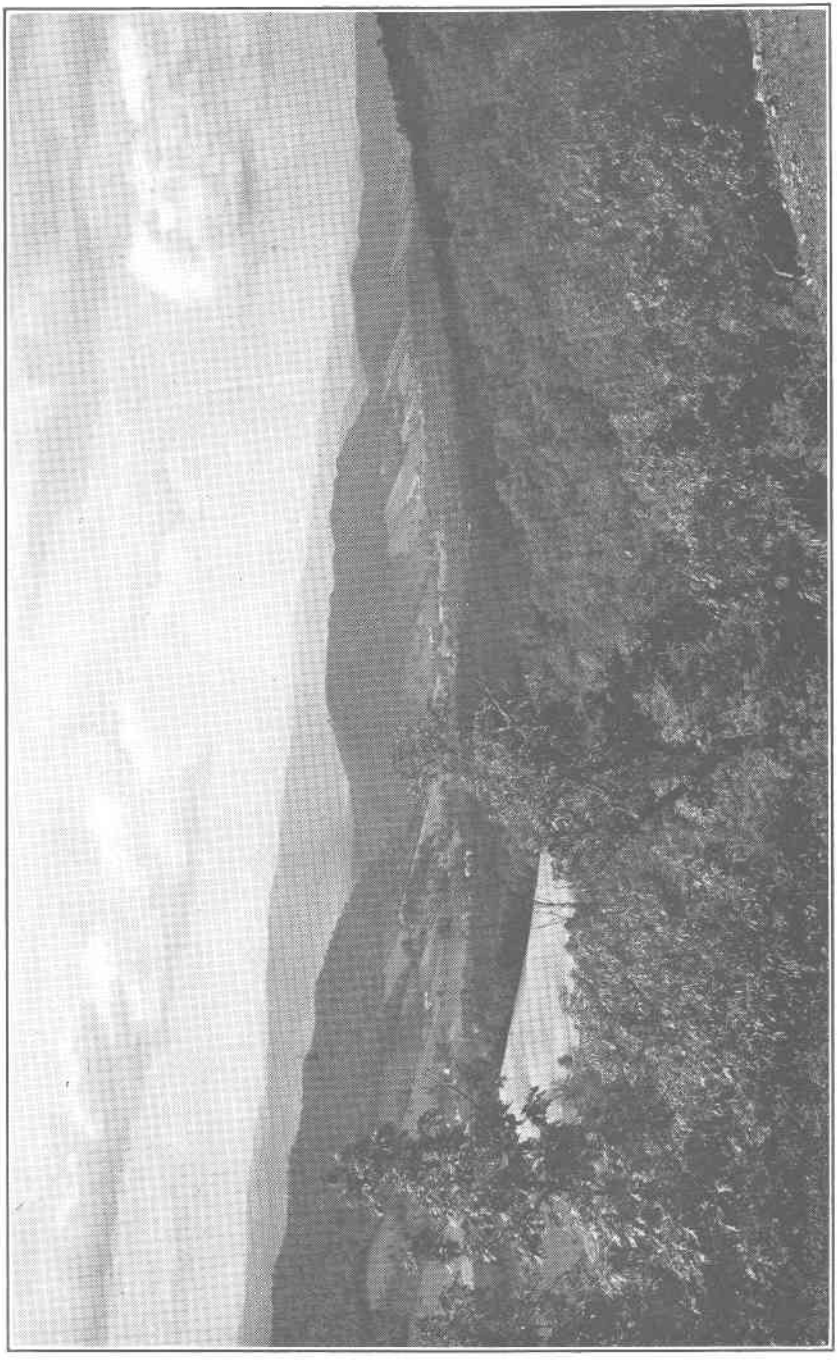
DISCHARGE

The discharge of the warm springs ranges from slow seepages of 1 to 2 gallons a minute to voluminous flows of several thousand gallons a minute. The group of six springs on the Homestead Hotel grounds at Hot Springs, which includes the hottest springs in the region, has a combined flow of approximately 300 gallons a minute. Those at Warm Springs, in the same valley, which are but slightly lower in temperature, have a combined flow of 1,000 to 1,200 gallons a minute. Most of the other warm springs have flows of several hundred gallons a minute, and many exceed 1,000 gallons a minute. Falling Springs, with a temperature of 65°-74°, has the largest flow of all the warm springs, its total discharge being between 6,000 and 7,000 gallons a minute. (See Pl. 6, A.) The warm springs having the smallest discharge are those at Healing Springs, Bath County, Va., and at White Sulphur Springs, Greenbrier County, W. Va., the discharge of the individual springs being but 1 to 2 gallons a minute. The difference in flow of the springs can not be correlated, as far as the writer could determine, with any visible features, such as stratigraphic occurrence or topographic position.

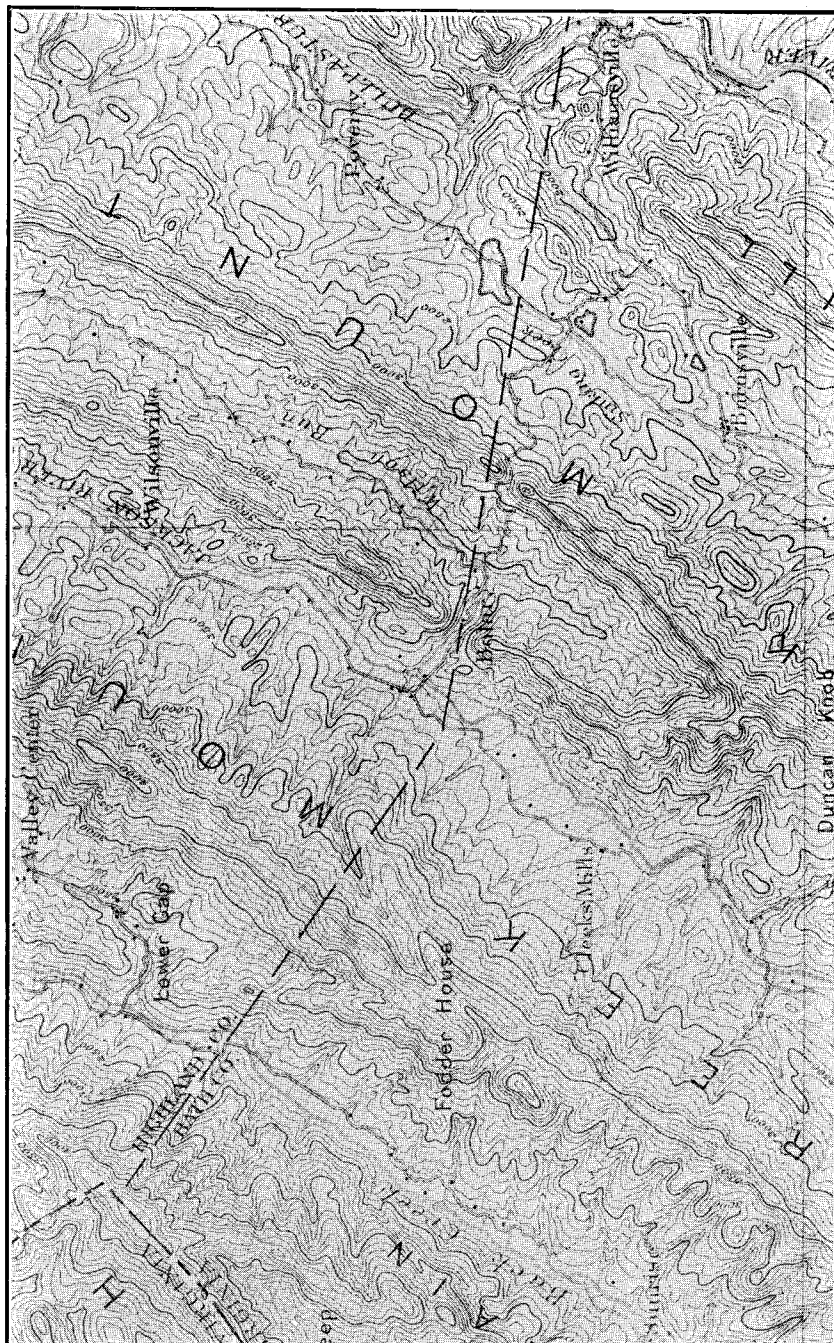
The relation of mineral content and temperature to discharge of individual springs can not be determined except by a series of observations distributed through a period of several months. From the writer's observations, made during his late winter and late summer visits to the springs, he concludes that the discharge of most of the warm springs is fairly constant throughout the year, and this conclusion is corroborated by statements of most of the owners of the springs. The only warm springs showing a marked fluctuation are Bolar and Falling springs. It is possible, of course, that a detailed study of the springs would reveal at least a slight seasonal variation in their discharge.



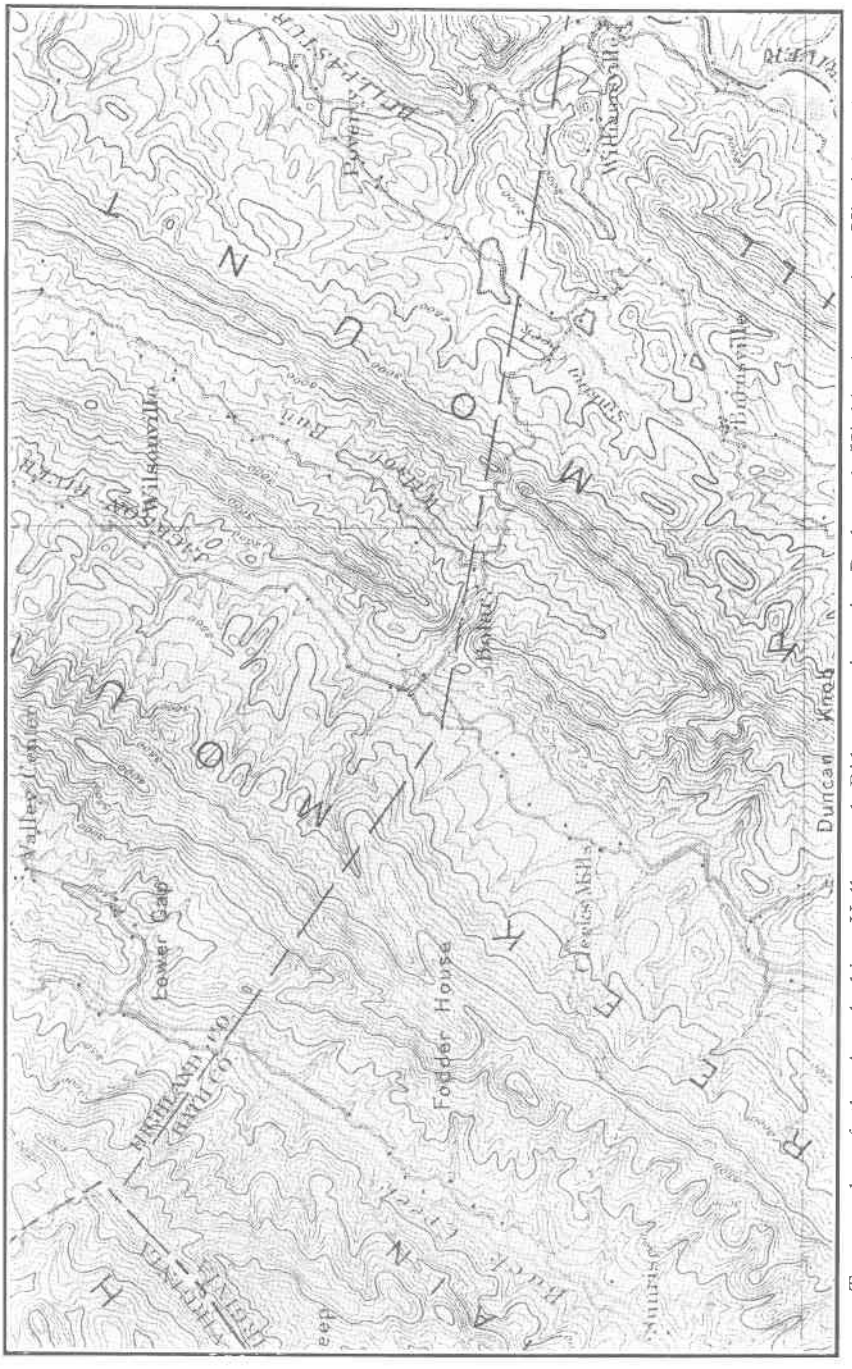
Warm Springs Valley, Bath County, Virginia. The valley has been eroded on an anticline with Silurian (Clinch) sandstone in the flanking ridges and Lower Ordovician limestones on the Valley floor. Looking northwest from Warm Springs Mountain. (See p. 21.) Photograph by H. A. Strohmeyer, Jr. (Courtesy of Virginia Department of Agriculture and Immigration.)



Warm Springs Valley, Bath County, Virginia. The valley has been eroded on an anticline with Silurian (Clinch) sandstone in the flanking ridges and Lower Ordovician limestones on the Valley floor. Looking northwest from Warm Springs Mountain. (See p. 21.) Photograph by H. A. Strohmeyer, Jr. (Courtesy of Virginia Department of Agriculture and Immigration.)



Topography of the Appalachian Valley and Ridge province in Bath and Highland counties, Virginia. (Part of Monterey sheet.) Scale, 1 inch equals about 2 miles; contour interval, 100 feet. (See p. 21.)



Topography of the Appalachian Valley and Ridge province in Bath and Highland counties, Virginia. (Part of Monterey sheet.) Scale, 1 inch equals about 2 miles; contour interval, 100 feet. (See p. 21.)

CHEMICAL CHARACTER OF THE SPRING WATERS

The following discussion of the chemical composition of the spring waters is furnished by Miss M. D. Foster, who analyzed the samples collected from the springs.

"Analyses of more than 150 waters from springs in the Hot Springs region, made in the water resources laboratory of the United States Geological Survey, indicate that most of the springs of the region yield waters in which calcium carbonate predominates, with a low content of sodium and chloride. The sulphate content is usually low, although it varies over a wide range. The amount of mineral matter in solution ranges from less than 25 to more than 2,500 parts per million. Most of the waters, however, contain less than 300 parts per million. Only five springs had a mineral content of more than 1,000 parts per million. The analysis of Seahorn Spring (No. 285), near Collier Creek post office, Rockbridge County, Va., a typical spring of the region, is shown graphically in Figure 4.

"As shown in Plate 3, there is no definite relationship between mineral content and temperature, although most of the waters that contained more than 300 parts per million of dissolved mineral matter came from warm springs. A few of the cold spring waters were among the most highly mineralized of the samples analyzed, but these were unusual waters from shale in which sulphate rather than bicarbonate predominates. In chemical character the waters of the warm springs are similar to those of the cold springs, the higher mineral content of some of the warm springs being due to relatively greater amounts of calcium bicarbonate and calcium sulphate, which may be attributed to longer contact with the rocks at higher temperatures because of deeper percolation.

