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THE HOT WATER SUPPLY OF THE HOT SPRINGS, ARKANSAS[1]

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CONTENTS

INTRODUCTION

An investigation of the geology of the hot springs in the Hot Springs National Park was recently undertaken for the purpose of determining whether the supply of hot water can be increased. Some new facts were obtained, earlier work critically examined, and recommendations made. The problem is intimately related to the ultimate origin of the water. Thus an investigation begun solely for economic reasons led to a consideration of one of the most

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[1] Published by permission of the Director of the United States Geological Survey.

intricate and uncertain realms of geologic theory. Is the hot water of meteoric, juvenile, or mixed origin? On the answer to this question depends, in a measure, the future of Hot Springs, Arkansas.

ACKNOWLEDGMENTS

To the officials of the National Park Service, through whose co-operation the work was undertaken, the writer is indebted for the opportunity of making this study. The local officers of the Park Service and Colonel John R. Fordyce extended numerous courtesies in Hot Springs. Messrs. H. G. Ferguson, O. E. Meinzer, Clyde P. Ross, and W. D. Collins have read the manuscript and offered valuable suggestions. Mr. H. D. Miser has generously allowed the use of much unpublished material from his extensive researches in the geology of Arkansas.

CHARACTER OF THE HOT WATERS

The waters of forty-six springs have been analyzed by Haywood.[1] The mineral contents vary from 170 to 310 parts per million, and in only a few of the springs do the mineral contents fall below 270 parts or rise above 290 parts. Silica is an important constituent ranging from 32.5 to 52.3 parts per million but being usually between 44 and 47 parts. Calcium (Ca) ranges between 26 and 50 parts per million while the bi-carbonate radicle (HCO_3) ranges between 94 and 172 parts per million. The excess of carbon dioxide is satisfied by small amounts of magnesium, potassium, and sodium. The sulphate radicle ranges from 6 to 28 parts per million, and chloride from 2.36 to 3.33. Their salts therefore form only a small part of the total solids. Small quantities of manganese, traces of phosphorus, of combined nitrogen, iron, and aluminum are present. Boron, iodine, and bromium are reported as small quantities or in traces.

The waters of two cold springs which are located at the pavilion north of the Arlington Hotel have a mineral content of 36.4 and 43.7 parts per million. The water is similar to the hot water except

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[1] J. K. Haywood, *Report of an Analysis of the Waters of the Hot Springs*, etc. Sen. Doc. 282, 57th Congress, 1st Sess. (1902), pp. 1–78.

for lower mineralization and greater proportionate content of silica and magnesium.

The contrast in mineral content between the hot water and the two cold springs mentioned above seems to be general in the region, and in a later paragraph the available temperature measurements are discussed. In the table below the water of one of the hot springs is compared with four other springs in Garland County. Big Chalybeate, Mountain Valley, Blanco, and Dripping springs are

ANALYSES OF SPRING WATERS IN GARLAND COUNTY, ARKANSAS

(Parts per million)

Constituents	A	B	C	D	E	F	G	H	I	J	K
Silica (SiO_2)	45.6	3.8	16	22	14	12.5	15.1	6.5	5.1	12	15
Iron (Fe)	.2	7.4	.2	.3	1.2	3.4	3.4	.2	.9	4.6	6.3
Aluminum (Al)		......	1.2	.3	Tr.			.1		......	.5
Calcium (Ca)	46.9	70	78	83	76	1.9	3.8	5.3	1.7	3.8	1.4
Magnesium (Mg)	5.1	4.1	12	8.4	2.9	1.4	1.4	.7	......	2.4	1.5
Sodium (Na)	4.7	1.4	6.5	3.9	2.1	2.1	2.2	1.5	.8	.5	2.4
Potassium (K)	1.6	3.1	.5	3.3	.5	.9	1	.3		.1	.9
Bi-carbonate radicle (HCO_3)	168.1	260	284	288	228	12.1	15.1	18	8	2.4	9
Sulphate radicle (SO_4)	7.8	9.4	25	8.2	12	2.5	2.3	1.9	......	21	16
Chloride radicle (Cl)	2.5	2	4.4	7	6.2	1.8	2	2.7	2.9	3.3	4.4
Total solids (calculated)	198.5*	229.7	283	278.7	226.8	42	41	28.3	17.6	49.5	52.4

* Total solids determined.

EXPLANATION OF TABLE

A. Big Iron Spring, No. 15 of Hot Springs group. Small amounts of nitrogenous material; PO_4, .05; BO_3, 1.29; Br and I, trace; Ba and Sr, trace; Li, trace; gases, nitrogen 8.8, oxygen, 3.79, carbon dioxide (free) 6.92, cubic centimeters per liter at 0° C. and 760 mm. pressure. Analyst, J. K. Haywood, 57th Congress, Sen. Doc. No. 282, p. 46.

B. Big Chalybeate Spring; NW. ¼, SE. ¼, Sec. 22, T. 2 S., R. 19 W. Analyst, A. E. Menke. Reported by J. C. Branner, "Mineral Water of Arkansas," *Arkansas Geol. Survey Ann. Rept. 1891*, Vol. I (1892), p. 28.

C. Mountain Valley Spring, Sec. 19, T. 1 S., R. 19 W., 12 miles north of Hot Springs. Reported by Branner, *ibid.*, p. 69.

D. Blanco Spring, NE. ¼, Sec. 1, T. 2 S., R. 21 W. Reported by Branner, *ibid.*, p. 30.

E. Dripping Springs, one of Grandma Chase's springs, 6 miles northeast of Hot Springs. Reported by Branner, *ibid.*, p. 48.

F. Liver Spring. Cold spring in pavilion north of Arlington Hotel. Small amounts of nitrogenous matter; PO_4, trace; BO_3, trace; Br and I, trace; Li, trace; gases, nitrogen 14.36, oxygen 6.24, carbon dioxide (free) 21.8, cubic centimeters per liter at 0° C. and 760 mm. pressure. Analyst, J. K. Haywood, *op. cit.*, p. 75.

G. Kidney Spring. Cold spring in pavilion north of Arlington Hotel. Small amounts of nitrogenous matter; PO_4, BO_3, Br, I, and Li, traces; gases, nitrogen, 15.3, oxygen 5.3, carbon dioxide (free) 28.5. Analyst, J. K. Haywood, *op. cit.*, p. 76.

