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THE TEMPERATURES OF HOT SPRINGS AND THE SOURCES OF THEIR HEAT AND WATER SUPPLY. IV[1]

THE HOT SPRINGS OF ARKANSAS

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The general geologic setting of the Hot Springs of Arkansas, the oldest of our national parks, has been described by a number of authors, but the most comprehensive description of the area appears in the recently published folio by Purdue and Miser.[3] The hot springs are situated in the Ouachita Mountains on the southern border of one of the smaller ranges and on the northern border of an intermontane basin. The rocks are Paleozoic in age and deformed by folding of Appalachian type. The hot water rises through fractured sandstone at the nose of a plunging anticline. Numerous

[1] Continued from *Journal of Geology*, Vol. XXXII, p. 399.

[2] Published by permission of the director of the U.S. Geological Survey, and the director of the National Park Service.

Secretary's note: On account of Mr. Bryan's early departure for field work his paper was presented only by title, and was originally represented among the papers submitted for publication only by a brief abstract. The delays incident to publication have fortunately made it possible, through the kindness of the editors of this *Journal*, to substitute this informative new material for the original abstract.—R. B. S.

[3] A. H. Purdue and H. D. Miser, *U.S. Geol. Survey, Geol. Atlas* (1923), Folio 215.

small dikes cut the folded structures, and near by at Potash Sulphur Springs and at Magnet Cove are small, stocklike intrusions. The igneous rocks are thought to be of Cretaceous age.

The spring openings at Hot Springs are numerous, but all are found within an area of about 20 acres. The total flow has been estimated at 165 gallons a minute and the temperatures range from 35° to 64° C. Analysis of the somewhat random measurements made in the past 120 years gives no trustworthy evidence of a permanent increase or decrease in flow or temperature.

The writer has recently published[1] a description of the geological conditions at the Hot Springs of Arkansas, and to this paper the reader is referred for the details of the geological work done at Hot Springs in 1921. The hypotheses which have been proposed to account for the supply of heat and water are summarized below, but, in the paper already referred to, the history of speculation regarding the origin of the water and heat is reviewed at greater length.

There are three principal hypotheses of origin. According to the one having the greatest number of advocates, the water is entirely meteoric and enters a porous bed in an anticline northwest of the springs, passes under a syncline, and emerges in the next anticline because of hydrostatic pressure. Because the probable depth of the line of travel under the syncline is small and heating of the water by depth alone seems improbable, it is assumed that here the water comes in contact with hot rock, perhaps a cooling plug of igneous origin. However, the lowest part of the anticline in which the water is to gather is lower than the highest of the springs; therefore, there can be no movement due solely to hydrostatic head. Evidence is also brought forward to show that there are other springs of strong flow in the surrounding region of similar mineralization and with temperatures above normal. Therefore, a special mechanism for flow or as a source of heat is invalid, and a general cause, capable of producing all the springs, must be sought. On this account the simple hypothesis that the water is derived from a cooling and crystallizing igneous mass directly under the springs

[1] Kirk Bryan, "The Hot Water Supply of the Hot Springs, Arkansas," *Jour. Geol.*, Vol. XXX (1922), pp. 425–49.

seems unlikely, for it would be necessary to postulate several such masses distributed over an area 50 miles in diameter, and there is no other evidence of igneous activity save the dikes and stocks, previously referred to, which are of Cretaceous age.

It seems more likely that in the Pleistocene uplift of the region deep fissures or faults were formed of which no surface expression has been discovered. These fissures doubtless extend into the deep interior of the earth whence juvenile water rises and, mixed with meteoric water, comes to the surface through shattered rock at the end of the Hot Springs anticline. In its rise this water is purged by various chemical reactions of most of its original dissolved contents and has acquired the moderate mineralization now characteristic.