"In general the waters from the Oriskany sandstone are less highly mineralized than those from limestone or shale, though both limestone and shale yield some waters of very low mineralization. Some of these samples may have come from shallow springs and may represent water that has been in contact with rock materials only a short time and thus has had little opportunity to take mineral matter into solution. Most of the shale spring waters analyzed contained less than 25 parts per million of sulphate, but six, all from cold springs of very small flow, contained more than 95 parts per million of sulphate with relatively small amounts of bicarbonate. The waters of high sulphate content from warm springs were all from limestones and were characterized by high bicarbonate as well as high sulphate. The high sulphate content of these springs probably results from the alteration of pyrite to ferrous sulphate by the action of oxygen. On contact with water the ferrous sulphate is hydrolyzed, with more or less complete precipitation of ferric oxide and

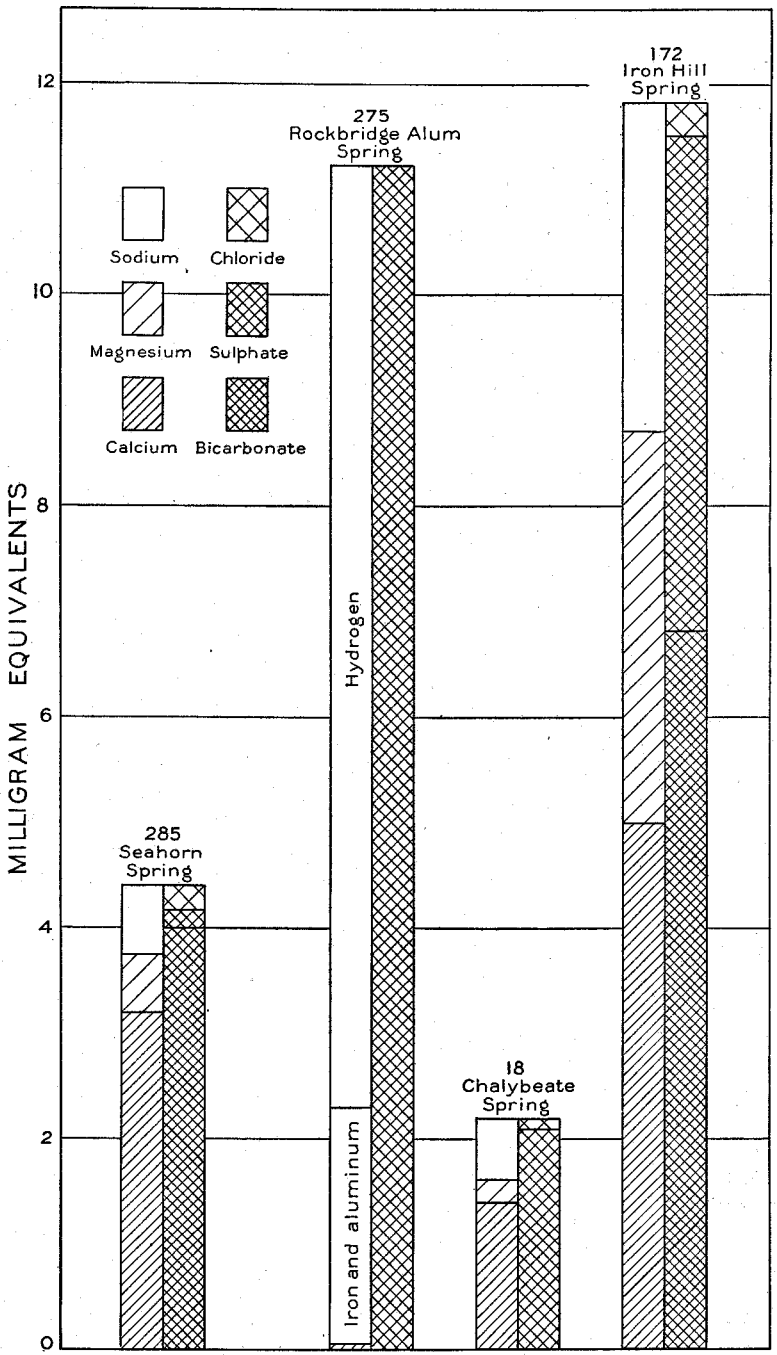


Figure 4.—Analyses of types of springs in the thermal springs region of Virginia. Numbers refer to springs on Plate 1 and in Table 7.

the formation of free sulphuric acid. These acid solutions act strongly on the other rock constituents with progressive neutralization of the acid by carbonates, finally producing, if in contact with rock long enough, an alkaline water of high sulphate content. The sulphates contained in natural waters are largely derived from this source, at least primarily. All steps in this action were found among the waters analyzed from this region. Three are shown graphically in Figure 4.

"No. 275 is an acid water from Rockbridge Alum Spring, at Rockbridge Alum post office, Rockbridge County, Va.

"No. 18 is a water which is practically at the neutral point and represents the Chalybeate Spring at White Sulphur Springs, Greenbrier County, W. Va.

"No. 172 is an alkaline water of high sulphate content from Iron Hill Spring, near Sweet Chalybeate, Rockbridge County, Va. The first two of these springs issue from shale; the third from limestone. All have a very small discharge.

"Analyses of a few of the more important warm and hot springs of the region are shown in Table 4."

TABLE 4.—*Analyses of waters from warm springs in Bath County, Virginia* [a]

(Margaret D. Foster, Analyst.)

Composition (Parts per million)	Boiler Spring at Hot Springs (No. 123) [b]	Soda Spring at Hot Springs (No. 127)	Drinking Spring at Warm Springs (No. 95)	Drinking Spring at Healing Springs (No. 93-B)	Falling Spring (No. 134)
Silica (SiO_2)	24	16	24	25	20
Iron (Fe)	.30	.15	.11	.30	.13
Calcium (Ca)	138	102	118	140	153
Magnesium (Mg)	38	24	22	38	31
Sodium (Na)	7.4	4.4	6.5	8.4	7.4
Potassium (K)	6.6	5.1	2.4	7.3	6.5
Carbonate (CO_3)	0	0	0	0	0
Bicarbonate (HCO_3)	455	330	192	471	310
Sulphate (SO_4)	131	90	228	131	261
Chloride (Cl)	3.0	2.2	2.4	3.6	2.9
Nitrate (NO_3)	.05	.75	0	0	1.7
Total dissolved solids	586	423	525	596	672
Total hardness as $CaCO_3$ (calculated)	501	353	385	506	510

a Samples collected in July, 1929.
b Numbers of springs refer to designation in Table 7.

Hot Sulphur, Spout, and Magnesia springs, at Hot Springs, Va., are similar in composition to Boiler Spring. Cold Magnesia Spring is much lower in mineral content.

The hot springs whose temperature is above 80° seem to remain constant in composition through the year, but those having a temperature below 80° seem to vary in composition from time to time.

GAS CONTENT OF THE SPRING WATERS

In most of the warm springs and many of the cold springs a noticeable amount of gas escapes from the bottom of the springs, rising to the surface of the water in large bubbles. Samples of these gases were collected from eight springs that showed a wide range in temperature and were analyzed by the United States Bureau of Mines. The results of the analyses are given in Table 5. The gases present are those found in the atmosphere, and although only one sample (No. 195) contains them in approximately the same proportions as in the atmosphere, the variation shown is attributable to the different chemical reactions possible between the gases and the minerals in solution in the water.

TABLE 5.—*Analyses of gases collected from warm springs of Virginia and West Virginia*

(By U. S. Bureau of Mines.)

SPRING	CO_2	O_2	CH_4	C_2H_6	N_2	He
21	22.72	0.31	Trace	0	76.97	Trace
23	1.45	10.66	0	0	87.89	0
131	6.18	1.82	0	0	92.00	Trace
122	7.27	11.68	0	0	81.05	Trace
95	1.65	.13	0	0	97.22	0
267	1.45	10.07	0	0	88.48	0
252	.36	11.26	0	0	88.38	0
195	1.36	22.59	0	0	76.05	0

21 Old Sweet Spring, Sweet Springs, Monroe County, W. Va.
23 Lynside Spring, 3 miles west of Sweet Springs, Monroe County, W. Va.
95 Warm Springs, 0.6 mile northeast of Warm Springs post office, Bath County, Va.
122 Octagon Spring, Homestead Hotel, Hot Springs, Bath County, Va.
131 Bathing pool, Healing Springs post office, Bath County, Va.
195 Dices Spring, 1 mile southeast of Burketown, Augusta County, Va.
252 Easternmost of 3 springs in Panther Gap, 1.6 miles west of Goshen, Rockbridge County, Va.
267 Lithia Spring, Rockbridge Baths, Rockbridge County, Va.

GEOLOGY OF THE THERMAL SPRINGS

TOPOGRAPHY OF THE REGION

The thermal springs under consideration are situated in that part of the Appalachian Highlands that lies between the Blue Ridge, on the east, and the Allegheny Front, which has generally been referred to as the Appalachian Valley and is now designated by some physiographers[17] the Valley and Ridge province. This province where it crosses Virginia and West Virginia has a northeasterly trend and is 50 to 60 miles wide. Its eastern part consists of a broad fertile valley, generally referred to as the Valley of Virginia, which is a valley only in the sense that it lies 2,000 to 3,000 feet below the summits of the Blue Ridge on the east and of the mountain ridges on the west. Actually it has considerable relief, and its altitude in most areas is 1,000 to 1,500 feet or more above sea-level. West of the Valley of Virginia is a series of northeastward-trending mountain ridges and narrow valleys, known as the Valley Ridges. (See Pl. 4.) The summits of the ridges, which are commonly 3,500 to 4,000 feet above sea-level, make a fairly uniform sky line and are regarded as the remnants of a former peneplain surface. (See Pls. 4 and 5.) The surfaces of the intermontane valleys are more irregular and in most places lie between 2,000 and 2,500 feet above sea-level.[18]

AREAL AND STRUCTURAL GEOLOGY

The principal features of the areal and structural geology of the region are shown on the geologic map (Pl. 1) which is based upon data derived from Folios 14 and 61 (Staunton and Monterey quadrangles) of the Geologic Atlas of the United States, by the United States Geological Survey, the 1928 edition of the geologic map of Virginia, by the Virginia Geological Survey, the geologic map of Monroe and Pocahontas counties, W. Va., by the West Virginia Geological Survey, reconnaissance mapping in Greenbrier County, West Virginia, by the writer, and recent unpublished mapping in the Appalachian Valley and Ridge province in Virginia by Butts. In the eastern part of the region the rocks that crop out are chiefly dolomite and limestone, which are less resistant than the other rocks of the region and hence have been eroded more to form the lowland known as the Valley of Virginia. These limestones are folded and thrust faulted, as is indicated in a general way by section A-A' of Plate 1. In the part of the Valley and Ridge province to the northwest of this valley the surface strata con-

[17] Fenneman, N. M., Physiographic divisions of the United States: Annals Assoc. Am. Geog., vol. 18, no. 4, pp. 274, 296-301, 1928.

[18] Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, pp. 16-24, 1919.

Wright, F. J., The physiography of the upper James River basin in Virginia: Virginia Geol. Survey Bull. 11, 67 pp., 1925.

sist principally of Devonian and Silurian limestones and sandstones, the underlying Ordovician rocks being exposed only in a few narrow belts. As illustrated in the cross sections (Pl. 1), the strata in this part of the province are folded into a series of narrow anticlines and synclines with a northeasterly trend. On the limbs of the anticlines the strata are tilted at steep angles, in some localities occupying vertical or overturned positions on the northwest limbs, and in a few being cut by thrust faults. (See Pl. 1.) The erosion of these highly tilted strata, which vary greatly in their resistance to erosion, gives rise to the alternation of ridges and valleys that is the characteristic physiographic feature of the province. (See Pl. 5.) Wherever folding of the strata has been sufficient to bring the Ordovician limestones to the level of denudation, especially in the northwest belts of the Valley Ridges, as in the Warm Springs anticline, in Alleghany and Bath counties, Va., the crest of the anticline is a narrow valley flanked by high mountain ridges marking the outcrop of the resistant Silurian rocks. (See Pl. 4.) In some of the synclines the downfolding has been sufficient to bring strata of late Devonian and early Carboniferous age below the level of peneplanation. Inasmuch as these strata are also relatively resistant to erosion, the synclines in which they are present also form mountain ridges.

STRATIGRAPHY

Alluvium and calcareous marl.—The youngest strata in the region are the alluvial deposits that fill stream bottoms and the warm spring deposits of calcareous marl. The latter are composed largely of calcium carbonate precipitated from solution by the warm spring waters. They have no great extent, being mostly limited to small patches a few feet wide and possibly several hundred feet long in the valleys of streams fed by warm springs. Not all the warm springs have formed such marl deposits. Some are forming them at present, and others are cutting away the marl formed at an earlier period. The deposits are also not limited to warm springs, calcareous marls occurring below springs that at present are cold; for example, along Falling Spring Creek, about 6 miles northeast of Covington. (See Pl. 6.)

Mississippian strata.—The bedrock formations of the region are given in Table 6. With the exception of the alluvium and calcareous marls, the youngest strata present in the region are of early Mississippian age. These beds consist of a few hundred feet of sandstone and sandy shale (Pocono formation) which have been preserved in the synclinal areas and partly on the summits of knobs in such areas. Small cold springs issue at the base of some of these sandstones, but their limited distribution and occurrence at the summits of the mountains prevent them from being an important source of spring water.

TABLE 6.—*Generalized columnar section of the bedrock formations in the thermal springs region, west-central Virginia*

SYSTEM		FORMATION	APPROXIMATE THICKNESS—FEET
Mississippian		Pocono sandstone	200-800
Devonian		Catskill formation Chemung formation Brallier shale Romney shale Oriskany sandstone Helderberg limestone	3,500-8,000
Silurian		Cayuga limestone Clinton formation Tuscarora (Clinch) sandstone	1,000-1,500
Ordovician		Juniata formation Martinsburg shale Chambersburg limestone Lowville limestone Athens shale Stones River limestone	4,500-6,000
	Canadian	Beekmantown limestone	
	Ozarkian	[a] Copper Ridge dolomite Conococheague limestone	
Cambrian		Elbrook limestone Rome (Watauga) formation Shady dolomite Erwin quartzite Hampton shale Unicoi quartzite	8,000-10,000

a The Copper Ridge dolomite and the Conococheague limestone are probably approximately equivalent.

Devonian strata.—The strata of Devonian age consist of a great mass of shale, sandy shale, limestone, and sandstone having a thickness of 6,000 to 8,000 feet in the northeastern part of the region, and 3,500 to 4,800 feet in the southwestern part. The upper two-thirds of the Devonian consists of sandy shale and hard sandstone (Catskill, Chemung, and Brallier formations). Below is the black carbonaceous shale of the Romney formation and underlying this is the Oriskany sandstone. (See Pl. 6.) In most localities this sandstone is a massive, coarse-grained, loosely cemented rock 100 to 150 feet thick. In other places it is much thinner and finer grained. At its most southwesterly outcrop, in Bath and Alleghany counties, it is reported by Darton[19] to be of greatly reduced thickness and to be probably entirely absent in places. The Oriskany, being at the top of a considerable thickness of resistant strata, forms the outer slopes of some of the mountain ridges,

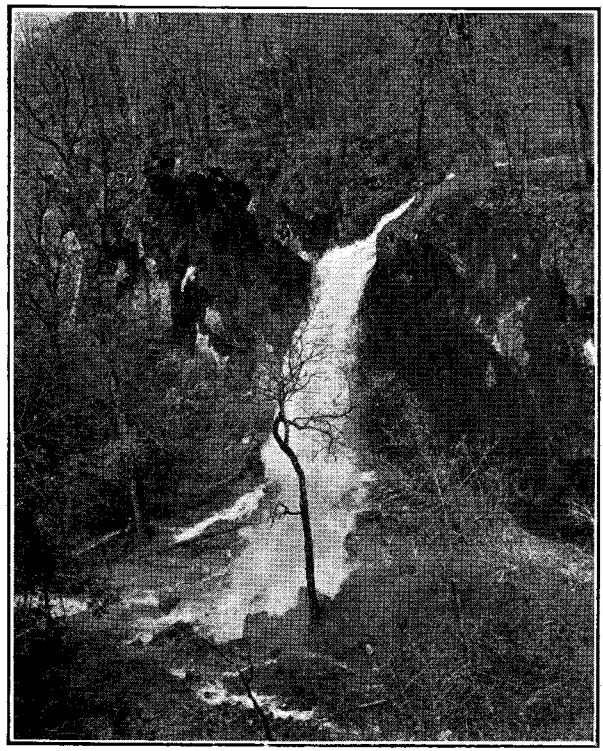
[19] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Monterey folio (No. 61), p. 4, 1899.

in which Silurian sandstone forms the mountain summits and the overlying shales the bordering valleys. Because of the permeability of the Oriskany sandstone and its position at the base of the mountain slopes, numerous cold springs issue from it. It is also the source of several warm springs. The underlying Helderberg limestone is a light to dark bluish-gray thinly to thickly bedded, more or less cherty limestone, with intercalated sandstone strata as much as 100 feet thick in its southwestern development in Alleghany County. Its distribution is about like that of the Oriskany sandstone. It has a thickness of 300 to 500 feet in the northeastern part of the region, and less than half of this in the southwestern part. In Monroe County, W. Va., it is commonly less than 100 feet thick and in some localities is entirely absent. Many cold springs and a few warm springs issue at the outcrop of the Helderberg limestone. In localities where it is exposed considerably above stream level solution channels form in it, permitting underground drainage and the development of caves. (See Pl. 7.)