H. Happy Hollow Spring, 600 yards north of Arlington Hotel. Reported by Branner, *op. cit.*, p. 52.

I. Same as above. Analyst, R. B. Riggs. Reported by Branner, *op. cit.*, p. 53.

J. Red Chalybeate Spring, one of Grandma Chase's springs. NE. ¼, NE. ¼, Sec. 25, T. 2 S., R. 19 W. Reported by Branner, *op. cit.*, p. 50.

K. Happy Hollow Chalybeate, 100 feet west of Happy Hollow Spring. Reported by Branner, *op. cit.*, p. 54.

all relatively strong springs, though none of them are considered to be "hot" springs. The two cold springs in the pavilion, Liver and Kidney, are small seeps and their waters are similar in type and total content with Happy Hollow, Happy Hollow Chalybeate, and Red Chalybeate springs. The last-mentioned spring was not seen but the two Happy Hollow springs and the springs in the pavilion have their origin in the storage of rain water in soil, talus, and the upper fractured part of the underlying rocks. There seems then to be a notable difference between the shallow meteoric waters and the waters of larger springs.

In 1904 Boltwood[1] determined the radioactivity of samples from forty-four springs. He found no evidence of radium salts in the water and attributes the radioactivity to the presence of radium emanation, a gas. The intensity of radioactivity varies from 0.5 to 265.8, a numerical expression for the equivalent uranium represented by the radium emanation ($g \times 10^{-4}$ U). There are, therefore, great differences in the radioactivity of the springs, but their average intensity is 24.9. The cold springs north of the Arlington have activities of 17.4 and 106.8. The spring having an activity of 106.8 is exceeded by only one of the hot springs, and the other has an activity not far from the average of the hot waters. Boltwood says: "As a general summary it can be stated that it has been found impossible to establish any connection between the temperature, flow, location, or chemical composition of the water of the springs and the observed differences in the radioactive properties."[2]

Previous observations on temperature have been reviewed by Weed:

> In 1804 Dunbar and Hunter recorded a temperature of 100° F., for the larger spring and 154° F. for another spring. . . . . The comparison of the old records with those recently made shows that the highest temperature known today is 147° F. as against 154° in 1804, and 150° by Glasgow and 148° by Owen in 1860. In a number of springs there is a decline of 2° since the latter date. Such a slight difference might, however, be due to differences in the manner or place of taking temperatures, or the instruments used in the

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[1] Bertram B. Boltwood, *Ann. Rept. Secy. of Interior*, 1904; also *Amer. Jour. of Sci.*, 4th Ser., Vol. XX (1905), pp. 128–32.

[2] *Ibid.*, p. 132.

earlier years may not have been accurate. In one instance, that of Alum Spring, there is a marked decrease in temperature. . . . . In 1804 this had a temperature of 132°. In 1859 . . . . 133° . . . . and today it is but 114.8°.[1]

Haywood[2] gives temperature measurements for forty-four hot springs which range from 95.4° to 147° F. For thirty-nine springs he gives two measurements each, separated by about two months' time. In fourteen of these thirty-nine springs there is a decrease in temperature, in eighteen there is an increase, and in seven there is no change during this interval of about two months. The average difference between readings is 1.5° F. The maximum decrease is 6.3° F. and the maximum increase 6.4° F. With such unsystematic discrepancies in the measurements of a competent observer with good instruments, no conclusion can be reached as to a general decrease in temperature or to the character of the probable variations in temperature.

The Hot Springs are usually considered to be the only hot springs of the region. Three warm springs, however, are known from the vicinity of Caddo Gap, about 50 miles west of Hot Springs. Data concerning these springs collected in 1915 by H. D. Miser are given in the following table:

SPRINGS NEAR CADDO GAP

Name	Location	Geological Formation	Temperature (Degrees Fahrenheit)
Springs in bed of Caddo River at Caddo Gap	NE. ¼, Sec. 19 T. 4 S., R. 24 W.	Upper part Arkansas novaculite	
North opening			94
South opening			96.8
Spring on Little Missouri River	N. ½, Sec. 17 T. 4 S., R. 27 W.		74.3
Spring on Redland Mountain	SW. ¼, Sec. 12, T. 5 S., R. 26 W.	Arkansas novaculite	77.0

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[1] W. H. Weed, "Notes on Certain Hot Springs of the Southern United States," *U.S. Geol. Survey, Water-Supply Paper 145* (1905), pp. 204–5. See p. 439 of this article for references to Weed's authorities.

[2] *Op. cit.*, pp. 30–31.

Certain springs near Hot Springs conform to and others are above the mean annual temperature of the air at Hot Springs which, based on the thirty-year record of the United States Weather Bureau, is 60.5° F. To this temperature the water of "ordinary" springs should closely approximate. Springs above the normal temperature are probably common as shown by the table below:

TEMPERATURE OF GARLAND COUNTY SPRINGS

	Degrees Fahrenheit
Big Chalybeate*	78.9
Grandma Chase's Springs:*	
Dripping Spring	59.2
Red Chalybeate Spring	62.8
Happy Hollow Chalybeate* (Not Happy Hollow Spring)	64.6
Potash Sulphur Springs:*	
West Spring	64 –71.6
South Spring	70.2–72
East Spring	68 –69.8
Springs in Pavilion† north of Arlington Hotel:	
Liver Spring	46.4
Kidney Spring	55.4

* J. C. Branner, *op. cit.*, pp. 28, 48, 50, 54, and 77–81.

† J. K. Haywood, *op. cit.*, pp. 75 and 76.

GEOLOGIC SETTING OF THE HOT SPRINGS

Most of the following discussion of the general geology of the region is condensed from a paper by Miser[1] and from the manuscript of a geologic folio by Purdue and Miser,[2] to be published by the United States Geological Survey. The geologic map, Figure 1, is largely a redrawing of the map in this folio. The Hot Springs are situated in that part of Arkansas known as the Ouachita Mountains. These mountains are composed of numerous nearly east to west ridges and several intermontane basins. Some of these mountains are simple ridges, but others are small ranges. The

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[1] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Amer. Jour. of Sci.*, 5th Ser., Vol. II (1921), pp. 62–89.

[2] Purdue and Miser, "Hot Springs and Vicinity Quadrangle Geol. Atlas of U.S.," *U. S. Geol. Survey*, folio, in preparation.

Hot Springs are located in the southern edge of one of these ranges called the Zigzag Mountains, and on the northern border of a lowland called the Mazern intermontane basin.

The rocks of the Ouachita Mountains are nearly all of sedimentary origin, but at Magnet Cove and Potash Sulphur Springs there are small areas of igneous rocks and at numerous localities near by there are small dikes.