It is obvious that such a theory rests on general argument, yet the geological setting and the details of the local structure are relatively well known. It also seems unlikely that further study of the structural geology or geologic history will shed much light on the problem. Locally, the rocks have been mapped to an accuracy of 25 feet in the position of contacts, and, except for artificial exposures that may be made in the future, little new information can be gained by the ordinary methods of geologic inquiry. Therefore, further work must be directed toward the collection of physical and chemical data that, it is hoped, will yield useful information on the problems involved, and lead to specific rather than general evidence in favor of one or other of the proposed theories of origin.

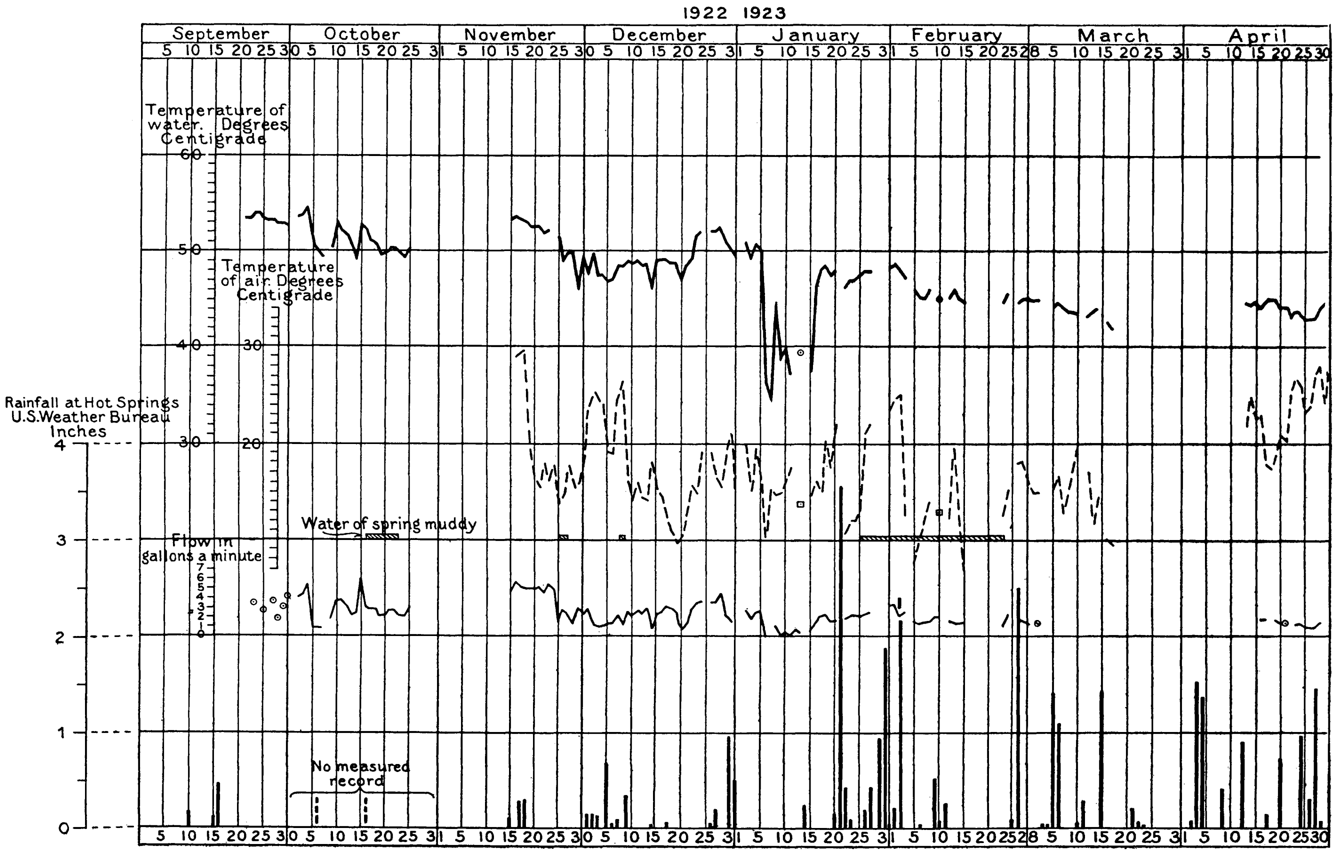
On a second visit to Hot Springs in September, 1922, the writer made observations on temperature and flow of certain springs, and discovered fluctuations heretofore unrecognized. These observations, begun for administrative purposes, have been continued to the present date by the National Park Service, through the interest of the administrative officials in Washington and of the superintendents at Hot Springs—Dr. C. H. Waring until April, 1924, and Dr. J. E. Bolten, the present incumbent. Except for the initial five days' observations all readings and measurements have been made, under detailed instructions from the writer, by William F. Walters, whose faithful and careful work is much appreciated.