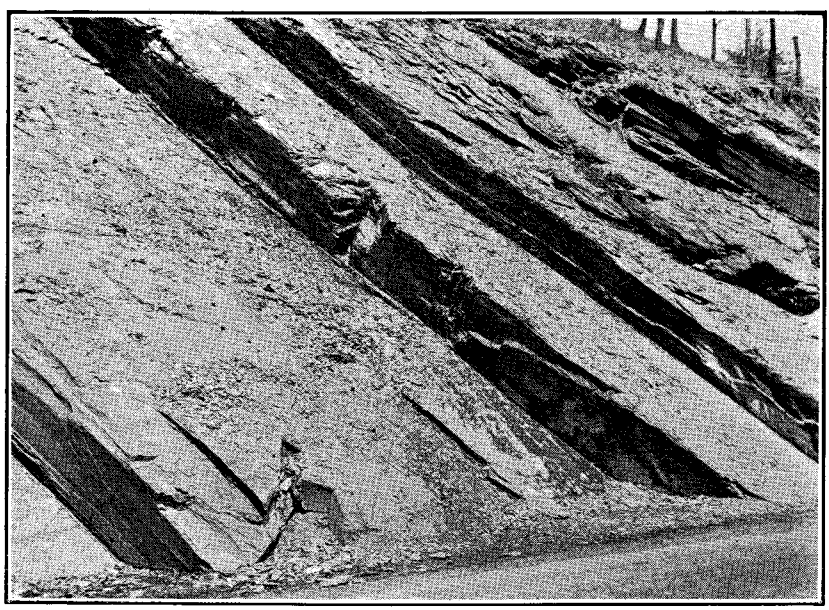
Silurian strata.—The strata of Silurian age consist of 1,000 to 1,500 feet of hard, fine-grained sandstone and sandy shale, with the Clinton and Tuscarora (Clinch) formations in the lower part and the Cayuga limestone, shale, and sandstone above. The lower sandstones are generally quartzites, which are very resistant to weathering, and as a consequence their outcrops form mountain ridges. (See Pl. 4.) Rarely are they sufficiently permeable to yield springs. In the northwestern part of the region and extending southwest as far as Craig County, 100 feet or more of limestone belonging to the Salina series, occurs at the top of the Silurian and yields springs from joints and solution channels.

Ordovician strata.—The Ordovician system consists of 4,500 to 6,000 feet of strata, principally limestone, dolomite, and shale. The top formation is the Juniata, consisting of sandstone and sandy shale. Beneath this is the Martinsburg shale, which consists largely of shale with some fine-grained sandstone in its upper part and limestone and a bentonite bed, or locally several bentonite beds, in its lower part. The sequence of the formations below the Martinsburg varies from place to place, but as a rule it is possible to recognize representatives of the Chambersburg, Lowville, Stones River, and Beekmantown limestones.[20] The limestones and dolomites range from grayish-yellow, irregularly bedded, argillaceous and cherty limestones and dolomites to well-bedded, blue to black limestones and gray dolomites. At their outcrop the limestones and dolomites have a fine-grained crystalline texture, or at least appear to be too dense to permit water to flow through them. Inasmuch as numerous springs issue at the base of hills

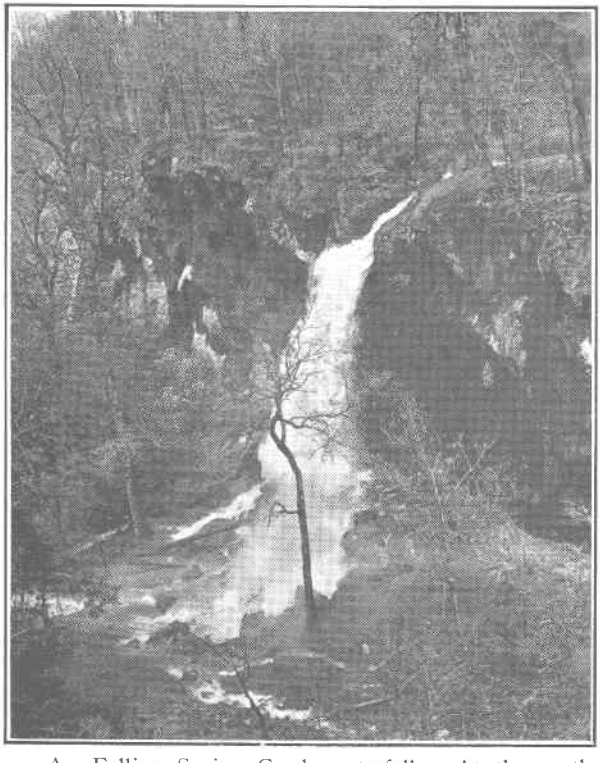
[20] The Beekmantown comprises in this region the Nittany dolomite and younger beds, all of which are included in the Canadian system of Ulrich.



A. Falling Spring Creek waterfalls. At the southwest end of Warm Springs Valley. The cliff is composed of travertine. (See pp. 16 and 22, and Table 7.) Photograph by Arthur Bevan.



B. Devonian (Romney) shale in Alleghany County, Virginia. The beds here dip steeply to the southeast. Photograph by Arthur Bevan.



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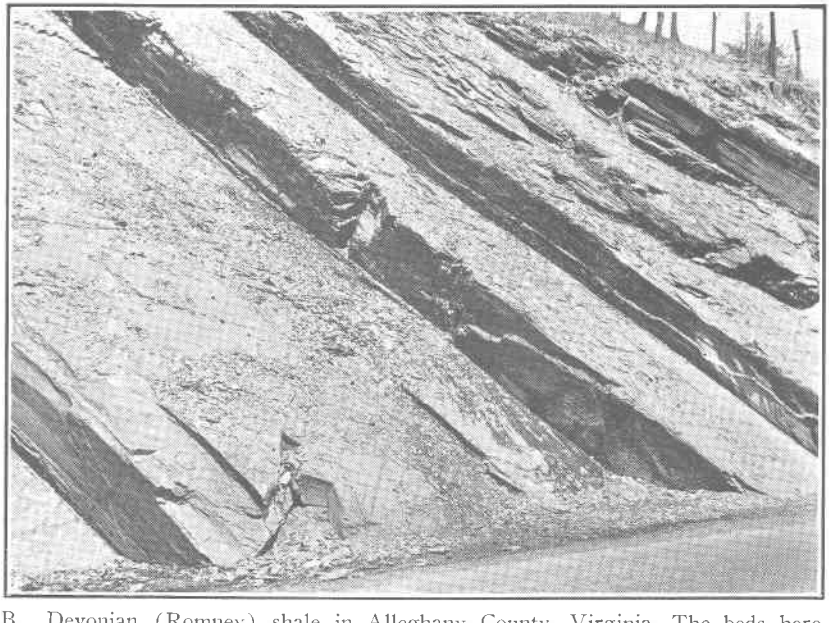

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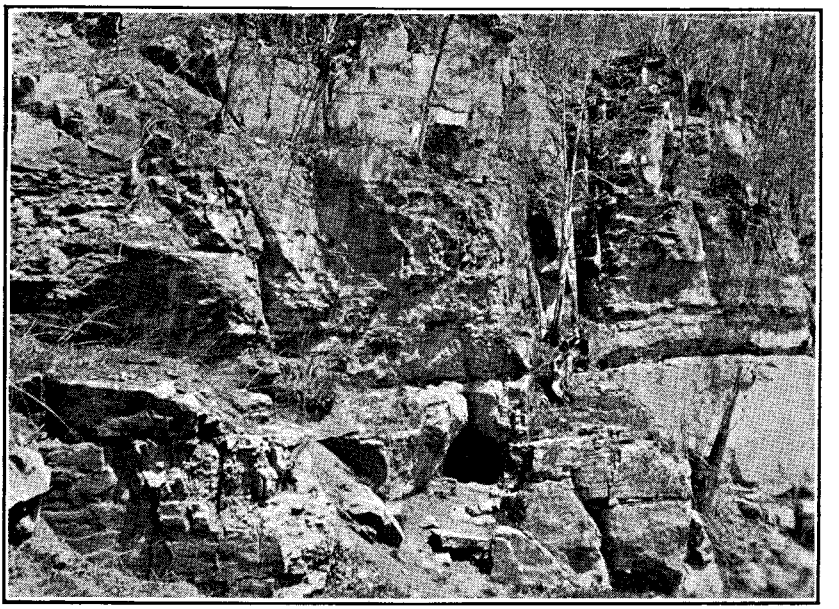
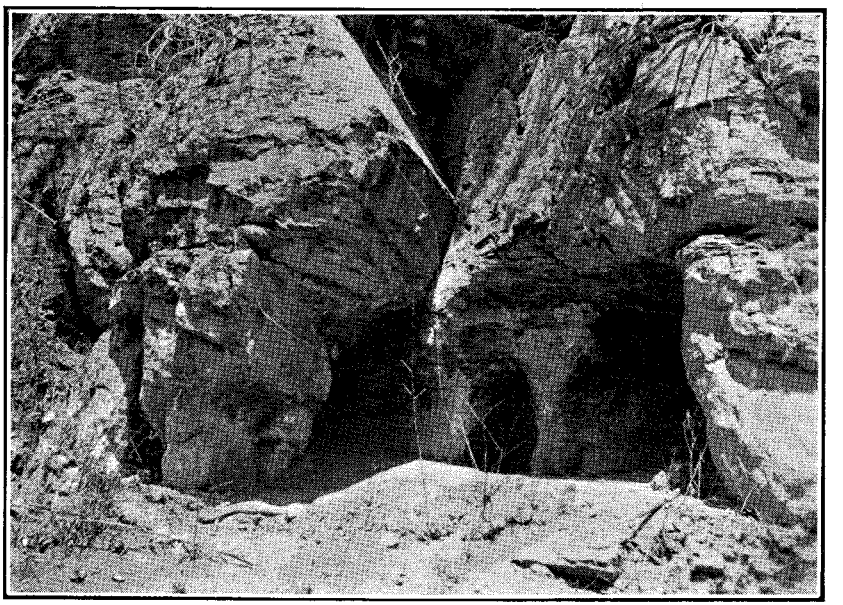
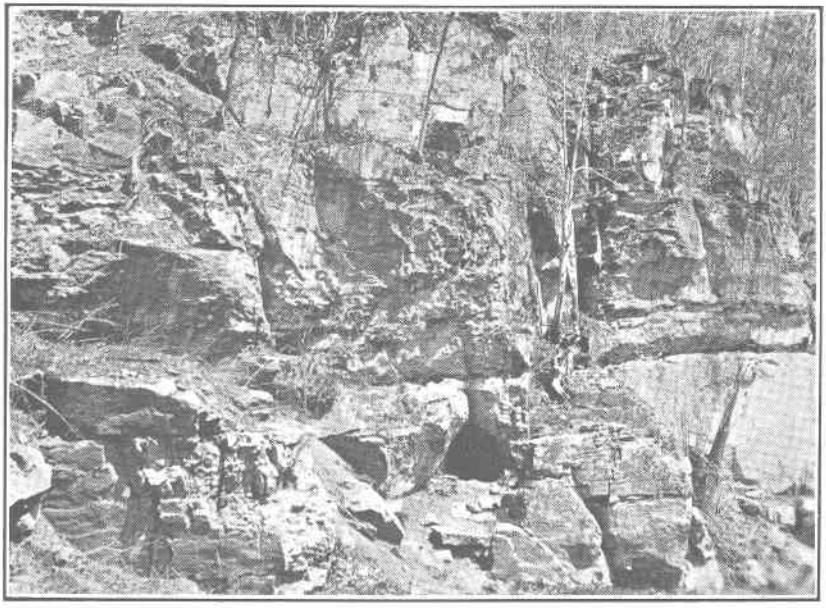


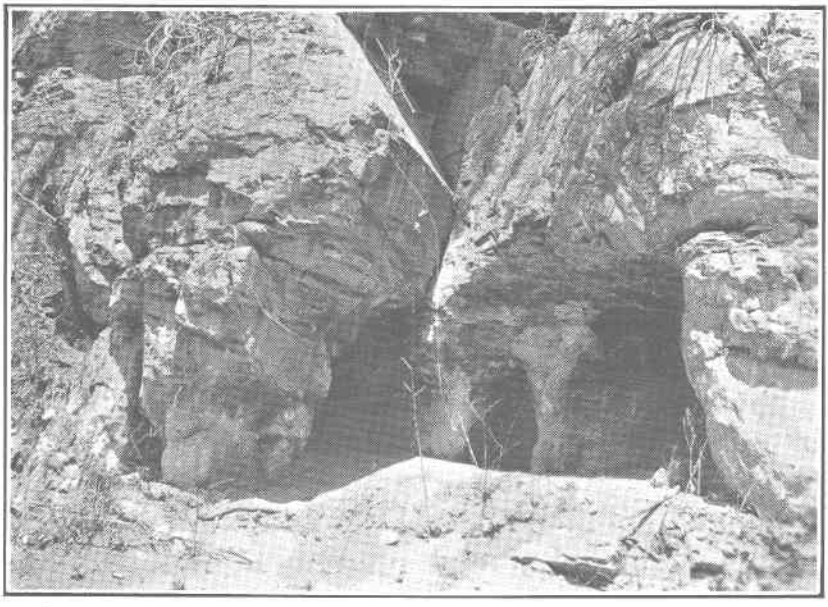
A. Helderberg limestone in Bath County, Virginia, showing local horizontal bedding and numerous joints. (See p. 23.) Photograph by Arthur Bevan.



B. Helderberg limestone showing solution channels along joints. At Blowing Cave, Bath County, Virginia. (See pp. 24 and 29.) Photograph by Arthur Bevan.



A. Helderberg limestone in Bath County, Virginia, showing local horizontal bedding and numerous joints. (See p. 23.) Photograph by Arthur Bevan.



B. Helderberg limestone showing solution channels along joints. At Blowing Cave, Bath County, Virginia. (See pp. 24 and 29.) Photograph by Arthur Bevan.

underlain by these formations, it is evident that water does flow freely through them, but this movement possibly takes place chiefly along joints widened by the solvent action of ground water and is probably confined largely to levels above the water table. There is also evidence that some of the formations, especially the Lowville limestone which yields many warm springs, contain beds of sufficient permeability to permit the circulation of water at levels below the water table.

Cambrian strata.—The Cambrian rocks consist of limestone, dolomite, shale, and sandstone that have a total thickness of 8,000 to 10,000 feet in the Valley of Virginia. Their thickness in the remainder of the Appalachian Valley and Ridge province is not known, because the Cambrian formations are not exposed there. The geologic sequence generally recognized in the Valley of Virginia in the area under consideration is, in descending order, Copper Ridge dolomite or Conococheague limestone,[21] Elbrook limestone, Rome (Watauga) shale, Shady dolomite, Erwin quartzite, Hampton shale, and Unicoi quartzite. The limestones and dolomites yield numerous large cold springs, which are probably fed by water circulating through joints and solution channels lying above the water table. A few moderately warm springs also issue from Cambrian formations.

Igneous rocks.—A few dikes and one or two small irregularly shaped masses that may represent volcanic necks occur in the northern part of the region,[22] being known as far south as the central part of Bath County. The igneous rocks consist principally of basalt and granite-felsophyre. Two miles west of Harrisonburg, in Rockingham County, there is a high hill formed by a peridotite. The age of these intrusive rocks is not definitely known, but they are somewhat similar to the igneous rocks of Triassic age found in the Piedmont region east of the Blue Ridge. There is no evidence to indicate that the igneous rocks are related in any way to the occurrence of the warm springs.

FORMATIONS FROM WHICH THE SPRINGS ISSUE

Numerous cold springs issue at the outcrops of the Oriskany sandstone, the Helderberg limestone, and the limestone formations of Ordovician and Cambrian age. The springs found at the outcrops of the other formations are generally small, most of those in shale formations being simply slight seepages of water relatively high in sulphates. Practically all the warm springs having temperatures above 60° issue

[21] The Copper Ridge dolomite of the western belts and the Conococheague limestone of eastern belts in the Appalachian Valley in Virginia are probably approximately equivalent. They represent here the Ozarkian system of Ulrich.

[22] Darton, N. H., On dikes of felsophyre and basalt in Paleozoic rocks in central Appalachian Virginia, with notes on the petrography by Arthur Keith: Am. Jour. Sci., 4th ser., vol. 6, pp. 305-315, 1898.

Watson, T. L., and Cline, J. H., Petrology of a series of igneous dikes in central-western Virginia: Geol. Soc. America Bull., vol. 24, pp. 301-334, 1913.

at outcrops of the Oriskany sandstone and Helderberg limestone, of early Devonian age, and of the Lowville limestone, of middle Ordovician age. The most notable of the warm springs issuing from the Oriskany sandstone and Helderberg limestone are as follows: The Layton Spring (No. 142), on Jackson River; the Panther Gap Springs (Nos. 251-252); the Lithia Spring (No. 301), on Mill Creek, Botetourt County; and the warm springs occurring along the flanks of the Browns Mountain anticline extending between White Sulphur Springs and Greenbank, W. Va. The principal warm springs that issue from the Lowville limestone comprise the warm springs of the Bolar Spring Valley in Highland County, Va., the Warm Springs and Rich Patch valleys in Bath and Alleghany counties, Va., and probably most of those in the Old Sweet Spring Valley of Alleghany County, Va., and Monroe County, W. Va. The only springs with temperatures above 60° F. that do not issue from the above-mentioned formations are the Rockbridge Bath Springs (Nos. 267-269), Rockbridge County, in the Beekmantown limestone; the warm spring (No. 189) near Bridgewater, Rockingham County, in Chambersburg or Athens limestone; the Dices Spring (No. 195), near Burketown, Augusta County, in the Copper Ridge dolomite; and the Fitzgerald Spring (No. 202), in Augusta County, in the Elbrook limestone.