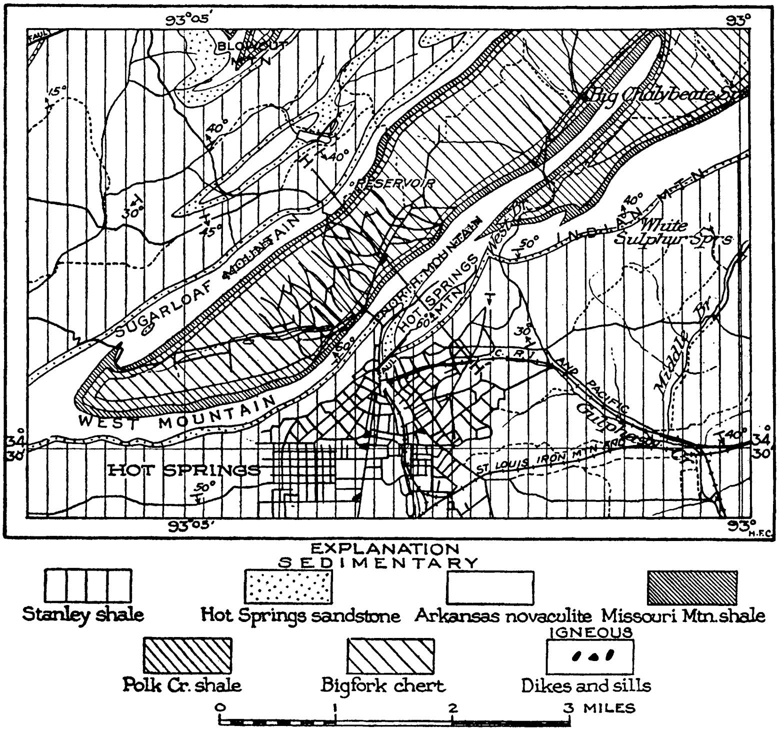

FIG. 1.—Geologic map of vicinity of Hot Springs, Arkansas, after Purdue and Miser.

The sedimentary rocks are indurated and hard, but are only slightly affected by metamorphism. The maximum thickness of the rock beds exposed in the Ouachita Mountains is 37,000 feet, but only a fraction of this total is exposed in the vicinity of the Springs.

The rocks exposed near the Hot Springs consist of the following, though both older and younger are known in the Ouachita Mountains:

GENERAL SECTION OF ROCKS NEAR HOT SPRINGS, ARKANSAS

Geologic Age	Name of Formation and Description	Thickness, Feet
Carboniferous (Mississippian)	Stanley Shale; black, fissile, clay shale, and hard compact sandstone	3,500±
	Hot Springs Sandstone; hard quartzitic laminated gray standstone with heavy bedded conglomerate at the base	200
	Unconformity	
Devonian	Arkansas Novaculite; upper half mainly thin-bedded novaculite and black shale; lower half massive novaculite	500±
	Unconformity(?)	
Silurian	Missouri Mountain Shale; clay shale generally dark greenish drab to black but red in many places	150
	Unconformity(?)	
Ordovician	Polk Creek Shale; black graphitic shale in which graptolites are abundant	200
	Bigfork Chert; thin-bedded gray to black chert much shattered and black shale	700

The rocks mentioned above were deposited one above the other in great sheets. Since their deposition they have been subjected to intense lateral compression which besides lifting the area has produced folds of a general east and west trend. Near the springs these folds have a northeast and southwest trend and the edges of the strata now appear at the surface, and on the map form great looping curves. The major folds consist of numerous smaller folds only a few miles in length, overlapping each other lengthwise. It is with these smaller folds that the springs are associated.

The structures which have the most to do with theories of the origin of the spring waters are the anticlinal fold whose limbs inclose the valley between West, Indian, and Sugarloaf mountains, the synclinal fold of North Mountain, and the anticlinal fold of

Hot Springs Mountain. The character of these folds is brought out in Figures 1 and 2.

GEOLOGY OF THE SPRINGS AREA

The hot water rises in an area of about 20 acres that lies along the east side of Hot Springs Creek, at the southwest base of Hot Springs Mountain. One spring lies west of the creek. Five are said to have risen in the bed, though only one of these can now be found. The spring area is marked by a deposit of calcareous tufa (travertine) from a few inches to eight feet thick over the older rocks. To the tufa the springs are daily making additions, though the present structures for collecting the waters have reduced the rate of formation of the tufa.

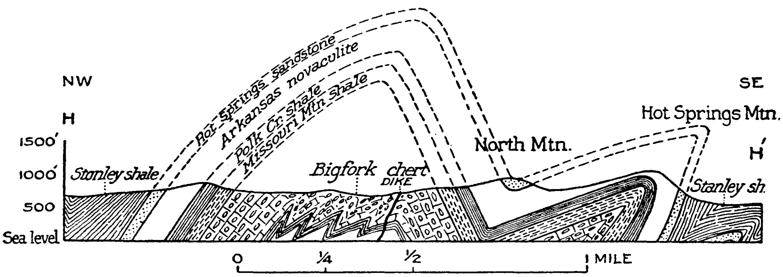

FIG. 2.—Geologic cross-section from Sugarloaf Mountain to Hot Springs Mountain (line *H–H′*, Fig. 1), after Purdue with modifications.

The grounds and springs were carefully mapped by Captain R. R. Stevens, U.S.A., in 1890, and he mapped the tufa, hard-rock outcrops, and springs. Figure 3 reproduces his boundaries for the tufa and for rock outcrops, except that corrections in the rock outcrops have been made at critical points during this investigation. On this map (Fig. 3), the boundaries of the geologic formations have been traced. Landscape gardening, roads, walks, and buildings all tend to conceal outcrops and in a number of places, as stated below, the location of geologic boundaries is uncertain.