The hot springs have been in use as a bathing resort since prehistoric time, but active interference with natural openings began between 1860 and 1870 when open wooden troughs as a means of conveying hot water to the bathhouses were replaced by pipes. The most extensive changes were made in 1890–92 when the hillside above "Bathhouse Row" was converted into a park by landscape gardening. Since that time a complicated system of spring structures, collecting reservoirs, and pipe systems has been evolved that makes impossible a measurement of the total flow of the springs at any one instant. Existing "measurements" are summations of the flows of individual springs taken at intervals extending over a week or more. Only a few of the springs are sufficiently accessible so that even temperature observations can be made at frequent intervals. Due to these practical difficulties the system of measurements set up in 1922 is incomplete and inadequate for a complete analysis. The results so far obtained are, however, interesting and suggestive, and it is hoped that a continuation of the observations will yield data not only useful in the administration of the national park, but of scientific value.

Measurements of temperature have been made at three springs only. The readings are made with a mercurial thermometer totally immersed in the hottest part of the pools in which the water issues. Several thermometers, all centigrade, have been used. The early ones were graduated to degrees only, and it was necessary for the observer to estimate tenths. The present type read directly in tenths of degrees. The corrections to be applied to the readings are all small, and for some of the instruments can be disregarded. The ordinary time of observation is from eight to nine in the morning, and more than one reading was made on a few days only. Nearly every Sunday is missing, and there are other gaps in the record for various causes. Of the three springs two have rather strong flows and emerge in the basements of bathhouses where they are protected from the extremes of air temperature. The third spring, known as the "Stevens," or "No. 37," emerges on the hillside under a masonry arch and within a masonry curb, from which it overflows through a pipe. The pool of water is 3 feet long by 2 feet wide and 2 feet deep. It is possible to measure the flow of this spring by turning a valve and allowing the water to flow into a bucket, and this measurement has been made at the same time as the observations on temperature.

Data pertaining to Stevens Spring for the period September 20, 1922, to January 31, 1924, are shown graphically in Figure 1. A preliminary examination indicates that during the period the flow varied from zero to 6 gallons a minute, and the temperature from 34.4° C. to 54.5° C., a range of 20 degrees. From September 20 to December 30, 1922, the temperature exceeded 50° C. frequently, but since that time such high temperatures have not occurred, the maximum being 48.5°C. During the period of high temperatures the largest flows were recorded, and there is a nice correlation of flow and temperature, the highest temperatures being recorded at times of greatest flow. There is evidence, not as complete as one would wish, that artificial draft on sources situated at lower levels caused the lower flows during this period. The lower temperatures at these times were therefore consequent on cooling of the diminished quantity of water passing through the spring opening into the masonry basin. The air temperature at the time of reading the water temperature was recorded from November 16, 1922, to January 31, 1923, but it is obvious from an inspection of the plotted curves in Figure 1 that this temperature is not decisive. It is the accumulated deficiency of temperature through the preceding night that cools the water. From January 6 to January 16 the temperatures of the spring water that were recorded are very low and on several days fall below 40° C. During this period the flow is also very small, and on January 6 the spring was dry. Heavy pumping from a source of hot water at a lower level is also recorded at this time and is the proximate cause of this low flow. The unusually low temperatures are the necessary consequence of the cold weather of winter and the slow rate at which water entered the basin.