OCCURRENCE OF WARM SPRINGS IN RELATION TO GEOLOGIC STRUCTURE

Nearly a century ago W. B. Rogers[23] pointed out that the principal warm springs then known in Virginia were located along anticlinal axes. This generalization as to the geologic occurrence of the principal warm springs is corroborated by all the information obtained in the course of the present study. An inspection of the geologic map (Pl. 1) shows that all the warm springs in the Bolar Springs, Warm Springs, Rich Patch, and Old Sweet Springs valleys issue where the Ordovician rocks are brought to the surface by pronounced anticlinal folding. The geologic map also indicates clearly that most of the other warm springs of the Appalachian Valley and Ridge province issue from the Oriskany sandstone and Helderberg limestone at their outcrops on the limbs of anticlines. Because of the lack of published detailed geologic mapping in the Valley of Virginia, the structural positions of the moderately warm springs in that area are not definitely known, but the data at hand indicate that most of them issue where Ordovician and Cambrian formations rise to the surface from considerable depths as the result of anticlinal folding. Some of these anticlines are broken by thrust faults, but there is no positive evidence that any of the warm springs are along faults. Most of the springs of the region undoubtedly are not

[23] Rogers, W. B., On the connection of thermal springs in Virginia with anticlinal axes and faults: Assoc. Am. Geologists and Naturalists, Rept. of 1st, 2d, and 3d meetings, pp. 323-347, 1840-42; A reprint . . . . geology of the Virginias, pp. 577-597, New York, 1884.

so located, and it is probable that few of the springs are fed by waters rising along fault planes or through fissures bordering fault planes.

TOPOGRAPHIC POSITION OF THE WARM SPRINGS

The warm springs invariably are situated at the lowest outcrop above sea-level of the spring-bearing formations in the different anticlines or overthrust sheets. They therefore generally occur in the valley bottoms (Pl. 4) where the major streams have cut water gaps through anticlinal ridges. This fact is brought out to some extent by Plate 1, which shows that all the warm springs are located on the larger streams that head in or flow across the anticlines. As a rule the springs issue either in the valley bottoms a few feet above low-water level or in the stream beds themselves. It is not uncommon to find two or more springs in an alluvium-filled bottom that have an alignment paralleling the strike of the underlying rocks.

SOURCE OF THE HEAT AND WATER SUPPLY OF THE WARM SPRINGS

HYPOTHESIS HELD BY PREVIOUS OBSERVERS

Most observers who have given attention to the problem of the origin of the warm springs agree that the spring waters are of meteoric origin. This is the conclusion reached by Rogers[24] and Watson[25] and the one held by the writer. The chief basis for this conclusion is the similarity in the chemical character of the water from the cold and warm springs and the fact that the dissolved gases are principally of atmospheric origin. No definite agreement as to the source of the heat of these warm springs has heretofore been reached. Rogers[26] held the view that the temperatures are an expression of the earth temperatures normal to the depths at which the waters circulate; but his explanation of the manner in which the circulation was induced is not convincing. In brief, he assumes that the surface water entering the rocks at their outcrop in high anticlinal ridges sinks to considerable depths along joints and fissures until it reaches a permeable bed and then rises along the dip of this bed to its outcrop in an adjacent valley.

Watson,[27] after discussing the various hypotheses that had been offered as to the source of the heat, expressed the view that the final solution of the problem must await more detailed geologic observation.

HYPOTHESIS SUPPORTED BY PRESENT GEOLOGIC STUDY

The data obtained in the present geologic study of the springs make it possible, the writer believes, to present a satisfactory explanation of their origin. This explanation is that the springs are produced by meteoric waters entering a permeable bed along its outcrop at a relatively high altitude on the crest or limb of one anticline and rising to the surface where the same bed crops out at a lower altitude in another anticline, the temperature of the waters being an expression of the normal earth temperature in the deep synclinal basins through which the water circulates. This hypothesis is somewhat similar to the one offered by Rogers in that it attributes the temperature of the springs to normal earth temperature; but it differs from Rogers' hypothesis in that it predicates movement through permeable beds from one anticline to another rather than movement through joints and fissures from an anticlinal ridge to adjacent valleys.

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[24] Rogers, W. B., On the connection of thermal springs in Virginia with anticlinal axes and faults: Assoc. Am. Geologists and Naturalists, Rept. of 1st, 2d, and 3d meetings, p. 333, 1840-42.

[25] Watson, T. L., Thermal springs of the southeast Atlantic States: Jour. Geology, vol. 32, no. 5, p. 383, 1924.

[26] Op. cit., pp. 346, 347.

[27] Op. cit., p. 384.

EXTENT TO WHICH FIELD DATA SUPPORT THE HYPOTHESIS OF ARTESIAN CIRCULATION

A review of the data pertaining to the geologic occurrence of the springs indicates to what extent they support the above suggested hypothesis as to the origin of the warm springs.

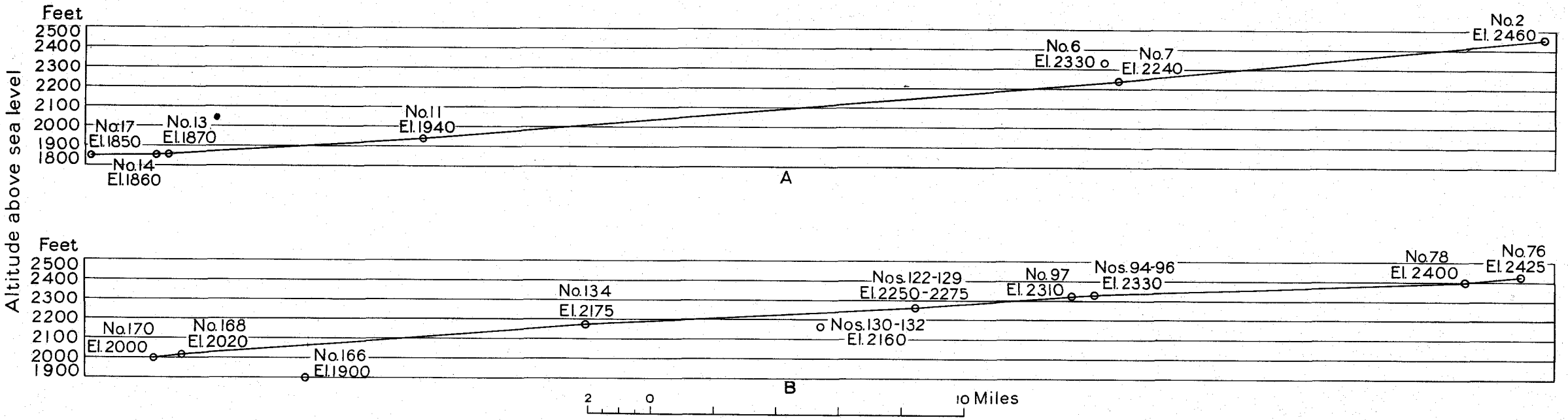
It is evident that the geologic structure, as shown in Plate 1, and the topographic relief (Pls. 4 and 5) of the region decidedly favor such a circulation of ground water. Given permeable beds with such structure and relief, artesian circulation of the type predicated would be the natural consequence. Moreover, it can be shown that practically every geologic feature of the springs fulfills the conditions that the hypothesis requires. These may be summarized as follows: (1) The springs are located where permeable beds, or beds whose lithology suggests permeability, rise to the surface from considerable depths on the axes or flanks of anticlines; (2) their position at the lowest outcrop of these beds in the different anticlines is the position where artesian water would be discharged; and (3) they are found in anticlines where the permeable beds crop out at lower altitudes than in adjacent anticlines.

Relation to permeable beds exposed in anticlines.—There is no question that permeable beds through which ground water could circulate exist in this region and that some of the springs issue from them. In the first place, the Oriskany sandstone and Helderberg limestone contain permeable beds. Numerous large cold springs issue from these formations and they have yielded copious flows of water where they have been penetrated in deep wells in the oil fields of West Virginia and Pennsylvania. The Ordovician and Cambrian limestones and dolomites from which some of the warm springs issue, appear to be too tight-grained to permit an interstitial movement of water. Presumably they can act as aquifers only where they possess a system of connecting joints and fissures. At their outcrops they are undoubtedly much jointed, and it is largely because of this jointing and the solubility of the rocks that their outcrops are marked by sink-holes and caves in high land and cold springs in low land. Possibly they possess connecting joints that are sufficiently open in the deep synclinal basins to furnish continuous channels for the circulation of ground water. There is also a possibility that some permeable sandstones now poorly exposed at the surface may be interbedded with the limestone and dolomite. Whether or not the presence of permeable beds or deep connecting joints can be established from surface observation, the other data pertaining to the occurrence of the springs are so definitely in agreement with the suggested hypothesis, namely, they are due to the artesian circulation of water through synclinal basins, that the capacity of the rocks from which they issue to transmit water either through their pores or along joints and bedding planes is fairly definitely established.

Relation to elevations of outcrops in each anticline.—The fact that the springs are invariably located at the lowest outcrop of the water-bearing formations in the different anticlines indicates clearly that the spring waters issue under an artesian head that is sufficient to raise them only to certain levels and that the channels of circulation are those of a continuous permeable bed. In some places it is possible from observation of the relative altitudes of the springs in a given anticline to determine the general direction of the underground movement, the gradient of the moving water, and the source of intake. An example is afforded by the springs issuing from the Oriskany sandstone and Helderberg limestone at their outcrop along the northwest flank of the anticline extending northeastward from White Sulphur Springs to Green Bank, W. Va. The altitude of these springs from northeast to southwest is shown graphically on Plate 8. They fall practically within a plane having a southwestward inclination of about 13 feet to the mile, which intersects the Oriskany sandstone underground throughout the whole extent of the anticline except at the position of the springs where streams have cut valleys below this plane and tapped the artesian water head. On the southeast flank of the anticline there is only one Oriskany warm spring, that at Minnehaha. This spring has an altitude of 2,330 feet, which is 90 feet above the spring issuing 2½ miles west of it, on the northwest flank of the anticline. It apparently, therefore, is fed by waters subjected to a greater hydrostatic head than the spring water on the northwest flank of the anticline. But this is not surprising, inasmuch as there is no underground connection between the springs on the two flanks of the anticline except around its northeast and southwest ends.

The data presented above suggest that the movement of artesian water in the Oriskany sandstone in this area is southwestward, and that the intake is somewhere toward the northeast. Further consideration of this possibility is deferred to a later paragraph. The other Oriskany warm springs issue at, or but slightly above, the level of the two largest rivers crossing the Appalachian Valley and Ridge province. The position of these springs is mostly attributable to the fact that the waters feeding them are subjected to a hydrostatic head only sufficient to raise them to about these levels. The distribution is too meager to furnish any data as to the direction of movement of the underground waters.

The altitude of the springs issuing from the Lowville formation in the Bolar Springs, Warm Springs, and Rich Patch valleys of Highland, Bath, and Alleghany counties, shows a decline toward the southwest (Pl. 8) of about 10 feet to the mile, indicating a southward movement of the water. The only springs not conforming to the gradual decline are those at Healing Springs (Nos. 130-132) and the Fridley Spring (No. 166). The discordance shown by Fridley Spring



Uniform southwestward decline in altitude of warm springs. A, In the Browns Mountain anticline, West Virginia; B, in Bolar Springs, Warm Springs, and Rich Patch valleys, Virginia. Numbers refer to springs in Table 7 and on Plate 1.

may be attributed to the fact that it lies on the southeast flank of an anticline, whereas all the other springs, with the possible exception of two or three at Hot Springs, lie on the northwest flanks of anticlines and are therefore in more direct communication with the underground flow yielding the springs. No explanation can be offered for the low altitude of Healing Spring, or rather of the fact that, in spite of its low altitude, it has a smaller flow than the other springs on the anticline, except that the permeability of the spring-bearing formation here may be less than elsewhere, or that faulting along the west flank of the anticline may interrupt the movement of water from the adjacent synclines.

The springs in Old Sweet Springs Valley are not widely enough distributed or do not show a sufficient difference in altitude to furnish a basis for any statement as to the direction of movement or intake of the water feeding them. They issue at altitudes of 2,000 to 2,025 feet.

The springs so far discussed in connection with the subject of artesian head comprise most of the springs in the Valley Ridges section of the Appalachian Valley and Ridge province. The lack of detailed geologic and topographic maps makes it impossible to work out a satisfactory analysis of hydrostatic conditions that yield the springs in the Valley of Virginia.

Relation to elevations of outcrops in adjacent anticlines.—Evidence that the springs occur in anticlines where the spring-bearing formations crop out at lower altitudes than in adjacent anticlines is afforded by the distribution of the springs issuing from the Oriskany sandstone in the Valley Ridges section. The relative altitude of the Oriskany at its outcrop in the Browns Mountain anticline and at its nearest exposure in the next anticline 10 miles southeastward is first considered. Northeast of Naples, in Highland County, Va., the Oriskany sandstone crops out at an altitude of about 3,200 feet, and it does not fall much below this for miles to the northeast of the area shown on Plate 1. With this high intake and a water table practically as high, the water in the Oriskany sandstone in the synclinal basin lying west of Naples could readily be subjected to a hydrostatic pressure sufficient to produce the artesian flows at warm springs Nos. 2, 7, 13, 14, and 17 on the northwest flank of the Browns Mountain anticline. These springs have altitudes of 2,460, 2,240, 1,870, 1,860, and 1,850 feet, respectively.

The only anomalous feature of the occurrence of warm springs in the Browns Mountain anticline, is warm spring No. 6, at Minnehaha, the altitude of which is 2,330 feet, or 300 to 400 feet higher than the lowest exposures of the Oriskany sandstone at its nearest outcrop to the southeast. The hydrostatic head that causes the discharge of water here is probably due to the high outcrop of the Oriskany northeast of Naples, but why the water is discharged here and not at lower points near Mountain Grove can not be explained, unless the Oriskany at those

points is too impervious to conduct water. Some evidence that this is the explanation is furnished by the absence in that area of large cold springs in the Oriskany and the fact, as reported by Darton,[28] that the formation is uncommonly thin there.

The two warm springs (Nos. 141 and 142) near Falling Spring (formerly Barber), Alleghany County, Va., issue where the Oriskany sandstone crops out at lower altitudes than in adjacent anticlines, for they occur practically in the bed of Jackson River where it cuts across an anticline, and adjacent outcrops of the Oriskany are not truncated by the river. The two slightly warm springs (Nos. 151 and 153) along Jackson River below Covington also issue but a few feet above river level. The intake of the water that feeds these springs is probably in the high ridges north and south of the river. At Clifton Forge, where conditions are favorable for the occurrence of warm springs, none were noted by the writer, although, according to W. B. Rogers,[29] there were warm springs on the southeast flank of this anticline about 100 years ago. The warm spring on Mill Creek (No. 301), Botetourt County, occurs on the nose of an anticline and at the lowest position of the Oriskany sandstone in that anticline, which is considerably lower than the outcrop of the Oriskany in the next anticline to the southeast. Farther northeast along the same anticline, there is another warm spring (No. 255), which is probably fed by water taken in at the outcrop of the Oriskany in the next anticline to the northwest. The Panther Gap Springs (Nos. 251-253) occupy a somewhat anomalous position, for they do not lie as low as the Oriskany outcrop 2 miles to the east. Presumably, the Oriskany along its outcrop around the rim of the intervening syncline is high enough to give a hydrostatic pressure that causes water to flow from the lowest exposures of the Oriskany along both margins of the syncline.

