ORIGIN OF THE HOT SPRINGS AT HOT SPRINGS, NORTH CAROLINA.

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ABSTRACT. Thermal springs occur at the town of Hot Springs in the Blue Ridge Plateau of North Carolina. The springs are in the Hot Springs window of the Great Smoky overthrust block which has been domed and later eroded, exposing overridden rocks in an oval window. In the vicinity of the encircling fault, structures in the Ocoee series and underlying early pre-Cambrian granite gneiss, which make up the overthrust block, dip away on all sides from the rocks of the window which comprise early pre-Cambrian granite gneisses, overlying Lower Cambrian quartzites of the Chilhowee group, and Shady dolomite and Rome formation. The springs come to the surface in the Shady dolomite on the flood plain of the French Broad River at an altitude of 1,332 feet and have a temperature of 104°. Lower Cambrian quartzites that underlie the Shady dolomite in the syncline are regarded as the aquifer, and the high temperature is acquired by the water circulating to a depth of more than 5,000 feet in that syncline. The difference in altitude between that of the upland around Vann Cliff, where the quartzites are at the surface, and that at the springs gives an adequate head for the artesian flow. The water is assumed to rise on a normal cross fault that is inferred from the observed structural and stratigraphic break in the rocks of the window.

INTRODUCTION.

HOT SPRINGS, Madison County, is a small town in northwestern North Carolina on the south side of French Broad River, 26 miles northwest of Asheville and four miles east of the Tennessee-North Carolina State line. It is located on the Southern Railway and on U. S. Highway 25-70 which leads from Asheville westward into Tennessee. The town takes its name from several hot springs, adjacent to which are a hotel and a bath house for the therapeutic use of the hot water of the springs. The chief scientific interest in the springs is the high temperature of the water, and this paper suggests a solution of the origin of the hot water.

The Hot Springs area lies in the northwest quarter of the Asheville quadrangle* which Keith[1] described in the folio covering that area. In the map shown in Fig. 1 the writers present their interpretation of the geology in the vicinity of

* Names of places and topographic features not on the Asheville quadrangle may be found on the Hot Springs, Spring Creek, Paint Rock, and Lemon Gap quadrangles of the U. S. Tennessee Valley Authority.

[1] Keith. Arthur: 1904, Geology of the Asheville quadrangle, U. S. Geol. Survey, Geologic Atlas, Folio no. 116.

Hot Springs, based to some extent on their own field work in the region during which they revised in part Keith's mapping and changed the names of some of the rock units. The location of the fault on the west side of the Hot Springs window follows Keith's map in the Asheville folio.

The Hot Springs area is near the northwest border of the Blue Ridge Plateau, a wide upland 3,000-3,500 feet in altitude. The French Broad River is one of many streams that have deeply dissected the plateau surface, and at Hot Springs its valley is 1,332 feet in altitude. A range of mountains rises above the plateau at its northwest edge and overlooks the Appalachian Valley to the west. In the Asheville quadrangle and vicinity this front range is named the Bald Mountains. They follow a curving southwesterly course which marks the North Carolina-Tennessee State line. The Bald Mountains extend from Big Butt (4,838 feet in altitude) at the northeast (Greeneville quadrangle) to Snowbird Mountain (4,200 feet in altitude) just northeast of Pigeon River (Mt. Guyot quadrangle) at the southwest. West of Hot Springs the Bald Mountains have a maximum altitude of only 3,050 feet.

GENERAL GEOLOGY.

The hot springs are located in the Hot Springs window[2] of the Great Smoky overthrust block where that thrust plate was domed and later eroded through, exposing the underlying rocks in an oval-shaped window. It extends in an east-west direction from the vicinity of Sandy Bottom westward to Wolf Creek, a distance of ten miles. From near Bluff to the north side the window is five miles wide. The French Broad River flows across the northeastern part of the window, and its valley and that of two tributaries—Spring Creek and Shut In Creek—afford excellent outcrops of the rocks in the window and in the Great Smoky overthrust block.

The rocks in the window comprise pre-Cambrian granitic gneisses and overlying Lower Cambrian rocks which, in rising succession, are quartzites of the Chilhowee group, Shady dolomite, and Rome formation. The rocks in the Great Smoky

[2] Stose, G. W., and A. J.: 1944, The Chilhowee group and the Ocoee series of the Southern Appalachians: Amer. Jour. Sci., **242**, 385-386.

overthrust block which frames the window are graywacke and quartzite of the lower part of the Ocoee series, of late pre-Cambrian age, and older granitic gneisses on which the Ocoee series lies unconformably. These granitic gneisses and those exposed below the Lower Cambrian quartzites in the window are both part of the injection complex of early pre-Cambrian age.