After January 30, 1923, the correlation between temperature and flow is not obvious. The flow is small and relatively constant, ranging from 1 to 2 gallons a minute, and there seems to be no tendency toward the large flows and high temperatures of the previous period. However, the air temperature at the time of reading seems to have more importance, and in a number of instances


1922 1923
September
October
November
December
January
February
March
April
Temperature of water. Degrees Centigrade
Temperature of air. Degrees Centigrade
Rainfall at Hot Springs U.S. Weather Bureau Inches
Water of spring muddy
Flow in gallons a minute
No measured record

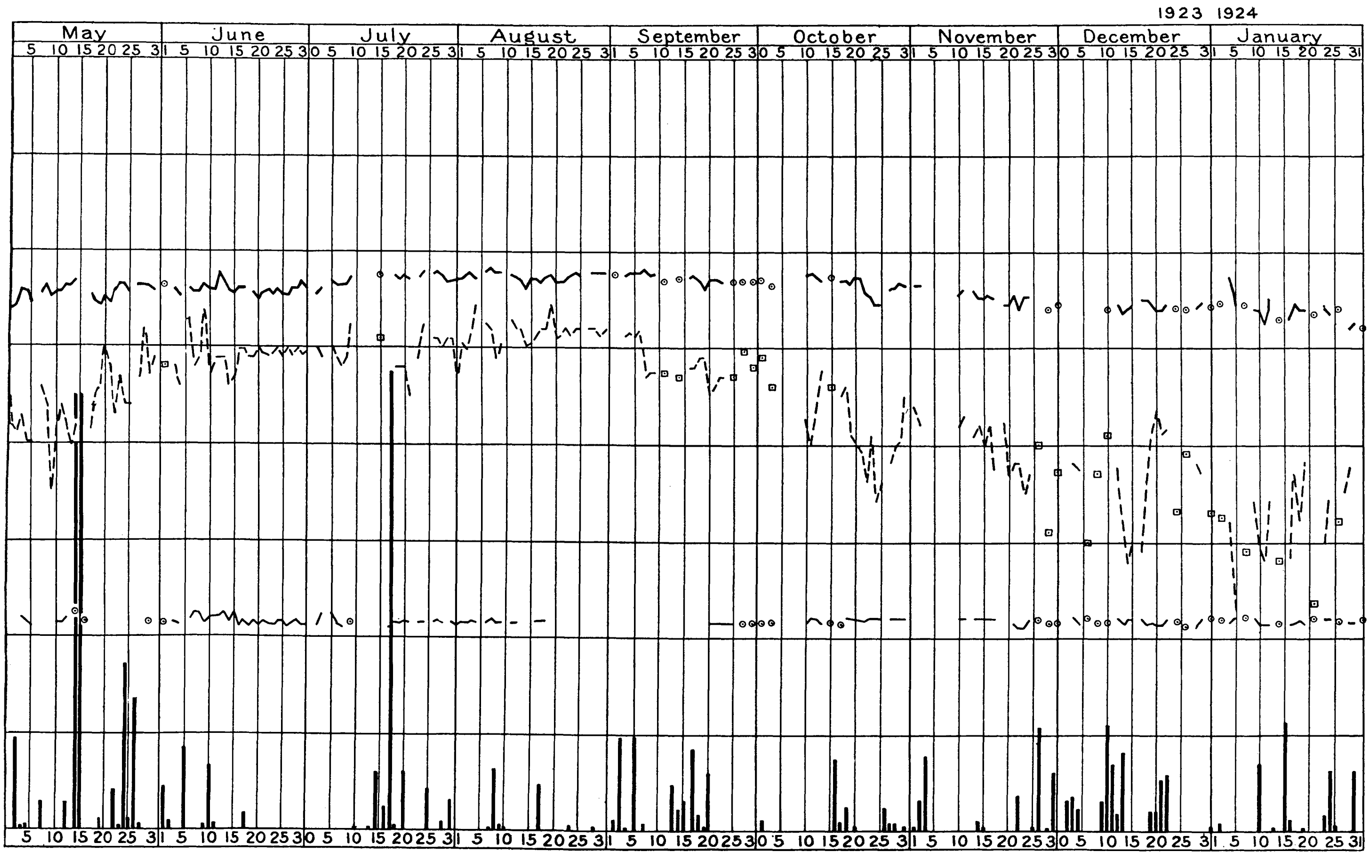


FIG. 1.—Observations at Stevens Spring, September 20, 1922, to January 31, 1924. Readings of temperature of water in heavy line; of temperature of air in dashed line; of flow in medium line.

there is some similarity between the curves of air and water temperature, as plotted in Figure 1. This tendency is more noticeable in the winter months. It is probable that this correlation between temperatures of air and water is a consequence to be expected at periods of low flow.

The influence of rainfall on the flow and temperature of the spring is not wholly clear. Table I summarizes the rainfall of the years 1921–23.

The observations recorded in Figure 1 were started in September, 1922, in a notable period of drought that began in May, 1921, and continued to January 20, 1923. During this time the accumulated deficiency exceeded 17 inches, and only one month, March, 1922, had a notable excess of moisture. It is possible that the high water-temperatures observed from September 20 to December 30, 1922, may have been due to the drought and consequent lack of contamination of the hot water by local seepage. Certainly the small rains of October, November, and December tended to make the water of the springs muddy or turbid, and the rainy period from January 18 to February 11, 1923, brought on a long