The warm springs that issue from the Lowville formation in the Bolar Springs, Warm Springs, and Rich Patch valleys are lower than the lowest outcrop of the Lowville in Crabbottom Valley in western Highland County, Va. On the southeast side of Crabbottom Valley the Lowville comes to the surface in a belt that has an altitude of 2,750 to 3,200 feet and the lowest exposure of the formation in the entire valley is about 2,500 feet above sea-level. Presumably water is fed into the Lowville in this valley and, after passing through the intervening syncline, emerges as the warm springs at the outcrop in the Bolar and Warm Springs anticlines to the south. The relative altitudes of the springs suggest a southward movement of the warm spring waters, and the fact that most of the springs lie on the northwest limb of the anticline in-

[28] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Monterey folio (No. 61), p. 4, 1899.

[29] Rogers, W. B., On the connection of thermal springs in Virginia with anticlinal axes and faults: Assoc. Am. Geologists and Naturalists, Rept. of 1st, 2d, and 3d meetings, p. 330, 1840-42.

dicates that the water is rising out of the syncline that lies northwest of the anticline.

The warm springs in Sweet Springs Valley evidently have an intake from one or both of the anticlines in which Ordovician rocks crop out to the southeast. The springs issue where the Lowville formation has an altitude of 2,000 to 2,025 feet, whereas the lowest exposure of the formation at its outcrop in the next anticline 5 miles to the southeast, is 2,250 feet.

A discussion of the relative altitude of the formation that yields warm springs in the Valley of Virginia can not be presented, because of the lack of detailed geologic and topographic maps in that area. It is evident, however, that the springs issue at the lowest exposures of the formation, for they are invariably located along the major streams.

EFFECT OF EARTH TEMPERATURE ON WATER CIRCULATING UNDER ARTESIAN HEAD

In view of the data presented above, it seems that the hypothesis that the springs are fed by meteoric water circulating under artesian head through synclinal basins can be accepted as a fairly well demonstrated fact. With such a circulation the simplest and most reasonable explanation of the temperature of the springs is that it has been produced by the rocks through which the water circulates. Measurements made by Van Orstrand[30] in deep wells in West Virginia and Pennsylvania show an increase of 1° F. for every increase in depth of 60.8 to 71.4 feet, and there is no reason to assume that appreciably lower gradients exist in the area under consideration. In fact, there is a possibility that in the anticlinal areas the temperature gradient exceeds the normal gradient of the region because of the heating effect of warm water ascending from considerable depths. In the synclines it may be slightly less than the average for the region, because of the slight cooling effect of surface water circulating through them. But at any rate, with a gradient of 1° F. for every 75 feet in depth and with a mean annual temperature at the surface of 50° F., it is evident that at a depth of 5,000 feet the earth temperature exceeds that of the hottest springs in the region.

Cross section A-A' of Plate 1 shows that the spring-bearing Lowville limestone in the synclinal basin lying between the intake of the water in Crabbottom Valley and its outlet in Bolar Springs, Warm Springs, and Rich Patch valleys probably attains a depth of approximately 5,000 feet. A similar depth between the intake and outlet is reached by the formation yielding the springs in Old Sweet Springs Valley. In fact, most of the spring-bearing formations in the basins through which the circulation occurs probably carry the water down to

[30] Van Orstrand, C. E., On the nature of isogeothermal surfaces: Am. Jour. Sci., 5th ser., vol. 15, p. 509, 1928.

depths where the rocks are several degrees warmer than the spring waters. The Oriskany sandstone, for example, probably attains a maximum depth of 5,000 feet in the synclinal trough lying east of the Browns Mountain anticline, and its depth in synclines adjacent to the other slightly warm springs in it is 3,000 to 4,000 feet. There is, therefore, little reasonable doubt that the spring-bearing formations in the bottoms of the synclines through which the water presumably circulates have a temperature appreciably higher than that of the warm spring waters. Undoubtedly, water moving slowly through these basins would attain temperatures approximately equivalent to that of the rocks at these depths. The chief question is the extent to which the waters will be cooled as they come into contact with colder rocks in ascending to the outlet of springs. If the rate of flow from intake to outlet were constant, the water would probably emerge at about the average temperature of ordinary springs. But the conditions of intake and outlet are such that the rate of flow through the basins is not uniform. Water is fed into the basins along the whole extent of the outcrop of the spring-bearing formation, whereas the water escapes at only a few places. Water entering at the intake, moreover, probably sinks but a few feet before it reaches the water table, and its downward movement thereafter is very slow, being dependent upon the rate of discharge of the warm springs and the capacity of the rock reservoir in the basin. The discharge of water from the basin at the warm spring is probably not analogous to the overflow of a lake or pond, in which the top water is drained off. There is reason to believe that, under the hydrostatic pressures, the frictional resistance offered to flow, and the buoyant effect of hot water, with cold water on the intake side of the inverted siphon and warm water, which has lower specific gravity, on the discharge side, warm springs of appreciable discharge are fed by water rising directly from deep parts of the syncline. The movement toward the outlet is analogous to the coning action noted in some oil fields where the lowering of pressure produced by the too rapid discharge of gas, oil, or water results in the rise of deep hot waters into the well. Warm springs often build by deposition impermeable walls, so that the spring water rises through a definite tube, doubtless at relatively high velocity. The result is that the discharge of the spring is somewhat analogous to the discharge of water through a well that taps a deep artesian flow. The conditions suitable for such a discharge undoubtedly vary directly with the dip of the rocks. Where the rocks rise abruptly out of a syncline, as they do at the position of the warm springs in Warm Springs Valley, there is opportunity for the warm water in the deeper part of the basin to reach the surface without being cooled to any great extent. On the contrary, water rising out of a basin along gently dipping rocks, such as are exemplified by the Oriskany sandstone at spring No. 6 (Pl. 1), will doubtless be appreciably cooled be-

fore it emerges at the surface. The dip of the strata at the outlet of the spring is probably one of the most influential factors in determining the relative temperature of the spring and probably explains why the warmest springs are most common in the northwest, more steeply dipping flanks of the anticlines. This factor, together with the depth and width of the synclines, the rate of discharge, and the possibility of warm spring waters being mixed with cold surface waters, probably accounts for most of the difference in the temperature of the springs.

SUMMARY

In the northwestern part of Virginia and adjacent parts of West Virginia there are 90 or more warm springs that have temperatures ranging from slightly more than the mean annual air temperatures to 105° F. These springs yield waters that are predominantly calcium carbonate in character. Except that the warmest springs have a slightly higher mineral content and are relatively richer in sulphates than most of the cold springs, the warm springs are very similar in mineral composition to the cold springs. The gases issuing from the warm springs are composed almost entirely of the atmospheric gases, though CO_2 occurs in greater volume than in the air. Nearly all the warm springs issue from the Oriskany sandstone, the Helderberg limestone, and the Lowville limestone where these formations rise to the surface from considerable depths as a result of anticlinal folding. They invariably issue only at the lowest exposures of these rocks in the different anticlines and are therefore commonly found where the major streams have cut water gaps through anticlinal ridges, but only in those anticlines in which the water-bearing formations are exposed at lower levels than in adjacent anticlines.

The hypothesis as to the source of the heat and water supply of the warm springs that is most consistent with the facts of their chemical composition and geologic occurrence is that they are due to the artesian circulation of meteoric water through permeable beds, the water being taken in at a relatively high outcrop of the permeable bed in an anticline and discharged where the same bed is exposed at a lower level in an adjacent anticline, the temperature of the springs being an expression of the normal earth temperature in the synclinal basins through which the water circulates.

The requisite condition for the occurrence of warm springs having such an origin is a highly folded terrane with considerable relief, containing beds which are sufficiently permeable to act as aquifers and whose continuity is not broken by faulting. The unusual number of warm springs in the region under consideration and their absence or scarcity to the northeast and southwest may be due in part to the scarcity of thrust faults in this region.

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia*

POCAHONTAS COUNTY, W. VA.

Number I	Number II	Name and location	Date, 1928	Flow [a] (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence [b]
1	.....	Spring 2 miles east of Dunmore	Mar. 17	5	46	42	Romney shale.
2	.....	Pritchard Spring, 0.5 mile southeast of Dunmore	do	1,500	61	40	Oriskany sandstone, northwest limb of anticline.
			Sept. 17	1,000	63.2	57	
3	.....	Spring 1.1 miles southeast of Dunmore	Mar. 17	30	46	36	Helderberg limestone, near axis of anticline.
4	.....	Spring 1.6 miles southeast of Dunmore	do	5	41	36	Tuscarora sandstone on axis of anticline.
5	.....	Sherman Gibson Spring, 1 mile west of Frost	do	800	47.5	37	Helderberg limestone, southeast limb of anticline.
			Sept. 16	400	51.8	54	
			Nov. 7	400	51.4	48	
6	.....	Minnehaha Spring, Minnehaha	Mar. 19	800	66	33	Oriskany sandstone, southeast limb of anticline.
			Sept. 10	400	68.5	58	
7	.....	Curry Spring, Huntersville	Mar. 19	500	62.5	31	Oriskany sandstone, northwest limb of anticline.
			Sept. 10	400	64.2	53	
			Nov. 6	400	63	48	

I. Serial reference numbers of springs used in this report.
II. Numbers used in Springs of Virginia . . .: Virginia Commission on Conservation and Development, Water Resources and Power Div., Bull. 1, 1930.
a The flow is approximate.
b Some of the formation names used in this table have not been accepted by the United States Geological Survey, for the areas to which they are here applied.

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

GREENBRIER COUNTY, W. VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
8	.....	Alvon Spring No. 4, 1 mile north of Alvon	Mar. 31	500	48.5	45	Helderberg limestone, southeast limb of anticline.
			Sept. 6	350	56.3	71	
			Nov. 5	350	51	36	
9	.....	Alvon Springs Nos. 1 and 2, 0.5 mile northwest of Alvon	Mar. 31	800	54.2	45	do.
			Sept. 6	450	58	71	
			Nov. 6	450	57.2	36	
10	.....	Alvon Spring No. 3, 0.6 mile northwest of Alvon	Mar. 31	200	54	45	do.
11	.....	Anthony Cave Spring, 1 mile northwest of Alvon	do	500	58.8	40	Tuscarora sandstone, on axis of anticline near fault.
			Sept 10	500	58.7	47	
			Nov. 6	500	59.4	48	
12	.....	Hoylman Spring, 1 mile northwest of Alvon	Mar. 31	400	49	34	Tuscarora sandstone, on axis of anticline.
			Sept. 6	200	51.8	77	
13	.....	Reed Spring, 2.9 miles north of White Sulphur Springs	Mar. 31	800	59	45	Oriskany sandstone, northwest limb of anticline.
			Sept. 10	800	62.6	84	
14	.....	Reed Spring, 2 miles north of White Sulphur Springs	Mar. 31	1,000	61.5	47	do.
			Sept. 10	800	62.2	77	
			Nov. 5	800	61.5	42	
15	.....	Fish Hatchery Spring, White Sulphur Springs	Apr. 1	3,000	46	49	Oriskany sandstone, southeast limb of anticline.
			Sept. 10	1,500	53.2	66	
16	.....	Atkinson Spring, west side of White Sulphur Springs	Mar. 31	2	52.5	32	do.
			Sept. 10	2	57.2	71	
17	.....	White Sulphur Spring, Greenbrier Hotel, White Sulphur Springs	Mar. 30	30	60.5	47	Devonian shale overlying Oriskany sandstone on axis of anticline.
			Sept. 10	30	63.5	68	
18	.....	Chalybeate Spring, White Sulphur Springs	Mar. 30	1	48	45	do.
			Sept. 10	1	62.9	71	
19	.....	Alum Spring, White Sulphur Springs	Mar. 30	1	52	50	do.

MONROE COUNTY, W. VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
20	.....	Buttermilk Spring, 2 miles northeast of Sweet Springs	Apr. 1	100	70.5	50	Lowville limestone on faulted anticline.
			Sept. 11	10	71.6	77	
21	.....	Old Sweet Spring, drinking fountain and pool, Sweet Springs	Apr. 1	400	71.8	55	
			Sept. 11	400	73.4	50	do.
22	.....	Baker Spring, 2 miles west of Sweet Springs	Apr. 3	500	56	50	do.
23	.....	Lynside Spring, 3 miles west of Sweet Springs	do	500	54.2	54	
			Sept. 11	400	55.2	68	do.
24	.....	Spring 5 miles south of Sweet Springs	Apr. 3	500	56	50	do.
25	.....	Jenkins Spring, 6 miles south of Sweet Springs	do	200	47	50	do.
26	.....	Dunn Spring, 1.5 miles south of Sweet Springs	do	100	46	62	do.
27	.....	Huffman Spring, 3.5 miles south of Sweet Springs	do	300	49.5	62	Beekmantown dolomite on faulted anticline.
28	.....	Baker Spring, 3.5 miles south of Sweet Springs	do	500	49.5	57	do.
29	.....	Spring 1 mile northeast of Gap Mills	do	30	51	55	do
30	.....	Spring 1 mile northeast of Gap Mills	do	200	51	60	do.
31	.....	Spring at Gap Mills	Apr. 4	5	50	63	do.
32	.....	Spring 3 miles southwest of Gap Mills	do	100	49	63	do

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

HIGHLAND COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
33	441	Richard Crummitt Spring, 1.5 miles west of Crabbottom	Mar. 15	600	48.5	49	Beekmantown limestone on, or near, crest of anticline.
34	442	Swecker Spring, 0.5 mile west of Crabbottom	do	1,500	48	50	Stones River limestone on, or near, crest of anticline.
35	443	Spring in creek bottom, 5 miles northeast of Hightown	do	800	46	50	Beekmantown limestone on, or near, crest of anticline.
36	444	W. E. Snyder Spring, 4 miles northeast of Hightown	do	10	46	50	do.
37	.....	George Swecker Spring, 4.2 miles northeast of Hightown	Sept. 6	250	50	46	Stones River limestone on, or near, crest of anticline.
38	.....	C. E. Arbogast Spring, 4 miles northeast of Hightown	Mar. 16	95	46.5	42	do
			Sept. 6	100	53.2	54	
39	447	Kiser Spring, 3 miles northeast of Hightown	Mar. 15	1,200	49	53	Beekmantown limestone on, or near, crest of anticline.
			Apr. 6	1,000	52.7	55	
40	446	Spring 3.5 miles northeast of Hightown	Mar. 15	250	46	38	Stones River limestone on east limb of anticline.
41	448	Spring 2.4 miles west of Hightown	do	95	49.5	52	Beekmantown limestone on, or near, crest of anticline.
42	449	D. R. Cobb Spring, 1.2 miles northeast of Hightown	do	10	47.5	49	do.
			Sept. 6	10	52.4	60	
43	450	E. L. Rexrode Spring, 2 miles northeast of Hightown	Mar. 16	100	46	37	Stones River limestone on east limb of anticline.
			Sept. 6	100	50.5	52	
44	451	W. D. Eye Spring, 0.6 mile northeast of Hightown	Mar. 15	5	43	45	Beekmantown limestone on east limb of anticline.
45	452	H. E. Heavener Spring, 1 mile east of Hightown	Mar. 16	1,000	48.5	37	do.
			Sept. 6	500	51.4	57	
46	453	Spring 0.4 mile south of Hightown	Mar. 16	60	49	34	Beekmantown limestone on, or near, axis of anticline.
47	456	Spring 1.2 miles southeast of Hightown	Mar. 17	40	47	33	Stones River limestone on southeast limb of anticline.
48	459	Monterey Spring, 0.8 mile northwest of Monterey	Feb. 24	300	45	43	Helderberg limestone in syncline.
49	454	Spring 1.2 miles southwest of Hightown	Mar. 16	30	47	34	Beekmantown limestone on, or near, axis of anticline.
			Sept. 6	30	53.6	57	
50	455	Spring 1.2 miles southwest of Hightown	Mar. 16	60	49.9	34	Stones River limestone on, or near, axis of anticline.
			Sept. 6	60	52.2	57	
51	457	Spring 1.4 miles southeast of Hightown	Mar. 16	60	46	34	Stones River limestone on southeast limb of anticline.
52	458	Spring 1.6 miles southeast of Hightown	do	120	42	35	do.
53	460	Spring 1.2 miles southeast of Monterey	Feb. 24	80	41.5	44	Probably fed by stream.
			Sept. 6	30	49	55	
54	461	Jones Spring, 1.4 miles southeast of Hightown	Mar. 16	50	47	34	Beekmantown limestone on southeast limb of anticline.
55	462	Spring 3.8 miles southwest of Hightown	do	60	47	36	Beekmantown limestone on, or near, axis of anticline.
56	463	Mill Spring, 3.5 miles southwest of Hightown	do	100	45	35	Beekmantown limestone on southeast limb of anticline.
57	464	Spring 4.4 miles southwest of Hightown	Feb. 23	50	48	51	Beekmantown limestone near axis of anticline.
58	465	Spring 4 miles south of Hightown	do	100	45	41	Stones River limestone on southeast limb of anticline.
59	474	Spring 3.2 miles southeast of Monterey	Feb. 24	300	41	45	Helderberg limestone in syncline.
			Sept. 6	200	54	52	
60	475	J. L. Lockridge Spring, 1.8 miles west of McDowell	Feb. 24	1,000	47	36	Helderberg limestone near axis of anticline.
			Sept. 6	800	52	52	
61	476	Chalybeate Spring, 7 miles southeast of Monterey	Feb. 24	5	46.5	46	Romney shale in syncline.
62	477	Spring 1 mile east of McDowell	do	60	49	42	Helderberg limestone near axis of anticline.