ROCKS EXPOSED IN THE HOT SPRINGS WINDOW.

The formations recognized by the writers in the Hot Springs window are shown in the following table.

Formations in the Hot Springs window.

Age	Formation Name	Symbol	Estimated thickness	Generalized description
LOWER CAMBRIAN	Rome formation	Єr	300±	Red shale and sandstone
	Shady dolomite	Єs	500±	White to gray dense dolomite
Chilhowee group	Hesse quartzite	Єh	400-600	White and rusty-weathering quartzite
	Murray shale	Єm	200±	Gray shale
	Nebo quartzite	Єn	600-800	Hard white current-bedded quartzite
	Cochran quartzite	Єc	1200-1400	Arkosic quartzite, thin shale, and conglomerate beds
	Sandsuck shale	Єss	800-1000	Shale and soft arkose
	Vann quartzite UNCONFORMITY	Єv	1200-1400	Thick-bedded arkosic quartzite, shale, and hard feldspathic light-gray quartzite
EARLY PRE-CAMBRIAN	Granite gneiss	Ʒ∋d	....	Part of the injection complex

In the Hot Springs window the pre-Cambrian granite gneiss lies south of Stackhouse in an area which is crossed by French Broad River to a point a mile and one quarter east of Sandy Bottom (Fig. 1). The granite gneisses include coarse-grained granodiorite with pink feldspar, massive pink granite, and coarse pink pegmatite composed of pink microcline and blue quartz. Keith mapped them as Max Patch granite. They are part of the injection complex[3] of early pre-Cambrian age, which comprises the oldest rocks in the Appalachians. The injection complex consists of meta-sediments, injection gneisses, and gneissic rocks of granitic, granodioritic, and more basic composition. This rock series was intensely folded and metamorphosed during deformation in the early pre-Cambrian (Archean) cycle.

Just west of Stackhouse the Lower Cambrian quartzites in Dry Pond Ridge and Pine Mountain overlie the granite gneisses and initiate the Lower Cambrian sedimentation. Northward higher Cambrian quartzose formations succeed one another in rising stratigraphic sequence to the uppermost quartzite—the Hesse—which is exposed in the ridges south of the lowland around and northwest of Hot Springs; the overlying Shady dolomite and Rome formation crop out in that lowland. The Lower Cambrian quartzites that occur in the window belong to the Chilhowee group,[4] in which the formations are in large part named from type localities in Chilhowee Mountain, Tennessee. In the Asheville folio Keith[5] used names derived from the type locality for Lower Cambrian formations down to and including the Cochran conglomerate. The formations below the Cochran he called Hiwassee slate and Snowbird formation, names which he applied also to formations of the Ocoee series the type localities of which are in areas of that series and not in Lower Cambrian rocks. The writers therefore do not use these two names for Cambrian formations. For the slate mapped as Hiwassee they substitute the name Sandsuck shale, which is the name Keith used for the rocks below the Cochran quartzite in Chilhowee Mountain. For beds below the Sandsuck shale they here propose the new name Vann quartzite from exposure at Vann Cliff on Spring Creek, because the beds that lie beneath the Sandsuck shale in the Hot Springs area are not present or were not recognized in the type section in Chilhowee Mountain.

[3] Jonas, A. I., and Stose, G. W.: 1939, Age relations of the pre-Cambrian rocks in the Catoctin Mountain-Blue Ridge and Mount Rogers anticlinoria in Virginia: Amer. Jour. Sci., **237**, 580-582.

[4] Stose, G. W., and A. J.: 1944, op. cit., pp. 369, 387-390.

[5] Keith, Arthur: 1895, Geology of the Knoxville quadrangle, U. S. Geol. Survey, Geologic Atlas, Folio no. 16.