The Hot Springs sandstone outcrops on Fountain Street, in Happy Hollow, where it is nearly vertical. From this point it extends along the foot of Hot Springs Mountain southwesterly

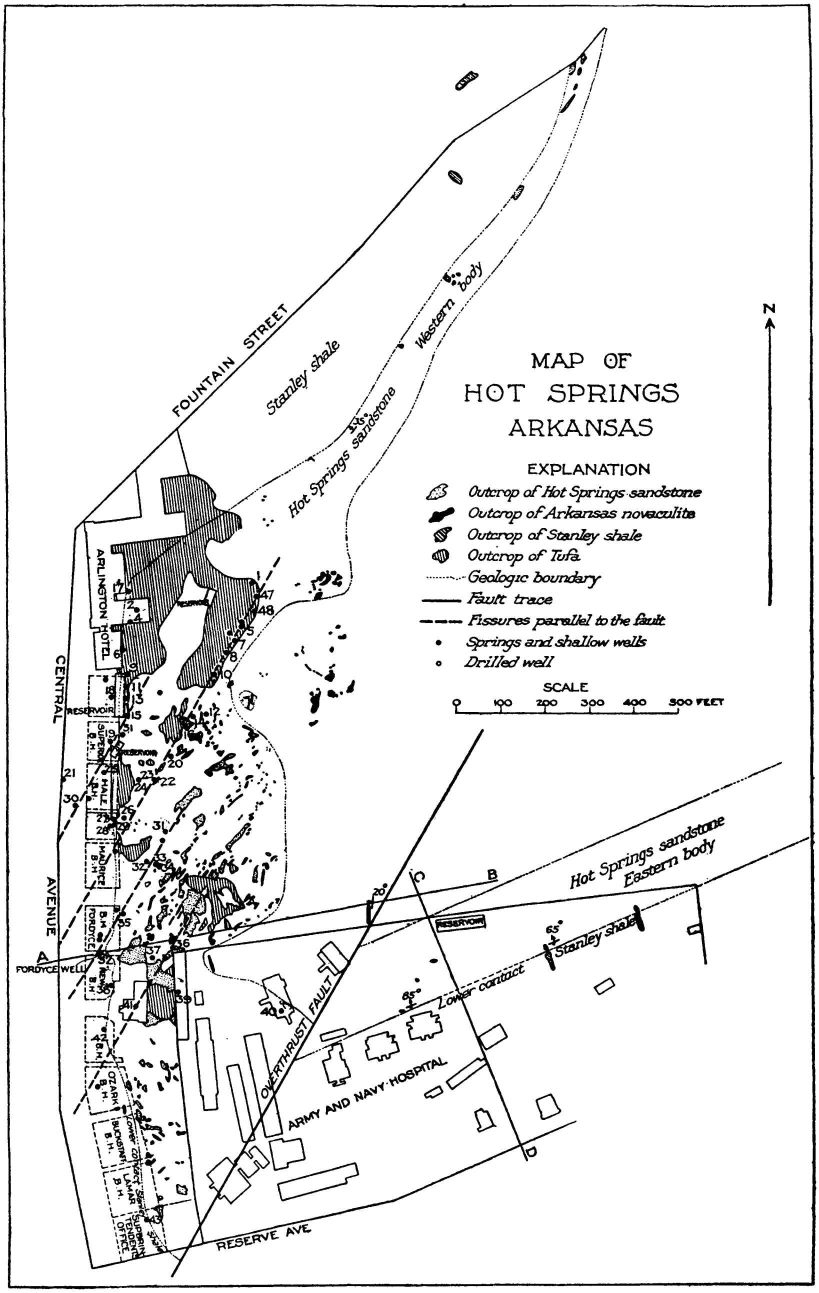

FIG. 3.—Map of the spring area, base and outcrops from Captain R. R. Stevens, U.S.A., 1890.

to the Arlington Hotel and then swings in a broader north and south belt to Reserve Avenue. In this broader belt it has a dip of about 30° and the contact with the overlying Stanley shale is well displayed in the basement of the Maurice, Fordyce, and "new" bathhouses. The lower contact of this body of Hot Springs sandstone extends along the hillside above the springs from the vicinity of the nurses' dormitory in the hospital grounds northwest. In general this contact can be located within 25 feet.

South of Reserve Avenue there are no outcrops of the sandstone, nor are there any in the western part of the hospital grounds.

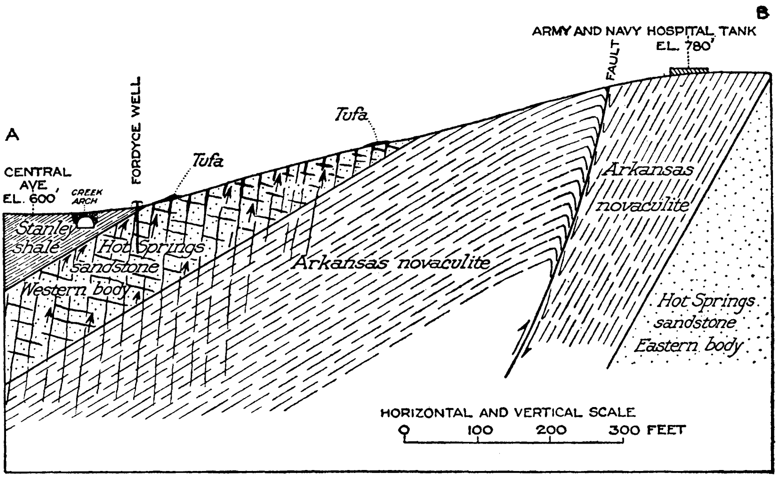

FIG. 4.—Geologic cross-section on line *AB*, Figure 3, through Fordyce well

Since the sandstone is hard and commonly produces outcrops it is assumed that the sandstone does not extend southward any appreciable distance beyond the park line.

This western body of sandstone is the northwestern limb of the Hot Springs Mountain anticline which in its extension along Bathhouse Row forms the nose of the plunging structure. Figure 4 is the cross-section of this part of the mountain on the line *AB* which shows the relation of this body of sandstone to the other rocks.

A second body of Hot Springs sandstone begins on the southeast flank of Hot Springs Mountain and extends southwesterly within the hospital grounds. This eastern body of sandstone dips northwesterly and is underlain by the younger Stanley shale and overlain by the older Arkansas novaculite. Obviously this body is the overturned southeastern limb of the Hot Springs Mountain anticline. Figure 5 is a cross-section of this part of the mountain and shows the relation of this body of sandstone to the other rocks.

The relation of these two bodies of sandstone once a continuous layer is somewhat uncertain because of the lack of outcrops in the western part of the hospital grounds. If the two bodies are continuous, an extremely close fold is necessary to bend the bed from a position dipping 30° west at the superintendent's office to 65° northwest near the reservoirs on the hospital grounds, 900 feet away. It seems likely that instead of bending, the beds broke along a thrust fault and this interpretation is shown in Figures 1 and 3. This postulated fault would have a plane which dips to the northwest and a trend about 30° east of north.