63	478	Stuart Spring, 2.6 miles east of McDowell	do	4,500	55	47	Oriskany sandstone on southeast limb of anticline.
64	.....	Spout Spring, 5 miles east of McDowell	Mar. 15	5	42	46	Catskill formation in syncline.
			Sept. 5	5	54	42	
65	466	Mackey Spring, 1 mile southwest of Vanderpool	Feb. 23	4,500	46.5	46	Spring probably fed by Jackson River.
66	.....	M. E. Church, 1 mile north of Mill Gap	do	20	49	57	Stones River limestone.
			Sept. 6	20	51.8	59	
67	.....	Spring 0.5 mile northeast of Mill Gap	Feb. 23	3,000	46.5	55	Stones River limestone on southeast limb of anticline.
			Sept. 6	3,000	50	57	
68	467	Stonacher Mills Spring, 2 miles south of Vanderpool	Feb. 23	100	46	46	Oriskany sandstone in syncline.
69	468	C. A. Corbett Spring, 4 miles south of Vanderpool	do	200	47	45	Helderberg limestone in syncline.
70	434	Beulah Spring, 2 miles southwest of Mill Gap	do	500	48.8	58	Oriskany sandstone on northwest limb of anticline.
			Sept. 6	400	50.1	53	
			Nov. 7	400	49.7	52	
71	435	Gilmer Spring, 1.4 miles southwest of Mill Gap post office	Feb. 23	3,500	47	55	Lowville limestone on northwest limb of anticline.
			Sept. 6	1,000	50	57	
			Nov. 7	1,000	49	52	
72	436	W. A. Crummett Spring, 8 miles south of Valley Center	Feb. 23	1,000	46	56	do.
73	437	S. B. Rexrode Spring, 1.6 miles south of Valley Center	do	1,000	45	50	do.
74	469	Spring 6 miles northeast of Bolar	do	400	47	42	Probably fed by stream.
75	470	Buzzard Spring, 4.5 miles northeast of Bolar	do	30	46.5	41	do.
76	471	Bragg Spring, 2.2 miles northeast of Bolar	do	60	74	32	Lowville limestone on northwest limb of anticline.
			Sept. 13	30	74.8	58	
			Nov. 7	30	73.8	45	
77	472	Spring 1 mile northeast of Bolar	Feb. 23	100	49	32	do.
			Sept. 13	100	52	57	
78	473	Bolar Spring, 3 miles northeast of Bolar	Feb. 23	3,500	66	32	do.
			Sept. 13	1,500	68.8	57.8	
			Nov. 7	1,500	71.8	46	

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

BATH COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
79	353	Cleeks Mill Spring, 3.2 miles southwest of Bolar	Feb. 22	5,000	45.5	39	Probably fed by mountain stream.
			Sept. 13	2,500	53	60	
80	354	Schoolhouse spring, 5 miles southwest of Bolar	Feb. 22	60	50	39	Helderberg limestone in syncline.
			Sept. 12	60	50.5	64	
81	355	McAllister Spring, 6 miles southwest of Bolar	Feb. 22	80	50.4	39	do.
			Sept. 12	80	53.6	50	
82	331	Kershner Spring, 1 mile northeast of Mountain Grove	Mar. 20	5	45	36	Oriskany sandstone on northwest limb of anticline.
83	324	Anderson Spring, 2 miles south of Mountain Grove	Mar. 20	30	49	39	Helderberg limestone on northwest limb of anticline.
84	325	W. P. Ayers Spring, 2.4 miles south of Mountain Grove	Mar. 20	60	50.5	39	do.
85	326	G. T. Landes Spring, 2.4 miles south of Mountain Grove	Mar. 20	40	51	39	Helderberg limestone on axis of anticline.
86	327	M. O. Shaffer Spring, 2.2 miles south of Mountain Grove	Mar. 20	500	49.8	39	Helderberg limestone on crest of anticline.
			Nov. 3	400	52.8	64	
87	328	M. O. Shaffer Spring, 2.4 miles south of Mountain Grove	Mar. 20	20	51.5	39	do.
			Nov. 3	20	52.4	66	
88	329	Blowing Spring, 2.4 miles south of Mountain Grove	Mar. 20	60	47.5	40	do.
			Nov. 3	60	50.5	65	
89	330	Darnell Spring, 2.6 miles south of Mountain Grove	Mar. 20	100	51.5	40	do.
90	332	Rorke Spring, 2 miles southeast of Mountain Grove	Mar. 20	30	46.5	40	do.
91	333	Fassifern Farm Spring, 4 miles northwest of Warm Springs post office	Mar. 21	30	51	46	Oriskany sandstone on southeast limb of anticline.
92	346	Spring 0.6 mile west of Warm Springs post office	Mar. 21	5	42	39	Romney shale on northwest limb of anticline.
93	347	Spring 0.4 mile northwest of Warm Springs post office	Mar. 21	60	46.5	33	Oriskany sandstone on northwest limb of anticline.
94	345	Ladies' pool at Warm Springs, 0.6 mile northeast of Warm Springs post office	Feb. 22		94	38	Lowville limestone on, or near, crest of anticline.
			Sept. 12		95.3	72	
			Nov. 2		.....	71.6	
95	345	Drinking fountain at Warm Springs, 0.6 mile northeast of Warm Springs post office	Feb. 22	1,000 to 1,200	95	38	do.
			Sept. 12		95.3	72	
			Nov. 2		95.5	60	
96	345	Gentlemen's pool at Warm Springs, 0.6 mile northeast of Warm Springs post office	Feb. 22		95.2	38	do.
			Sept. 12		96.2	72	
			Nov. 2		96	60	
97	350	Meadow spring at Warm Springs, 0.4 mile northeast of Warm Springs post office	Mar. 21	100	91	37	do.
			Sept. 12	100	91.2	75	
98	351	Spring, 0.5 mile northeast of Warm Springs post office	Mar. 21	100	55	37	do.
99	352	Spring 1.2 miles northeast of Warm Springs post office	Mar. 21	200	46	33	Basal Martinsburg formation on southeast limb of anticline.
100	356	Spring 3 miles east of Warm Springs post office	Mar. 21	4	38	45	Oriskany sandstone on southeast limb of anticline.
101	357	Bath Alum Spring, 3 miles east of Warm Springs post office	Mar. 21	10	49	44	Romney shale in syncline.
			Sept. 13	5	53.7	80	
102	366	Dove Spring, 1.2 miles southwest of Armstrong	Mar. 27	300	49	38	Oriskany sandstone on northwest limb of anticline.
103	367	Wandless Spring, 1.6 miles southwest of Armstrong	Mar. 28	300	52	36	Helderberg limestone on northwest limb of anticline.
104	368	Spring 3 miles south of Armstrong	Mar. 27	350	52.9	37	do.

105	369	Thomas Spring, 2.6 miles south of Armstrong	Mar. 27	100	50	34	Helderberg limestone on northwest limb of anticline.
106	370	Spring 3 miles south of Armstrong	Mar. 27	100	51.5	39	do.
107	371	Spring 3.4 miles south of Armstrong	Mar. 27	100	51	45	do.
108	372	Kinkaid Spring, 4 miles south of Armstrong	Mar. 27	60	51.4	45	do.
109	364	Spring 5.5 miles southwest of Armstrong, northeast of Millboro Springs	Mar. 28	30	47	35	Oriskany sandstone on northwest limb of anticline.
110	363	Spring 4.6 miles northeast of Millboro Springs	Mar. 28	30	49.2	39	do.
111	373	A. L. Lyle Spring, 5.2 miles northeast of Millboro Springs	Mar. 27	400	54.5	45	Oriskany sandstone on limb of anticline.
112	374	Gillock Spring, 4.8 miles northeast of Millboro Springs	Mar. 27	66	51	45	do.
113	375	M. M. Lyle Spring, 4.2 miles northeast of Millboro Springs	Mar. 27	500	51.5	45	do.
114	362	Rhea Spring, 3 miles northeast of Millboro Springs	Mar. 28	30	51.5	41	Oriskany sandstone on axis of anticline.
115	376	Spring 4.2 miles northeast of Millboro Springs	Mar. 27	60	45	40	Oriskany sandstone on limb of anticline.
116	378	Spring 4.4 miles northeast of Millboro Springs	Mar. 21	10	48	41	Oriskany sandstone on northwest limb of anticline.
117	.....	Spring 4.6 miles northeast of Millboro Springs	Mar. 20	200	50	40	Helderberg limestone on northwest limb of anticline.
			Sept. 13	100	55.7	80	
118	377	Crystal Spring, 3.4 miles northeast of Millboro Springs	Mar. 21	500	56	50	Helderberg limestone on southeast limb of anticline.
			Sept. 13	300	56.8	82	
119	359	W. R. Neff Spring, 1 mile north of Millboro Springs	Mar. 28	15	45	45	Romney shale in syncline.
120	360	Cold Spring, Millboro Springs	Mar. 21	5	47	39	Catskill formation.
			Sept. 13	3	55.4	84	
121	361	Sulphur Spring, 0.2 mile east of Millboro Springs	Mar. 21	1	39	39	Portage shale in syncline.
122	339	Octagon Spring, Homestead Hotel, Hot Springs	Feb. 22	67	95.1	40	Lowville limestone near axis of anticline.
			Sept. 12	67	98.6	70	
			Nov. 2	67	98.6	63	
123	338	Boiler Spring, Homestead Hotel, Hot Springs	Feb. 22	168	104	32	do.
			Sept. 12	168	104.9	70	
			Nov. 2	168	104.5	63	
124	340	Hot Sulphur Springs, Homestead Hotel, Hot Springs	Feb. 22	40	97.3	32	do.
			Sept. 12	40	98.5	70	
			Nov. 2	40	97	63	
125	341	Magnesia Spring, Homestead Hotel, Hot Springs	Feb. 22	30	95.8	32	do.
			Sept. 12	30	96.5	70	
			Nov. 2	30	95.9	63	
126	337	Spout Spring, Homestead Hotel, Hot Springs	Feb. 22	36	103	32	do.
			Sept. 12	36	105	70	
			Nov. 2	36	105.8	63	
127	344	Soda Spring, Homestead Hotel, Hot Springs	Dec. 4	140	72.2	.....	do.
128	342	Warm Spring, Homestead Hotel, Hot Springs	Feb. 22	15	90	32	do.
			Sept. 12	15	91.8	90	
129	343	Cold spring, Hot Springs	Feb. 22	350	56	32	do.
			Sept. 12	350	60.8	70	
130	335	Drinking spring, Healing Springs post office	Feb. 22	2	77.2	35	Lowville limestone on northwest limb of anticline.
			Sept. 12	2	84.2	75	
			Nov. 2	2	83	63	
131	.....	Bathing pool, Healing Springs post office	Sept. 12	10	84.2	75	do.
			Nov. 2	10	78	63	
132	.....	Bottling spring, Healing Springs post office	Sept. 12	1	86	75	do.
			Nov. 2	1	85	63	
133	336	Cascade Spring, 1 mile southwest of Healing Springs post office	Feb. 21	3,000	55	29	do.
			Sept. 12	2,000	59	71	

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

ALLEGHANY COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
134	287	Falling Spring, 8 miles southwest of Healing Springs	Feb. 21	7,000	65	34	Lowville limestone on northwest limb of anticline.
			Sept. 12	.....	66.7	68	
			Nov. 27	.....	74	.....	
135	282	R. M. Perkins Spring, 1 mile north of Falling Spring	Mar. 29	2,000	47	78	Oriskany sandstone on limb of anticline.
136	283	Smith's Chalybeate Spring, 1 mile south of Falling Spring	do.	2	50	63	Romney shale in syncline.
			Sept. 12	1	53.9	62	
137	278	G. A. McAllister Spring, 1.2 miles southwest of Falling Spring	Mar. 29	3,500	45	63	Helderberg limestone, probably fed by stream.
			Sept. 12	500	53.2	59	
138	276	R. S. McClintock Spring, 2.2 miles southwest of Falling Spring	Mar. 29	300	45.5	58	Helderberg limestone on northwest limb of anticline.
			Sept. 12	100	57.5	64	
139	277	R. S. McClintock Spring, 2.2 miles southwest of Falling Spring	Mar. 29	20	47.5	54	do.
			Sept. 11	20	54.5	60	
140	279	Spring on Indian Draft, 1.6 miles southwest of Falling Spring	Mar. 29	200	56	63	do.
			Sept. 11	200	56.1	70	
141	280	Spring on west bank of Jackson River 2 miles south of Falling Spring	Mar. 29	100	59.8	80	Oriskany sandstone on southeast limb of anticline.
			Sept. 11	100	63.1	71	
142	281	Layton Spring, on east bank of Jackson River 2 miles south of Falling Spring	Mar. 29	100	70.8	76	do.
			Sept. 11	100	71.6	71	
143	268	Bear Spring, 4 miles west of Callaghan	Mar. 30	30	44	62	Devonian shale in syncline.
			Sept. 11	10	57.5	73	
144	269	McAllister Spring, 1 mile north of Callaghan	Mar. 30	20	51	64	Helderberg limestone on northwest limb of anticline.
			Sept. 11	20	54.5	75	
145	273	Cave Spring, on Cave River 1.4 miles northeast of Callaghan	Mar. 30	1,000	51.5	56	Helderberg limestone on southeast limb of anticline.
146	270	Rumbold Spring, at mouth of Jackson Creek, 0.8 mile northeast of Callaghan	Mar. 30	30	47	65	Helderberg limestone on northwest limb of anticline.
147	274	Rumbold Spring, on Cave Run, 0.5 mile above its mouth, 1.2 miles northeast of Callaghan	Mar. 30	50	54.5	65	do.
148	271	Alfred Ball Spring, on bank of Ogles Creek 0.6 mile northeast of Callaghan	Mar. 30	60	47	65	Helderberg limestone on crest of anticline.
149	275	Rumbold Spring, on Dunlop Creek 500 feet above mouth of Cave Run, 0.8 mile northeast of Callaghan	do	30	54	65	Helderberg limestone on northwest limb of anticline.
150	272	Rumbold Spring, 0.4 mile northeast of Callaghan	do	80	51	63	do.
			Sept. 11	40	57.2	80	
151	288	Big Spring, 2 miles southeast of Covington	Mar. 29	300	55.5	52	Oriskany sandstone on northwest limb of anticline.
			Sept. 11	400	56.8	80	
152	289	Spring at covered bridge on Jackson River, 3 miles west of Lowmoor	Mar. 28	10	50.5	54	Helderberg limestone on limb of anticline.
153	290	Spring 1,000 feet east of covered bridge, 2.5 miles west of Lowmoor	do	200	56	50	do.
154	292	Spring on south side of railroad 1.8 miles west of Lowmoor	do	100	50.5	50	Oriskany sandstone on limb of anticline.