spell of muddy water (see Fig. 1). However, there is no evidence that rains increased the flow of water, nor is muddy water recorded during the remainder of the wet year of 1923 when the excess of rainfall was 13.21 inches. It seems, therefore, that the existing data are inadequate to show the relation, if any exists, between rainfall and the flow and temperature of the spring.

The general course of the temperature curve, disregarding the fluctuations from day to day, shows a seasonal swing. Higher temperatures from July to the middle of November and lower temperatures during the rest of the year are recorded. Doubtless this swing is due to the change from summer to winter. The lower air temperatures of winter affect the water in the spring basin and doubtless also the upper 20 feet or so of the rock conduit from which the spring issues. However, the use of water and therefore the draft on sources that may affect the flow of Spring No. 37 varies through the year. This fluctuation can be indirectly measured in the income of bathhouses for which statistics have been gathered for many years. As shown in Figure 2, the months January to

TABLE I

MONTHLY AND ANNUAL RAINFALL, IN INCHES, AT HOT SPRINGS, ARKANSAS, WITH DEPARTURES FROM THE NORMAL FOR THE YEARS 1921–23

(From published data of the U.S. Weather Bureau)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1921	1.61	4.83	7.21	9.07	0	3.40	1.85	4.40	3.29	0.49	5.89	3.62	45.66
Departures from normal	−3.49	+0.96	+2.13	+3.01	−6.01	−1.34	−2.69	+0.57	−0.29	−2.21	+1.42	−0.68	− 8.62
1922	1.90	4.21	9.58	4.80	7.41	3.40	4.44	2.22	0.72	3.22*	0.64†	3.25	45.79§
Departures from normal	−3.20	+0.34	+4.50	−1.26	+1.40	−1.34	−0.10	−1.61	−2.86	−0.87*	−3.83‡	−1.05	− 8.49§
1923	9.55	5.10	4.64	7.81	14.26	2.41	7.10	1.30	4.83	1.56	3.37	5.56	67.49
Departures from normal	+4.45	+1.23	−0.44	+1.75	+8.25	−2.33	+2.56	−2.53	+1.25	−1.14	−1.10	+1.26	+13.21
Means	5.10	3.87	5.08	6.06	6.01	4.74	4.54	3.83	3.58	2.70	4.47	4.30	54.28

* Record at Mount Ida, Arkansas.