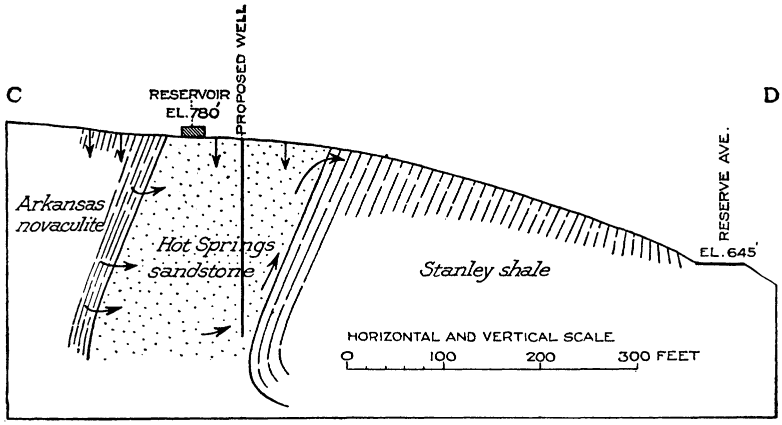

FIG. 5.—Geologic cross-section on line *CD*, Figure 3, through proposed cold-water well.

RELATION OF THE SPRINGS TO THE WESTERN BODY OF SANDSTONE

As shown in Figure 3, all the hot springs shown on maps since 1890 or now in existence emerge from the outcrop of the western body of sandstone or from the immediately adjacent Stanley shale. Similarly all the bodies of tufa which indicate the position of springs active or formerly active lie on the sandstone or on the immediately adjacent Stanley shale.

The Hot Springs sandstone of this body is somewhat harder than normal, is a darker color, and is much fractured. These fractures are commonly sealed with quartz and calcite, both apparently deposited by the hot waters. In a number of instances, notably in the Maurice and "new" bathhouses, where excavation has exposed the sandstone, the hot water can be seen emerging from the cracks and fissures of the rock.

The fractured sandstone is then the conduit for the hot water which is prevented from breaking out in the lower depression (the creek bed) by the Stanley shale through which it maintains only a few openings. Similarly the water closes the cracks and joints of the sandstone by deposition and consequently all the springs do not break out at the contact of the sandstone and Stanley shale but many of them emerge higher up the hill.

On the hillside, back of the bathhouses, the outcrops of sandstone are each extended in a northeasterly direction. Each outcrop in addition is marked by strong, nearly vertical jointing in this direction. The maps show also that the spring openings are arranged in lines of which the most marked is that belt of springs from the Egg Spring, No. 1, to the Maurice Bathhouse, which includes the strongest springs of the group. Four such lines of springs are marked on the map. These lines are approximately parallel to the thrust fault, postulated between the east and west bodies of the Hot Springs sandstone. A fifth line may be drawn parallel to the contact of the sandstone with the shale, but this line includes many springs situated on other lines. Obviously, if the sandstone were uniformly permeable and the shale uniformly impermeable, all the springs would lie on the contact.

The strong jointing in the sandstone, and the distribution and elongation of outcrops indicate a fracturing of the sandstone in a direction north northeast parallel to the Hot Springs anticline. Weed[1] noted the line of springs extending from Egg Spring, No. 1, to the Maurice Bathhouse and suggested that this line was a "fault fissure." It seems more likely that this line and the three

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[1] *Op. cit.*, p. 201.

other lines of springs simply mark the position of more open joints like the joints visible in the outcrops but that all the joints are parallel to and related in origin to a thrust fault which lies to the south of them. Doubtless similar cracks might have been formed by simple folding. However, the very absence of outcrops in the western part of the hospital grounds seems to be an argument in favor of faulting which would shatter and comminute the rocks along the line of the fault and thus make them more susceptible to erosion. Folding without faulting, on the other hand, would give a a double thickness of sandstone which would be almost sure to outcrop, and this same folding would presumably so shatter the sandstone as to make the line of the fold the locus of springs.

Whatever the ultimate origin of the water, it emerges through the cracks and joints of the Hot Springs sandstone and mainly along the strong jointing parallel to and probably related in origin to the postulated thrust fault. The bearing of these relations on development of the springs is obvious.

THEORIES OF ORIGIN OF THE HOT WATER

In 1804 William Dunbar[1] and Doctor Hunter visited the springs. They observed that the mountain was "principally siliceous, some part of it being of the hardest flint, others a freestone extremely compact and solid and of various colors. The base of the hill, and for a considerable extent, is composed of a blackish blue shistus, which divides into perpendicular lamina, like blue slate." They make extensive comments on the tufa deposited by the water. They estimated the flow of all the springs at 165 gallons per minute or 237,600 gallons daily. They suggested chemical reactions as the cause of the heat of the water, having found no evidence of volcanic action in the vicinity.

In 1806 a writer relates that he saw a volcanic outburst and streams of molten rock near Hot Springs. He is generally disbelieved by later writers.[2]

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[1] Thomas Jefferson, *Message of the President of the U.S. Communicating Discoveries Made in Exploring the Missouri, Red River, and Washita by Captains Lewis and Clark, Doctor Sibley, and Mr. Dunbar,* etc. A. & G. Way, printers, Washington, 1806.

[2] *New York Medical Repository,* Vol. III, No. 1 (1806), pp. 47–50.

In 1860, David Dale Owen,[1] state geologist of Arkansas, published an account of the springs with analyses and observations on temperatures. He rejects all chemical theories of origin of the heat.

> On the contrary, I attribute the cause of it to the *internal heat of the earth*, I do not mean to say that the waters come in actual contact with fire, but rather that the waters are completely permeated with highly heated vapors and gases which emanate from sources deeper seated than the water itself.

Owen believed that the novaculite was a sand rock which had been changed by the "permeation" of heated alkaline waters and considered the hot springs merely the dying phase of this extensive movement of water. He gives, however, no mechanism or conduit for these waters.

In 1892 J. C. Branner,[2] state geologist, discusses the origin of the heat and attributes the heat of the water to "coming in contact with the masses of hot rocks, the cool edges of which may or may not be exposed at the surface."

In 1902 Walter Harvey Weed published a geological sketch of the hot springs.[3] Weed noted that the principal springs are arranged along a line running NNE., parallel to the axis of the fold forming Hot Springs Mountain. He thought this a fault fissure. Fissuring in connection with faulting seems confirmed (p. 438). Weed considered that the purity of the waters, particularly their low content of silica, and the included gas which appears to be dissolved air, all point to a meteoric origin of the water, i.e., that the water is derived from rain and differs from ordinary spring water only in being heated. He believed this heat to be derived from still uncooled igneous rock intruded into the sediments below the springs. The upper parts of similar bodies

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[1] David Dale Owen, *Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas*, etc., pp. 18–27, Philadelphia, 1860.