155	299	Big Spring, Lowmoor	do	1,500	49.2	50	Oriskany sandstone on limb of anticline.
156	300	Spout Spring, Clifton Forge	Feb. 20	100	52.4	32	do.
			Mar. 28	100	51.5	49	
157	.....	Spring on south side of Jackson River 1.2 miles east of Clifton Forge	do	20	54	55	Devonian or Silurian sandstone on northwest limb of anticline.
158	301	Iron Spring, 2.6 miles northeast of Clifton Forge	Feb. 19	2	48.1	42	Romney shale.
159	.....	Ben Ross Spring, Iron Gate	Mar. 24	15	51.5	55	Devonian shale.
160	.....	Spring 1 mile east of Iron Gate	Feb. 20	10	51	41	Romney shale.
161	293	Spring on Carne Creek 3 miles southwest of Lowmoor	Feb. 21	75	54.4	44	Oriskany sandstone.
162	294	Spring on Carne Creek 4 miles southwest of Lowmoor	Feb. 21	100	52	36	Lowville limestone on northwest limb of anticline.
163	295	E. L. Kamsey Spring, 4.2 miles southwest of Lowmoor	do	500	51.2	35	do.
164	296	Spring on Carne Creek 4 miles southwest of Lowmoor	do	60	50.6	36	Beekmantown limestone on northwest limb of anticline.
165	297	W. R. Fridley Spring, 5 miles southwest of Lowmoor	do	4,000	51.9	36	Lowville limestone on southeast limb of anticline.
166	298	W. R. Fridley Spring, 5.1 miles southeast of Lowmoor	do	3,000	59	36	do.
167	291	Spring 1 mile west of Old Rich Patch, 5.4 miles southwest of Lowmoor	do	60	52.2	34	Lowville limestone on northwest limb of anticline.
168	286	Blue Spring, 9.2 miles southwest of Lowmoor	do	3,000	57.5	34	Lowville limestone on nose of anticline.
169	285	Spring 2 miles southwest of spring No. 168, 10 miles southwest of Lowmoor	do	100	53.9	38	do.
170	284	Spring 5 miles southwest of spring No. 168, 10.2 miles southwest of Lowmoor	do	100	58	38	do.
171	261	Spring on Snake Run 3 miles north of Sweet Chalybeate	Apr. 2	200	56.5	66	Oriskany sandstone on northwest limb of anticline.
			Sept. 11	200	62.6	68	
172	264	Iron Hill Spring, 200 feet east of summer hotel, 2.8 miles northeast of Sweet Chalybeate	Apr. 2	60	63	62	Lowville limestone on southeast limb of faulted anticline.
			Sept. 11	60	67.5	73	
173	265	Iron Hill Spring, 400 feet east of summer hotel, 2.8 miles northeast of Sweet Chalybeate	Apr. 2	20	65.5	62	do.
			Sept. 11	20	68.2	73	
174	262	Lee Carter Spring, 1.4 miles northeast of Sweet Chalybeate	Apr. 2	30	61	65	do.
			Sept. 11	20	62.9	70	
175	260	C. B. Hunter Spring, 0.5 mile north of Sweet Chalybeate	Apr. 2	30	58	58	do.
			Sept. 11	10	59.9	53	
176	259	R. O. Stone Spring, Sweet Chalybeate	Apr. 2	100	66	65	do.
			Sept. 11	50	72.7	65	
177	258	Sweet Chalybeate Spring, Sweet Chalybeate	Apr. 2	1,000	74.2	58	do.
			Sept. 11	600	76.1	53	
178	257	Cold spring, 0.2 mile southeast of Sweet Chalybeate	Apr. 2	5	47	55	do.

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

ROCKINGHAM COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
179	541	Rawley Spring, 11 miles northwest of Harrisonburg	Feb. 7	1	48	33	Pocono sandstone in syncline.
180	542	Roy Aery Spring, 10.8 miles northwest of Harrisonburg	do	1	44.2	37	Upper Devonian shale.
181	548	Spring 0.6 mile west of Harrisonburg	Feb. 6	200	54	47	Martinsburg shale.
			May 1	200	54.5	58	
			Sept. 5	200	54.8	50	
182	555	Bear Lithia Spring, 2 miles north of Elkton	May 1	1,000	55	70	Copper Ridge dolomite.
			Sept. 15	1,000	55.4	70	
183	556	Samuel Spring, 1 mile south of Elkton	May 1	800	55.5	72	Rock talus at base of Blue Ridge.
184	553	Spring feeding bath at Massanetta Springs, 4 miles southeast of Harrisonburg	do	30	54	64	Beekmantown or Elbrook dolomite near fault.
			Sept. 15	30	58.1	54	
185	551	Principal spring at Massanetta Springs, 4 miles southeast of Harrisonburg	May 1	400	59	64	do.
			Sept. 15	300	59.9	59	
186	552	Drinking spring near hotel at Massanetta Springs, 4 miles southeast of Harrisonburg	May 1	20	51	64	do.
			Sept. 15	20	55.4	51	
187	549	Osaola Spring, 1 mile east of Rockingham	May 1	300	54	60	Beekmantown dolomite.
188	544	Spring feeding mill pond, 0.5 mile northwest of Dayton	Feb. 6	3,000	50.5	39	do.
189	545	Warm Spring, 1 mile south of Bridgewater	Feb. 8	500	63.5	40	Chambersburg or Athens limestone.
			Sept. 5	500	62.9	58	
190	543	Patterson Spring, 1 mile northwest of Spring Creek	Feb. 14	4,000	52.3	36	Elbrook or Conococheague dolomite.
191	546	Small spring 3 miles south of Bridgewater	Feb. 28	60	54	50	Formation not determined.
192	550	E. D. Pence Spring, 2 miles east of Burketown	May 1	200	56	60	Stones River limestone.

AUGUSTA COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
193	504	Blue Hole Spring, Mount Solon	Feb. 13	2,000	52.2	38	Elbrook limestone.
194	528	Small spring 3 miles south of Bridgewater	Feb. 28	30	54	49	Formation not determined.
195	531	Dices Spring, 1 mile southeast of Burketown	Feb. 8	2,000	63.2	48	Copper Ridge dolomite.
			Apr. 24	1,500	64	66	
			Sept. 14	1,500	64.4	55	
196	529	Seawright Spring, 3.6 miles southwest of Burketown	Feb. 8	1,200	59	56	Elbrook limestone.
			Sept. 14	1,000	59.7	71	
197	.....	Shale spring, 0.5 mile east of West Augusta	Feb. 14	2	48	42	Devonian shale in syncline.
198	486	Stribling Spring, on Moffats Run 3.8 miles west of Parnassus	Feb. 13	1	43	41	Upper Devonian shale.
199	487	Springdale Springs in Jennings Gap, 4.4 miles southwest of Parnassus	do	1	46.5	41	do.
200	489	Lone Fountain Spring, 2.2 miles northwest of Churchville	do	10	52.7	41	Tuscarora sandstone near fault.
201	488	Spring on Highway No. 39, 2.5 miles northwest of Churchville	Mar. 15	30	52	51	Elbrook limestone.
			Sept. 5	30	54.3	52	do.
202	506	Fitzgerald Spring at Middle River bridge, 2.2 miles west of Fort Defiance	Mar. 28	60	61.2	60	do.
			Sept. 14	60	60	70	do.
203	530	Willow Spout Spring, Fort Defiance	May 1	20	54.5	58	Stones River limestone.
204	534	Jollif Spring, 0.5 mile south of Harriston	Feb. 9	125	55.4	45	Elbrook limestone.
205	507	Harry Bowling Springs, 2.5 miles southwest of Fort Defiance	Feb. 8	20	55	61	Beekmantown limestone.
206	508	Quick Spring, 4 miles northeast of Staunton	do	1,000	58.3	59	Elbrook limestone near fault.
			Sept. 14	1,000	58.6	75	do.
207	509	B. M. Willer Spring, 4 miles northeast of Staunton	do	60	55	59	Stones River limestone.
208	499	Cave Spring, 1.6 miles south of Churchville	Feb. 13	2,000	48.1	42	Copper Ridge dolomite.
209	480	Craig Spring, Deerfield	Feb. 24	500	46	46	Probably fed by stream.
210	481	Spring 1.2 miles south of Deerfield	do	500	51.5	46	Oriskany sandstone on nose of anticline.
211	492	Spring in Buffalo Gap, 200 feet north of highway, 2.8 miles northwest of Swoope	Mar. 23	100	52	64	Helderberg limestone near thrust fault.
212	490	Spring in Buffalo Gap, 50 feet north of highway, 2.8 miles northwest of Swoope	do	10	52	75	do.
213	491	Spring in Buffalo Gap, south of railroad, 2.8 miles northwest of Swoope	do	300	54.5	65	do.
214	.....	Spring 1,000 feet north of school house at Westview, 1.6 miles northeast of Swoope	do	60	52	65	Conococheague limestone.
215	500	Frank Kennedy Spring, 0.5 mile north of Westview and 2 miles northeast of Swoope	Feb. 28	1,000	54.4	36	do.
216	510	Spring on Hebron road 1 mile southwest of Staunton	Feb. 8	10	54	59	Beekmantown limestone near fault.
217	511	Buttermilk Spring, 1.5 miles southwest of Staunton	Feb. 28	200	53	37	do.
218	513	Spring on Arbor Hill road, 2.8 miles southwest of Staunton	Feb. 27	200	49	33	do.

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

AUGUSTA COUNTY, VA.—Continued

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
219	512	Spring near limestone quarry 1 mile southeast of Staunton	Feb. 27	10	32	35	Beekmantown limestone.
220	515	Spring southeast of Betsy Bell hill, 2 miles southeast of Staunton	do	60	54	37	Stones River limestone.
221	516	Spring on Greenville road, 2.5 miles southeast of Staunton	do	20	53.2	37	Beekmantown limestone.
222	535	Koiner Spring, 1 mile northwest of Crimora	Feb. 9	90	53.4	46	Elbrook limestone.
223	536	Russell Barger Spring, 1 mile southwest of Crimora	do	40	52.9	47	do.
224	532	Small spring 1 mile east of Fishersville	Feb. 8	5	51.5	56	Beekmantown limestone.
225	482	Spring on road to Goshen 4 miles south of Deerfield	Feb. 24	50	55	45	Helderberg or Oriskany formation.
226	493	Iron Spring, Mount Elliott	Mar. 23	2	47	50	Romney shale in syncline.
227	494	Augusta White Lithia Spring, 0.5 mile east of Augusta Springs	do	800	44	59	Helderberg limestone on northeast limb of anticline.
228	495	Big Spring, 0.6 mile south of Augusta Springs	do	1,000	48	60	do.
229	484	William Bashaw Spring, 2.2 miles southwest of Craigsville	do	200	50	45	Helderberg limestone on southeast limb of anticline.
230	496	Cochran Spring, 2 miles northwest of Middlebrook	Feb. 28	1,000	54.5	40	Elbrook limestone.
231	501	J. J. Bowman's Spring, 3.3 miles northeast of Middlebrook	do	500	53	49	do.
232	502	Spring 1 mile northeast of Middlebrook	Feb. 25	350	52	33	do.
			Sept. 14	300	53.6	80	
233	497	Spring 3 miles northeast of Moffatts Creek	Feb. 25	100	48	39	do.
			Sept. 14	80	59	50	
234	498	Spring 2 miles northeast of Moffatts Creek	Feb. 25	30	51	40	do
			Sept. 14	30	59	80	
235	517	Mint Spring, Mint Spring post office	Feb. 14	20	55	47	Beekmantown limestone.
236	518	Spring 2 miles southwest of Mint Spring	do	50	51.6	45	do.
237	519	W. H. Agnor Spring, Greenville	Feb. 11	60	53.6	40	Copper Ridge limestone.
238	520	W. B. Speck Spring, 2 miles southwest of Greenville	do	100	52.6	34	Elbrook limestone.
239	521	Broadhead Spring, 2.3 miles southwest of Greenville	do	150	54.1	34	do.
240	.....	Spring 1.5 miles south of Moffatts Creek	Mar. 29	100	53	38	Beekmantown limestone or Rome formation near fault.
			Sept. 14	200	55.5	80	
241	522	Cold spring, 2 miles southwest of Greenville	Feb. 11	30	50.9	36	Beekmantown limestone.
242	523	Lacey Black Spring, 4 miles east of Greenville	Feb. 10	15	54	43	Copper Ridge limestone.
243	524	Barterbrook Spring, 2.5 miles northeast of Stuarts Draft	do	400	55	35	Stones River limestone.
244	525	Dodge Spring, 2.2 miles south of Stuarts Draft	do	2,000	49.1	44	In alluvial fan of stream flowing out of Blue Ridge.
245	526	Cohron Spring, 1.6 miles east of Stuarts Draft	do	80	53.1	39	Elbrook limestone.
246	527	Payne Spring, 1 mile north of Lipscomb	do	100	47	39	do.
247	533	S. G. Koiner Spring, 3 miles southwest of Waynesboro	Feb. 11	4,000	54.2	40	do.
			Sept. 14	2,500	55.4	75	
248	538	Baker Spring, southeast edge of Waynesboro	Feb. 9	5,300	54.2	43	Rome formation.
			Sept. 14	5,000	55	75	
249	539	Lithia Spring, east side of Waynesboro	Feb. 9	100	54.5	44	do.

ROCKBRIDGE COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
250	425	Linwood Dill Spring, 0.5 mile east of Bells Valley	Mar. 23	200	54	51	Helderberg limestone on northwest limb of anticline.
251	404	Westernmost of 3 springs in Panther Gap, 1.6 miles west of Goshen	Mar. 21	60	58	41	Helderberg limestone.
			Sept. 13	50	59.9	75	
			Nov. 2	50	59.5	47	
252	403	Easternmost of 3 springs in Panther Gap, 1.6 miles west of Goshen	Mar. 21	50	66	41	do.
			Sept. 13	50	66.2	75	
			Nov. 2	50	66	47	
253	405	Southernmost of 3 springs in Panther Gap, 1.6 miles west of Goshen	Mar. 21	800	62.3	60	do.
			Sept. 13	800	64.7	75	
254	406	Cold Sulphur Spring, 1 mile southwest of Goshen	Mar. 22	5	51	44	Brallier or Romney shale in syncline.
			Sept. 13	3	56.3	72	
255	407	Oak Carter Spring, 1 mile southeast of Goshen	Mar. 22	150	57	64	Oriskany sandstone on northwest limb of anticline.
256	408	Spring 800 feet east of spring No. 255, 1.2 miles southeast of Goshen	do	10	51	66	Helderberg limestone on northwest limb of anticline.
257	409	Spring 1.5 miles southeast of Goshen	Feb. 25	20	36	32	Clinton sandstone on anticline.
258	411	O. H. Humphrey Spring, 2.2 miles southeast of Goshen	Mar. 22	200	54	54	Helderberg limestone on southeast limb of anticline.
			Sept. 15	100	56.3	70	
259	410	Bridge Spring, 2.4 miles southeast of Goshen	Mar. 22	80	43	62	Probably fed by stream.
			Sept. 13	30	59	70	
260	414	Old distillery spring, 3.2 miles southeast of Goshen	Mar. 22	500	54.5	62	Oriskany sandstone on northwest limb of anticline.
			Sept. 13	500	55	62	
261	412	William Willfong Spring, 3.2 miles southeast of Goshen	Mar. 22	10	49	59	do.
			Sept. 13	5	55	65	
262	415	Spring 3.5 miles southeast of Goshen	Feb. 25	20	41	32	Clinton sandstone on limb of anticline.
263	416	Spring 2.5 miles northwest of Rockbridge Baths	do	200	37.5	32	Martinsburg shale.
264	417	Wilson Sulphur Spring, in North River, 2 miles northwest of Rockbridge Baths	do	160	52	34	do.
			Sept. 14	100	53.9	60	
265	419	Spring 1.4 miles northwest of Rockbridge Baths	Feb. 25	80	46	33	Probably fed by stream.
			Sept. 14	60	57	69	
266	420	Spring 1.5 miles west of Rockbridge Baths	Feb. 25	800	51	34	Chambersburg limestone.
267	421	Lithia Spring, Rockbridge Baths	Feb. 25	200	71.8	36	Beekmantown dolomite.
			Sept. 14	200	72.1	72	
268	423	Magnesia Spring, Rockbridge Baths	Feb. 25	600	71.8	36	do.
			Apr. 26	500	71.5	58	
			Sept. 14	300	71.6	72	
269	422	Warm spring in North River, Rockbridge Baths	Mar. 29	60	63	58	do.
			Sept. 14	60	64.4	72	
270	427	Spring 3.8 miles north of Brownsburg	Feb. 25	30	53	40	Beekmantown limestone.
			Sept. 14	30	57.7	81	
271	428	W. P. Whipple Spring, 1.2 miles southwest of Brownsburg	Feb. 25	40	52	38	do.
			Sept. 14	40	59	70	
272	429	Spring 2 miles southwest of Brownsburg	Feb. 25	5	51	40	do.