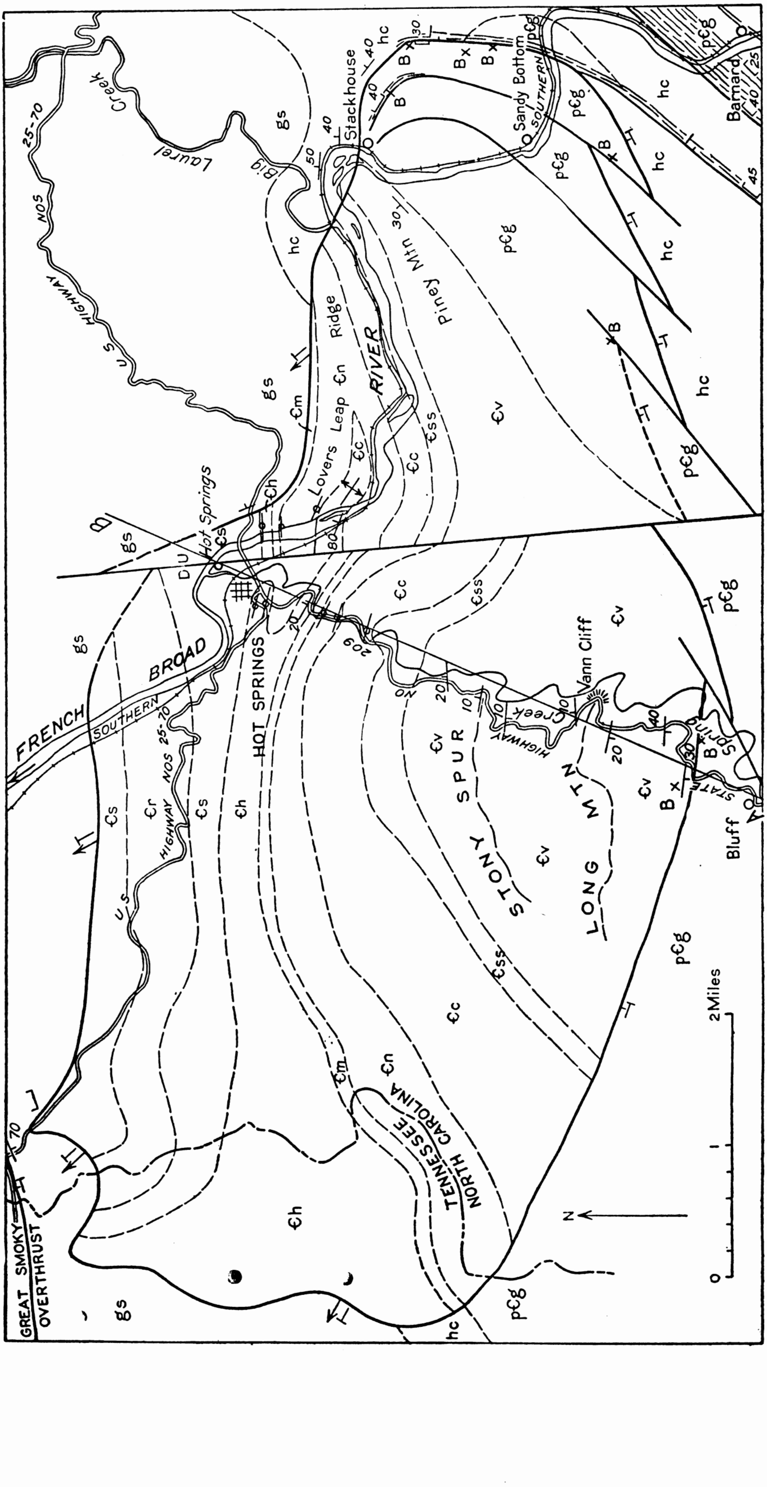
GREAT SMOKY OVERTHRUST
FRENCH BROAD RIVER
SOUTHERN
U S HIGHWAY NOS 25-70
Laurel Creek
Big
HOT SPRINGS
Hot Springs
Lovers Leap Ridge
Piney Mtn
Stackhouse
Sandy Bottom
Barnard
STATE HIGHWAY NO 209
Spring Creek
Vann Cliff
STONY SPUR
LONG MTN
Bluff
TENNESSEE
NORTH CAROLINA
N
0
2 Miles

Figure 1.