[2] J. C. Branner, "Mineral Waters of Arkansas," *Arkansas Geol. Survey, Ann. Rept., 1891*, Vol. I (1892), pp. 8–23.

[3] J. K. Haywood, *Report of Analysis of the Waters of the Hot Springs*, etc.; and Walter Harvey Weed, *Geological Sketch of Hot Springs, Arkansas*. Senate Doc. 282, 57th Congress, 1st Sess. 1902. Also with modifications *U.S. Geol. Survey, Water-Supply Paper 145* (1905), pp. 189–206, and separate by Interior Department, 1912.

are exposed at Magnet Cove, Potash Sulphur Springs, and as dikes in the vicinity of the Hot Springs.

In 1910, Purdue[1] published an elaborate paper on the origin of the hot water. He follows Weed in believing that the water has a meteoric origin and that in its passage through the ground derives heat from uncooled masses of igneous rock. He goes a step farther and outlines the structural conditions for the collection and transmission of the water. He believes that the water falls as rain in the anticlinal valley between North and Sugarloaf Mountains, where it is absorbed by the Bigfork Chert. "The considerable thickness of this chert, its much fractured nature, and the thin layers of which it is composed all combine to make it a water bearing formation of unusual importance."

The water having been collected in this formation is confined by the impermeable overlying Polk Creek and Missouri Mountain shales. Thus confined the water is conducted beneath the syncline of North Mountain, where it most probably comes in contact with some uncooled mass of igneous rock. Purdue suggests, but rejects the hypothesis that the water is expelled by the cooling of such an igneous mass.

Lindgren,[2] in 1919, accepts Purdue's views and considers that the springs have "clearly derived their saline constituents from the surrounding sedimentary rocks."

Another hypothesis should be advanced. On this hypothesis the water is of deep-seated origin derived from a covered mass of igneous rock intruded into the sediments, but not showing at the surface, which discharges water expelled from its molten interior by the gradual crystallization of its mass, or the water is derived from a deeper less definite but similar mass and rises to the upper crust through a deep, probably fault, fissure. Such water is commonly called juvenile, i.e., new water coming to the surface for the first time.

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[1] A. H. Purdue, The Collecting Area of the Waters of the Hot Springs, Hot Springs, Arkansas," *Jour. of Geol.*, Vol. XVIII, No. 3 (1910), pp. 278–85, 3 figs. Also *Indiana Acad. Sci. Proc. 1909*, pp. 269–75, 3 figs. 1910.

[2] Waldemar Lindgren, *Mineral Deposits*, p. 90. New York, 1919.

JUVENILE VS. METEORIC WATER

One of the great triumphs of modern geology has been to establish that the majority of metalliferous ore bodies, including most quartz veins, are deposited by ascending aqueous solutions which are derived from and excluded from crystallizing igneous bodies.

Granite rocks have been traced into pegmatite veins; pegmatite veins into metalliferous quartz veins; metalliferous quartz veins into quartz veins without impurities. It has thus been shown that aqueous vapors and gases gradually cooling and purging themselves of many substances rise through the crust and approach the surface in a purer and purer state. There is no theoretical objection to cold water with a minimum of mineral matter being attributed to a juvenile origin from an underlying crystallizing igneous mass, except the difficulty of proof. The majority of geologists do not hestitate to ascribe ore deposits to deposition from juvenile water, yet they hesitate to ascribe a juvenile origin to water emerging at the surface. It is well then to examine the criteria on which a discrimination between these two classes of water can be based.

Springs of small volume, and large variation in flow and temperature, can usually be referred to a meteoric origin. There are, however, many difficulties in determining the precise geological structure which gives rise to a particular spring. The requisite structures necessary for such a spring are: (1) an intake area, (2) a reservoir, and (3) a conduit to the surface. Under different geologic conditions the three requisites assume a multitude of forms and vary in size according to the hydraulic conditions. In a previous publication[1] twenty-four named varieties, divided into five groups, are described and illustrated. The field geologist, knowing the many possible structures, may have difficulty in deciding on the right one for any particular spring because of lack of evidence. Deep weathering of the rocks and a mat of vegetation and vegetable mold are usual at springs and tend to destroy, locally at least, the

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[1] Kirk Bryan, "Classification of Springs," *Jour. of Geol.*, Vol. XXVII (1919), pp. 521–61, 26 figs.

evidence of structure. However, a group of springs of common origin can usually be identified with the geologic structure to which they are due.

Springs of relatively large volume with little variation in flow or temperature present, especially if they are hot springs, difficult problems. Certain hot springs are undoubtedly of meteoric origin and depend for temperature on the descent of meteoric water from the surface into the crust and its rise, without great loss in temperature, to the surface. Such springs are due to the fracture, usually by faulting of the cover of a definite artesian structure, but unfortunately no adequate description of such a spring has yet been published. Buckhorn, Indian, and Willow springs in Antelope Valley, California, which served as examples of the fracture artesian[1] type of spring, are not thermal. Nearby flowing wells, having water of similar chemical composition, are from 200 to 400 feet deep. The artesian circulation in this valley does not go to great enough depths to yield hot water.

Many springs of steady flow and high temperatures arise in localities where it is impossible to postulate a structure which will receive the water at the surface, carry it to depths, and return it to the surface. Waring[2] found that of ninety-eight groups of hot springs in California, thirty-eight rise from granite or granitic rocks; of 155 carbonate springs, some of which are above the normal temperature, thirty-two occur in granite or granitic rocks. In such rocks the hot waters must arise from below through deep fissures. In California there is a notable association of the springs with faults, to which the fissures may be attributed. From these deep fractures in the crust, juvenile water from underlying magmas or incipient magmas may arise or there may be admixtures of meteoric and even connate waters which have or may have a circulation due to obscure or unknown forces. Certainly it seems simpler to assume that the water is juvenile. Certain springs, such as those near the Fish Springs Range, Utah,[3] are associated with faults of large

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[1] Kirk Bryan, *op. cit.*, pp. 553–55.

[2] Gerald A. Waring, "Springs of California," *U.S. Geol. Survey, Water-Supply Paper 338* (1915), p. 154.