† Incomplete record.

‡ Too large by small amount.

§ Approximate value due to substitutions noted in *, †, and ‡.

April, inclusive, are the period of large business and heavy draft. September to November, inclusive, are the months of minimum income and therefore of draft. This seasonal fluctuation resembles the seasonal swing in temperatures previously described and may be a factor in its production. If the record can be maintained for several additional seasons, analysis of this factor and its relation to the seasonal change in the climatic elements can be made more definite.

The two strong springs have very small fluctuations in temperature. One of them has a total range of half a degree centigrade, the other of 1.4°. Unfortunately, it is impossible, except at considerable expense, to measure the flows of these springs. The record of

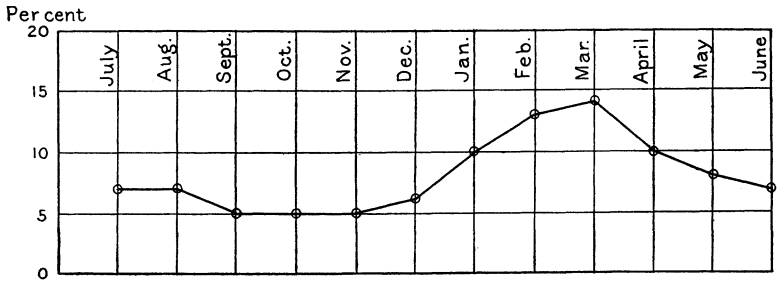


FIG. 2.—Diagram showing the variation by months in the use of hot water expressed in percentage of the mean income of bathhouses for the years 1915–20.

fluctuations in temperature has not yet been thoroughly studied, but there is no doubt that the recorded variations in temperature are real and not due to errors, and that a seasonal swing similar to that shown in the record of the Stevens Spring seems to hold for these larger springs.

General conclusions can hardly be expected at this stage of the observations briefly reviewed above, and must await a longer period of record and a more complete analysis. Irrespective of the ultimate origin of the water, its passage through the surface rocks within the zone of seasonal change in temperature and its issuance into a spring basin will produce seasonal changes such as have been recorded. The high temperatures and strong flow of the Stevens Spring in the fall and early winter of 1922 were not repeated in the same period of 1923 and may, in this instance, be due to differences in climatic factors, specifically the abnormally dry seasons of 1921 and 1922, or may be due wholly to artificial control. The element of artificial control is, until much longer and more complete records are available, almost impossible to eliminate in the study of the fluctuations in flow of these springs.

One of the most useful things brought out by the records is the mere fact of fluctuation and its range, amounting to 20° C., in a spring of small flow. Random measurements of temperature in such springs seem, in the light of this experience, to have small value. Even springs of relatively large flow protected from extremes of air temperature have detectable variations in temperature.

HOT SPRINGS AND FUMAROLES OF "THE GEYSERS" REGION, CALIFORNIA

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(Notes by the Secretary)

The speaker visited the region in 1922, with the permission of the owner of the property, and made measurements of temperatures and other observations on the fumaroles and springs, but the detailed data are not yet available for publication.

These hot springs and fumaroles—they include no true geysers—are in Sonoma County, California, about 70 miles northwest of San Francisco. They are in a general hot-spring region which includes the neighboring counties of Lake and Napa, at the western base of the Coast Range. A description of "The Geysers" has been published by Waring,[1] with twelve analyses of the waters. The temperatures of the springs whose waters were analyzed were from 21° to 100° C. The temperature in 1909 of the best-known fumarole vent, known as Steamboat Geyser, is given as 205° F., but much higher temperatures are known to exist in the region.

[1] G. A. Waring, *Springs of California, U.S. Geol. Survey Water-Supply Paper 338*, 410 pp., 13 pls., 1915. ("The Geysers," pp. 83–88, Plate X.) This publication contains the most complete available description of the hot springs of California.