The writers in a previous paper[6] attempted to correlate the formations of the Chilhowee group with Lower Cambrian formations of the Holston Mountain block in which beds below the Hampton shale comprise the Unicoi formation, characterized by the presence of basalt flows that do not occur in the Chilhowee group. In that correlation the Hesse quartzite, Murray shale, and Nebo quartzite were shown as equivalent to the Erwin quartzite. Further field work on the Chilhowee group has led the writers to correlate only the Hesse quartzite with the Erwin. The Murray shale, although much thinner, seems to represent the Hampton shale; and the Nebo quartzite in Nebo Mountain (Knoxville quadrangle) is a pure white current-bedded quartzite very similar to the white quartzite in the upper part of the Unicoi formation.

The following description of the succession of the rocks in the window is from exposure on U. S. Highway 25-70, on French Broad River and the Southern Railway south of Hot Springs, and on North Carolina Highway 209 which follows Spring Creek south of the town to and beyond Bluff on the south side of the window.

Figure 1. Geological map of the Hot Springs window, N. C. Based in part on the mapping by Arthur Keith in the Asheville folio, revised in part by the writers.

Rocks in the window

Cambrian

- Єr, Rome formation (Watauga shale of Keith)
- Єs, Shady dolomite
- Єh, Hesse quartzite
- Єm, Murray shale
- Єn, Nebo quartzite
- Єc, Cochran quartzite (includes Nichols shale and quartzite lentil of Keith)
- Єss, Sandsuck shale (Hiwassee slate of Keith)
- Єv, Vann quartzite (Snowbird formation of Keith)

Unconformity

- pЄg, Granite gneiss of the injection complex, early pre-Cambrian age

Rocks surrounding the window

Ocoee series, late pre-Cambrian age

- gs, Great Smoky quartzite
- hc, Hurricane graywacke

} Snowbird formation of Keith

Unconformity

- pЄg, Granite gneiss of early pre-Cambrian age

Shown by appropriate symbols

Dip of bedding and of cleavage

Anticlinal axes

T, overthrust side of thrust fault

← T, submerged side of window

Postulated cross fault

Mylonite zone along subsidiary thrust fault

B. Barite workings.

[6] Stose, G. W., and A. J.: 1944, op. cit., pp. 389-390.

North of Hot Springs the Rome formation makes low hills in the lowland which is underlain by Shady dolomite. Both formations are exposed on U. S. Highway 25-70 northwest of the town. For the most part the dolomite is weathered to a deep, red, granular, clay soil. The dolomite crops out at a point near the hot springs on U. S. Highway 25-70 east of the bridge over French Broad River and just south of the highway on Silver Mine Creek. On U. S. Highway 25-70 in the northern part of the town of Hot Springs the upper beds of the Hesse quartzite are exposed in an anticline. Here are shown about 100 feet of crumbly white quartzite interbedded with white clayey layers, probably calcareous when fresh, and soft rusty-weathering quartzite. South of Hot Springs hard vitreous white quartzite in the lower part of the Hesse makes a prominent ridge, which North Carolina Highway 209 follows to the bridge across Spring Creek. The quartzite dips 20° N. The same hard quartzite also forms cliffs on the east side of French Broad River south of the mouth of Silver Mine Creek. The quartzite here is vertical and is brecciated and the fragments are cemented by iron oxide, due to the proximity of the Great Smoky overthrust which, just to the east, cuts off both the quartzite and overlying Shady dolomite. The Murray shale is not exposed in the bluff on the river nor on Highway 209, but may be represented in these sections by ravines.

The Nebo quartzite makes riffles in the river, and white quartzite near its base rises in a prominent cliff on the east bank of the river. The quartzite is vertical and strikes S. 80° E. into Lovers Leap Ridge. To the south, white quartzite like the Nebo crops out on the west bank of the river to the north and the south of the Southern Railway bridge. These beds strike N. 20° W. and dip 50° NE. They are separated from the more northerly exposures of Nebo quartzite by arkosic quartzite of the Cochran with monoclinal 80° N. dips. A tentative explanation of the structure here is that the Cochran quartzite is in a tightly squeezed anticline over which the Nebo quartzite may be locally thrust (Fig. 3).