[3] Kirk Bryan, *op. cit.*, pp. 533–35.

throw and recent age. This association seems a definite indication of juvenile origin. Hot springs in volcanic regions are probably in part of mixed origin. The presence of uncooled or even molten rock near the surface makes easy the heating of meteoric water and its return to the surface. Doubtless some springs in volcanic regions have a wholly meteoric origin, as Hague[1] has proposed for the geysers of the Yellowstone. Yet beneath volcanoes magmas are crystallizing and expelling water. It is inconceivable that all of this water is absorbed in chemical reactions or in the interstices of the rocks below the surface. Some of it, with its contained minerals and gases, must reach the surface.

Springs with steady flow and without great variations in temperature or quantity, especially if they are hot, must then arise from some deep artesian circulation or be of juvenile origin. The artesian circulation should be susceptible of proof on structural grounds. In the absence of such proof the indication of juvenile origin is very strong.

Elaborate investigations of the chemical characteristics of water, with the object of discovering its origin, have so far proved disappointing. Sodium chloride and sodium carbonate waters from granitic rocks carry a strong presumption of juvenile origin since the ordinary springs of such regions have water of the calcium carbonate type.[2] But unusual substances such as boron and fluorine have been found in spring waters of such diverse types as to be without critical value.

ANALYSIS OF THE MERITS OF THE HYPOTHESES

The question of the ultimate origin of the water in the Hot Springs of Arkansas is not only of intense theoretical interest, but has practical bearings. If the water is juvenile there is presumably a constant supply, diminishing very gradually through the centuries in quantity and temperature. When all the water is conserved by adequate structures it is probable that no more can be obtained. If, on the other hand, the water has a meteoric origin, it is variable

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[1] Arnold Hague, "Origin of the Thermal Waters in the Yellowstone National Park," *Bull. Geol. Soc.*, Vol. XXII (1911), pp. 101–22.

[2] W. Lindgren, *op. cit.*, p. 64.

in quantity, fluctuating with the seasons or with the groups of years having heavy or light rainfall. Also if the intake area is adequate, heavy drafts on the springs as by pumping should reduce the quantity in the reservoir and increase the absorption of rainfall in the intake area. Such increase in the volume of water flowing through the system may decrease the temperature of the water, an important consideration from the standpoint of use. A meteoric origin implies an intake area and this area must be found and protected from pollution.

It should be confessed that the present state of the science of geology is so imperfect that a definite conclusion as to the ultimate origin of the water in the Hot Springs cannot now be reached. As pointed out by Weed, the absence of unusual substances in the waters, low mineralization, and a gaseous content of oxygen and nitrogen in the proper ratio to form air are facts which do not show any unusual or non-meteoric origin for the water. On the other hand juvenile waters by deposition might purge themselves of all unusual substances, though if they originally contained sodium chloride there are difficulties in accounting for the loss of this stable compound. The radioactivity of the water, or rather the fact that it contains radium emanation (a gas) as determined by Boltwood in 1904,[1] is not of critical significance, for the amount of radioactivity is not unusual in wells and springs.

The previous temperature determinations are analyzed by Weed who rightly considers that they do not indicate either decrease in the heat or fluctuation in heat. Similar conclusions are reached from previous measurements of the water. But the existing measurements of these factors are neither adequate nor systematic. Fluctuations in temperature and volume are easily determinable if they exist. The critical value of such measurements is so great that it is to be hoped that they will be made for a sufficient period to provide adequate data.

The meteoric hypothesis calls for a structure to carry the water from the intake area at the surface to depths and then return it to

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[1] Bertram B. Boltwood, "Annual Report of Secretary of Interior, 1904," *Amer. Jour. of Sci.*, 4th Ser., Vol. XX (1905), p. 168.

the surface. As postulated by Purdue,[1] the water falls on the Bigfork Chert in the anticlinal valley between West and Sugarloaf mountains, is absorbed in the chert and passes below the syncline of North Mountain and arises in the anticline of Hot Springs Mountain. The course of the water is shown in Figure 2. The contact of the Bigfork Chert with overlying beds along the southwestern base of Sugarloaf Mountain (see the geologic map, Fig. 1), is about 850 feet above sea-level. Other parts of the chert outcrop as low as 650 feet, this being the elevation at the point nearest the hot springs. The hot springs break out at elevations between 600 and 694 feet. Parts of the intake area are thus at the same level as the springs and below some of them. Assuming the greatest difference 200 feet, it is doubtful if 200 feet of head or 80 pounds of pressure per square inch is sufficient to force the water through the channel assumed by this hypothesis. Even if this head is sufficient, it is remarkable that the water comes across the strike under the North Mountain syncline, when it could swing northeastward and around North Mountain into the Hot Springs anticline without notable change in level. This path is possible because the North Mountain syncline plunges southwestward and near the "Gorge" of West Branch brings the Bigfork chert near the surface. From this analysis it appears that the postulated structure is a very special hypothesis of dubious validity.

Similarly the hypothesis calls for an uncooled mass of igneous rock below the North Mountain syncline to supply heat, for the internal heat of the earth would not raise the temperature the required amount unless the water descended to 5,000 feet and then came to the surface without loss of temperature. Obviously the postulation of such an igneous body is a special hypothesis, particularly when apparently the water could easily avoid the plug by a change in route as shown before. The occurrence of igneous masses in the neighborhood as at Magnet Cove and Potash Sulphur Springs adds probability to this hypothesis, but these intrusions are thought to be of Cretaceous age, a time so remote that it is stretching credulity to believe that rocks of this age are still uncooled at moderate depths.

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[1] A. H. Purdue, *op. cit.*

The emergence of the water through the Polk Creek and Missouri Mountain shales into the Hot Springs sandstone requires no special hypothesis, if the thrust fault with associated jointing and fissuring which seem to be indicated by field relations is granted.