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

ROCKBRIDGE COUNTY, VA.—Continued

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
273	431	G. C. Reed Spring, 2.2 miles northeast of Fairfield	Feb. 14	10	49.4	45	Conococheague limestone.
274	430	Gibson Spring, 1.5 miles southwest of Fairfield	do	60	52	38	do.
275	394	Rockbridge Alum Spring, Rockbridge Alum Springs post office	Feb. 18	5	42	37	Romney shale.
276	395	J. C. Patty Spring, 2 miles northeast of Rockbridge Alum Springs post office	do	5	52	42	do.
277	396	R. L. Montgomery Spring, 1.8 miles northeast of Rockbridge Alum Springs post office	do	60	52	39	Devonian shale.
278	397	J. H. Knick Spring, 4 miles northwest of Kerrs Creek	do	60	51.1	35	Martinsburg shale.
279	398	C. H. Miller Spring, 1.6 miles northwest of Kerrs Creek post office	do	300	53.1	43	do.
280	399	H. H. Alpin Spring, 0.8 mile northwest of Kerrs Creek	Feb. 17	100	49	43	Probably fed by Kerr Creek.
281	400	Big Spring, 0.8 mile southeast of Kerrs Creek	do	4,500	57.5	48	Stones River limestone.
282	401	Otto Obenchain Spring, 1 mile southeast of Kerrs Creek	do	100	54.8	50	do.
283	402	Spring 2.2 mile southeast of Kerrs Creek	do	20	55	54	do.
284	386	Spring 2.4 miles northwest of Collierstown	do	300	49.2	41	Chambersburg limestone.
285	387	Seahorn Spring, 2 miles northwest of Collierstown	do	2,500	53.3	38	do.
286	388	Coleman Spring, 0.5 mile northwest of Collierstown	do	1,200	59	46	Stones River limestone.
			Apr. 6	1,000	59	63	
287	389	Spring at Collierstown	Feb. 17	1,000	52	53	Athens limestone.
			Apr. 6	1,000	53	68	
288	390	Spring 0.5 mile southeast of Collierstown	Feb. 17	30	54	46	Stones River limestone.
289	391	J. G. McCorkle Spring, 1.4 miles west of Murat	do	600	52.3	46	do.
290	392	Ira Dickson Spring, Murat	do	1,800	53.6	48	do.
291	393	F. A. Snider Spring, 3.6 miles southeast of Murat	Feb. 15	40	55.5	56	Elbrook limestone.
292	382	C. B. Leech Spring, 4.4 miles west of Murat	Feb. 16	100	46	46	Beekmantown limestone.
293	383	J. H. Ayers Spring, 4 miles southwest of Murat	do	3,500	51.1	47	do.
294	379	Reagon Spring, 2 miles north of Rapps Mills	do	1,200	53.5	43	do.
295	381	Black Spring, 1.2 miles northeast of Rapps Mills	do	5,000	53.1	46	do.
296	380	Henderson Spring, 0.8 mile southwest of Rapps Mills	do	1,000	51.2	44	do.
297	385	S. R. Leckley Spring, 3.4 miles north of Natural Bridge station	Feb. 15	125	54.8	50	Copper Ridge dolomite.
298	384	Schoolhouse spring, 0.7 mile north of Natural Bridge station	do	250	53.7	48	do.

BOTETOURT COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
299	316	Daggers Spring, 2.4 miles east of Gala	Feb. 20	2	47.1	39	Romney shale.
300	318	Spring 3.4 miles east of Gala	do	2,000	51	41	Oriskany sandstone on nose of anticline.
301	317	Lithia Spring, 3.2 miles east of Gala	do	300	64.6	43	do.
302	319	Spring 4 miles east of Gala	do	1,000	58	43	do.
303	312	J. W. Owens Spring, 1.4 miles southwest of Eagle Rock	do	60	54.2	46	Conococheague or Beekmantown limestone.
304	320	W. C. Karnes Spring, 3.4 miles northwest of Indian Rock	Feb. 16	6,000	51	42	Stones River limestone.
305	323	J. S. Pogue Spring, 3.2 miles northeast of Indian Rock	Feb. 15 Apr. 5	450 400	54.1 54	47 65	Elbrook or Chambersburg limestone near fault.
306	321	Spring on Purgatory Creek, 3.4 miles northwest of Indian Rock	Feb. 11	500	51.4	40	Martinsburg shale.
307	322	Spring on Lee Highway, 1.8 miles southwest of Indian Rock	Feb. 15 Apr. 5	250 200	54.6 54	56 70	Conococheague limestone.
308	309	Zion Hill Church Spring, 4.8 miles southwest of Eagle Rock	Feb. 20	60	55	47	do.
309	310	J. L. Simmonds Spring, 7 miles southwest of Indian Rock	do	350	50.1	40	Stones River limestone.
310	313	Flowing Spring, 3.6 miles northeast of Fincastle	do	100	54.2	43	Beekmantown limestone.
311	311	Mineral Spring, 1 mile northeast of Fincastle	do	2	39.2	38	Athens shale near fault.
312	304	T. H. Potter Spring, 1.6 miles southeast of Haymakertown	Apr. 5	500	52	70	Stones River limestone.
313	303	H. J. Old Spring, 3.4 miles southwest of Haymakertown	Apr. 5	200	55	65	Copper Ridge dolomite.
314	.....	C. W. Francis Spring, 4.4 miles southwest of Haymakertown	do	60	54	59	

TABLE 7.—*Data on springs in the thermal springs region of Virginia and West Virginia—Continued*

CRAIG COUNTY, VA.

Number I	Number II	Name and location	Date, 1928	Flow (Gallons a minute)	Temperature (°F.) Water	Temperature (°F.) Air	Geologic occurrence
315	231	Walter Givens Spring, 0.5 mile southwest of Newcastle.	Apr. 4	60	55	75	Oriskany sandstone on nose of anticline.
316	230	C. E. Lefel Spring, 2 miles southwest of Newcastle	do	5,000	49.5	75	Stones River limestone on nose of anticline.
317	229	C. E. Lefel Spring, 2.2 miles southwest of Newcastle	Apr. 4	200	51.5	75	do.
318	228	Dudding Spring, 3 miles southeast of Newcastle	do	2,000	52	68	Probably fed by Meadow Creek.
319	227	O. G. McCartney Spring, 3.8 miles southwest of Newcastle	do	15	47	65	Beekmantown limestone.
320	226	O. L. Huffman Spring, 4.2 miles southwest of Newcastle	do	40	52	65	do.
321	225	Spring on Meadow Creek 6.4 miles southwest of Newcastle	do	30	52	64	do.
322	223	Minor Taylor Spring, 8.5 miles southwest of Newcastle	do	80	52	60	do.
323	222	C. Reynolds Spring, 9 miles southwest of Newcastle	do	60	52	60	do.
324	220	Spring 9.4 miles southwest of Newcastle	do	30	49	57	do.
325	221	Spring 9.4 miles southwest of Newcastle	do	10	49	60	do.
326	224	J. M. Givens Spring, 8.5 miles southwest of Newcastle.	do	600	49	59	do.

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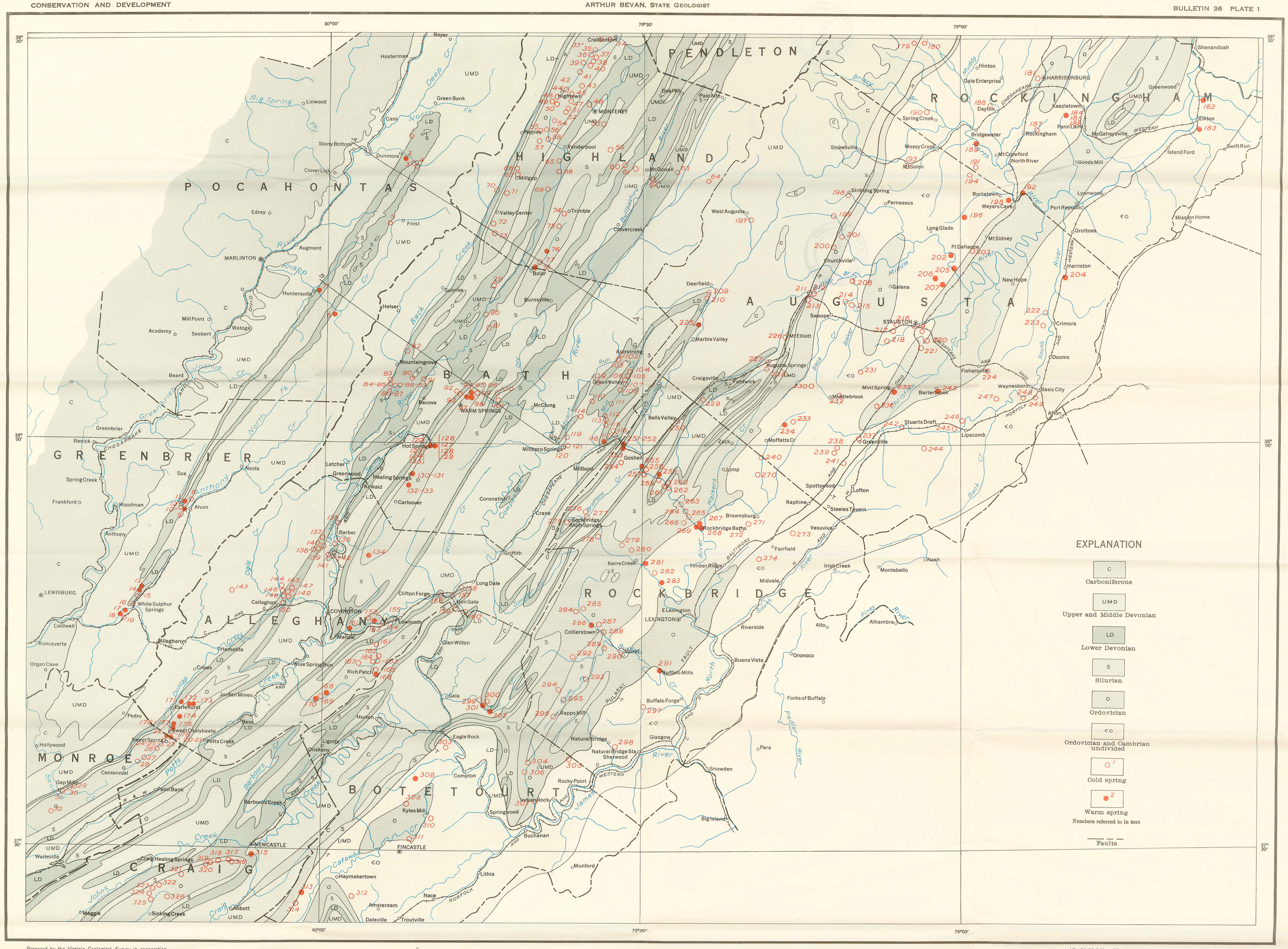
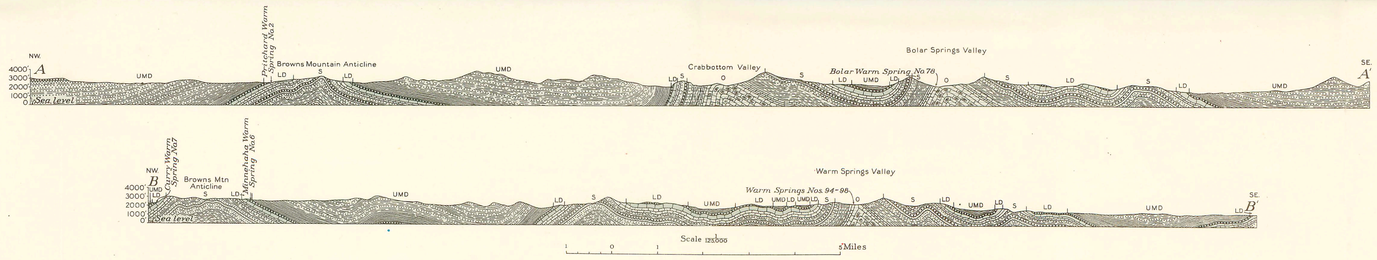
Watauga shale (see Rome shale).
Water Resources and Power Division, 3
Watson, T. L., cited 7, 14, 15, 25, 28
White Sulphur Spring 6, 15, 16
Wright, F. J., cited 21



Prepared by the Virginia Geological Survey in cooperation with the U. S Geological Survey.
Geology compiled by Frank Reeves, 1929, from the Geologic Map of Virginia, U. S. G. S. Geologic folios, and unpublished map of the Appalachian Valley in Virginia by Charles Butts. Recent work by Butts shows that some of the areas in southwestern Botetourt County, and in Craig County, mapped as Carboniferous, are Upper Devonian. Hydrology by Frank Reeves, 1929.



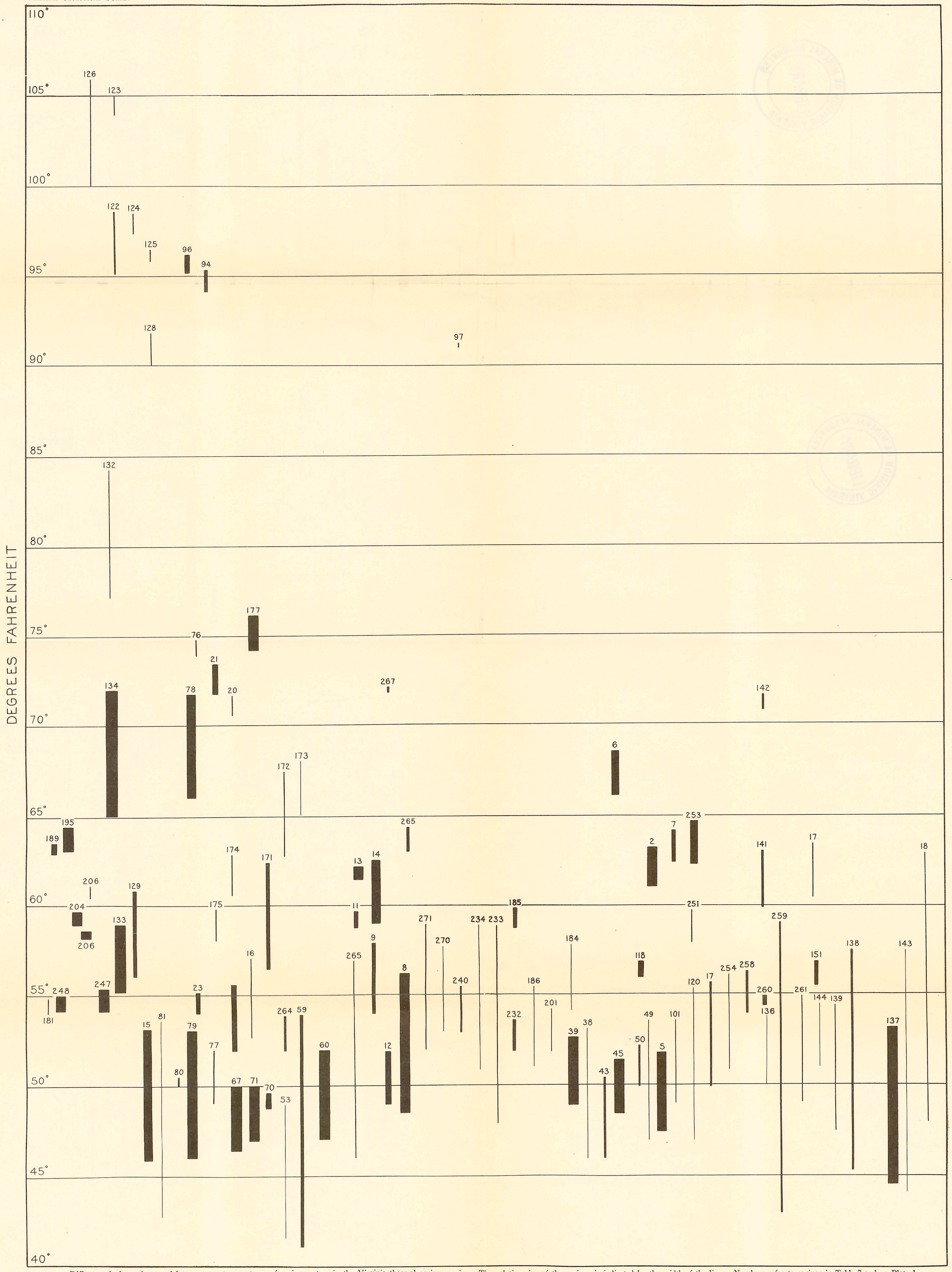
A. Hoen & Co. Lith. Baltimore, Md.

Structure sections are generalized and modified after N. H. Darton, U. S. Geological Survey, Geological Atlas, Staunton folio, (No. 14), 1894.

GEOLOGIC MAP OF THE THERMAL SPRINGS REGION OF VIRGINIA AND WEST VIRGINIA

Scale 1:250,000

0 5 10 15 Miles



Difference in late winter and late summer temperatures of spring waters in the Virginia thermal springs region. The relative size of the springs is indicated by the width of the lines. Numbers refer to springs in Table 7 and on Plate 1.