By reference to the table of temperatures, page 430, it will be seen that Big Chalybeate Spring has a temperature above normal. In chemical composition the water is of the calcium carbonate type, and of about the same mineralization as the Hot Springs waters, differing mainly in having less silica, (see table, page 427.) It has a strong and according to local observers a steady flow, which measured by H. D. Mitchell[1] was found to be 186 gallons per minute. This spring lies 5½ miles northeast of Hot Springs on the northwestern flank of the mountain which is the extension of the North Mountain syncline. The spring apparently arises from the Polk Creek shale in the flat valley of a tributary of the West Branch of Gulpha Creek. If the water is derived from rainfall on the Bigfork, which saturating the chert arises through a fracture in the shale, it is difficult to account for the abnormal temperature, 18° above the mean annual air temperature, unless an uncooled igneous plug is postulated for this spring also. The contact of the shale with the chert on the west is less than one-tenth of a mile away and less than 20 feet above the spring. The difference in head seems insufficient to force the water to travel to depths and return. On the other hand, southwest of the spring three-fourths of a mile is another anticlinal area of Bigfork chert which has its contact with the shale at elevations between 620 and 820 feet. It might be postulated that water from this area would flow northwest under the syncline and emerge at Big Chalybeate Spring. This hypothesis has the advantage that a depth of 1,000 to 2,000 feet would be attained, and this depth would doubtless be sufficient to account for the temperature of the water. The spring, however, has an elevation between 620 and 640 feet. For this postulate, also, there appears to be a lack of hydraulic head. The origin of Big Chalybeate Spring is then as much an unsolved problem as the origin of the Hot Springs, but because the waters are both thermal

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[1] J. C. Branner, *op. cit.*, p. 29.

and similar in chemical composition, it seems likely that they have a common origin. Special hypotheses are invalidated by this probability.

The meteoric hypothesis then suffers from two main defects: (1) A possible lack of head to force the water through the postulated structure; (2) the very special association of uncooled rock with the structure.

The hypothesis of juvenile origin for the waters when examined is perhaps more satisfactory, but suffers from conspicuous defects.

This hypothesis may take two forms: (1) That there is a buried mass of uncooled igneous rock which is discharging water due to cooling and crystallization; (2) that a fracture or fissure extends from the springs into the deep interior of the earth, similar in character to the great fault fractures and through this fracture deep-seated waters, juvenile or of mixed origin, rise to the surface.

A mass of uncooled igneous rock discharging juvenile water is a hypothesis of the same special character as the uncooled body postulated under the meteoric hypothesis. It is no more unreasonable to assume that it is still crystallizing and discharging water, than that it is not crystallizing, but is still hot enough to heat the water by contact. Moreover, the nearby igneous bodies are of Cretaceous age and there is no other evidence of igneous activity in the general region.

That a deep fracture or fissure exists is also a special hypothesis but only special in that it provides that the water rising in this fissure is warm at the surface. A source of heated water is everywhere present in the deeper crust and in regions of disturbance there is a rise in the geotherms and in some instances at least invasion of batholithic bodies. Deep fissures in this general region, though their position is now almost wholly concealed by erosion, must have occurred as late as the Pleistocene epoch during which time the principal uplift is thought to have occurred. Under a hypothesis of recent faulting the position of the springs at the nose of Hot Springs Mountain anticline is purely accidental except that the rising waters have taken advantage of the preexisting fracture by overthrust of the Hot Springs sandstone and the two underlying shales.

Faulting, except in connection with folding, throughout the general region around Hot Springs, is difficult to establish. However, in the coastal plain region of central and southern Arkansas and adjacent states, Late Tertiary and post-Tertiary faulting have probably taken place. According to Stephenson,[1] small faults are recognized in connection with the Preston anticline. In the Monroe Gas Field[2] a post-Eocene fault with a total displacement of 150 feet has been mapped. The theory of origin of salt domes advanced by Harris[3] rests on the postulate that faulting on an extensive scale has taken place throughout eastern Texas, Louisiana, and southern Arkansas. Quarternary faulting with a displacement of at least 1,000 feet has been shown for the Jennings oil field.[4] A post-Tertiary fault with a throw of 2 feet to the south was noted by Professor H. A. Wheeler[5] and Colonel John R. Fordyce 3 miles north of Stephens, Arkansas, a town 75 miles south of Hot Springs. This fault appears to be very recent.

The recorded evidence of recent faulting is thus incomplete, but the known uplift of Pleistocene time must have offered favorable conditions for faulting however difficult the matter of proof may be. While no recent faulting has been discovered at or near Hot Springs, the foregoing facts indicate that such faulting is not improbable and may yet be found.

The hypothesis of juvenile origin thus also rests on an insecure foundation since it postulates either a special igneous mass or a special fault fissure. For neither of these is there other evidence.

USE AND DEVELOPMENT OF THE HOT SPRINGS WATER

The quantity of the Hot Springs water used for bathing and drinking fluctuates from year to year but has gradually increased. The

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[1] L. W. Stephenson, "Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U.S. Geol. Survey, Contrib. to General Geol., Prof. Paper 120* (1919), pp. 129 ff.

[2] H. W. Bell and R. A. Cattell, *Louisiana Dept. Conservation, Bull. No.* 7, 1921.

[3] G. D. Harris, *Bull. Louisiana Geol. Survey No. 7* (1908), pp. 75 ff., also *Econ. Geology*, Vol. IV (1909), pp. 12–34, and *U.S. Geol. Survey Bull. 429* (1910), pp. 6–10, Pl. 1.

[4] G. D. Harris, "Oil and Gas in Louisiana," *U.S. Geol. Survey Bull. 429* (1910), pp. 56–61.

[5] Letter, October 22, 1921.

private investment in bathhouses and hotels is large and the government investment in the Free Bathhouse and in the Army and Navy Hospital is considerable. The volume of business can be measured by the number of baths given which reached a maximum of 1,194,872 in 1911. A careful engineering study will doubtless lead to improvements in the present system of distributing the water. Even though economies may increase the capacity of the resort to handle patients and visitors, large future growth of Hot Springs as a health and pleasure resort depends on an increased supply of hot water. The practical means by which additional hot water may be obtained are not here discussed, but it is obvious that development can be attempted intelligently only with accurate knowledge of the origin of the water.

The Fordyce Well, shown on Figures 3 and 4, is 6 inches in diameter and 67½ feet deep. It penetrates the Stanley shale and extends into the Hot Springs sandstone. The well has a flow of hot water amounting to 50,000 gallons daily. Since the well appears not to have decreased the flow of any existing spring or well, it must be supplied with water which had previously reached the surface in minor seeps and concealed springs. Other wells in the same geologic position near the contact between the shale and sandstone will save seepage, but will probably dry up the hillside springs. The resulting concentration of flow will be convenient for a single unified distributing system and the substitution of artificial openings for the natural openings or hot springs will be an inconsiderable sentimental loss.

Whether water not to be considered as salvage can be developed by such shallow wells depends on the ultimate origin and the mechanism of flow of the hot water. Each stage in attempted development of new water will raise anew these fundamental questions.