South of the bridge over Spring Creek on North Carolina Highway 209 the Nebo quartzite in vertical beds is well exposed in the road cut and forms falls in the creek. South of the Nebo, pebbly arkosic quartzite of the Cochran crops out to the big bend in Spring Creek. This formation as mapped by the writers probably includes also beds mapped by Keith as Nichols slate and a quartzite lentil. At the big bend in the creek, south of the Cochran quartzite, is a wide lowland underlain by shale and soft, green, fine-grained arkose called Sandsuck shale by the writers. The shale and arkose exposed on the highway are badly contorted, crushed, and cleaved so that the bedding is destroyed. The disturbed character of these beds may be due to a minor thrust fault. South of the Sandsuck shale, where the highway ascends the upland from the valley of Spring Creek, are exposed thick-bedded, arkosic quartzite, crumbly arkose, shale, and thick-bedded, light-gray feldspathic quartzite, which the writers have named the Vann quartzite. The upper beds of the formation comprise thick-bedded light-gray arkosic quartzite, some beds of which contain black quartz grains, and interbedded shale. They dip gently north beneath the Sandsuck shale. A low anticline at Stony Spur brings up hard thick-bedded light-gray arkosic quartzite in the lower part of the formation. Southward the beds have low rolling dips to a point on the highway above Vann Cliff where hard quartzites, probably at the same horizon as those at Stony Spur, are exposed in another anticline. These quartzites extend west into Long Mountain. South of Vann Cliff higher beds of soft quartzite and shale dip gently south to the bordering fault of the window, which the highway crosses half a mile north of Bluff. The quartzites exposed in the two anticlines appear to be the lowest exposed beds of the Vann quartzite.

From these descriptions it is seen that in the Spring Creek section the lower beds of the Cambrian are in a broad anticline, the north limb of which is monoclinal, with vertical dips in the middle beds and 20° N. dip in the Hesse quartzite which passes under the Shady dolomite. A minor anticline to the north at Hot Springs brings up the Hesse quartzite in the dolomite area. In the section on French Broad River and the Southern Railway, the general north-dipping monoclinal section is disturbed by a repetition of beds which is interpreted as an anticline exposing Cochran quartzite at the axis. This discrepancy in the sections will be discussed later in this paper.

ROCKS SURROUNDING THE WINDOW.

The Great Smoky overthrust[7] is a fault with great horizontal throw, which the writers have traced from the vicinity of Erwin, Tenn., southwestward across that State into Georgia, where it becomes the equivalent Cartersville overthrust of Hayes.[8] The Great Smoky overthrust block frames the Hot Springs window and is composed of late pre-Cambrian rocks of the Ocoee series and underlying early pre-Cambrian rocks of the injection complex. The complex borders the window on the south side, where Keith mapped it as Max Patch granite. The two lower formations of the Ocoee series surround the remaining part of the window.

The writers defined the Ocoee series in a previous paper,[9] where they stated that it is distinct in lithology from the Lower Cambrian quartzites of the Chilhowee group, that it is not of Cambrian age but is late pre-Cambrian, and that it is equivalent to other rock series of different lithology in other parts of the southern Appalachians. As a result of recent field work they[10] have divided the Ocoee series into four major units which, in rising sequence, are Hurricane graywacke, Great Smoky quartzite, Nantahala slate, and Big Butt quartzite. A fifth and uppermost unit, the Valleytown formation, is present only in southwestern North Carolina and northern Georgia, in the Murphy syncline. In the paper recently transmitted to the Geological Society of America on which the above mentioned abstract was based, they describe the type locality of the Hurricane graywacke as follows: "The name Hurricane graywacke is here applied to the lowest formation of the Ocoee series because of its fine exposures on Little Hurricane Creek and at the Hurricane settlement, N. C., at the junction of the creek with Big Laurel Creek (Asheville quadrangle) 6 miles northeast of Hot Springs, N. C. The initial sediments of the graywacke in this vicinity and northeastward along Shelton Laurel Creek rest on gran-

[7] Stose, G. W., and A. J.: 1944, op. cit., pp. 384-385, figs. 2A, 2B.

[8] Hayes, C. W.: 1891, Overthrust faults of the Appalachians; Geol. Soc. Amer. Bull., 2, 147-149.

[9] Stose, G. W., and A. J.: 1944, op. cit., pp. 367-390, 401-416.

[10] Stose, G. W., and A. J.: 1946, Ocoee series in the Southern Appalachians (abstract); Geol. Soc. Amer. Bull., 57, pt. 2, p. 1233.

ite gneiss of the injection complex." The Hurricane graywacke is a fine- to medium-grained, grayish black or grayish green graywacke consisting principally of angular grains of glassy quartz and feldspar in a matrix of very fine mica flakes and black dust. In part it has thin, dark-gray, siliceous partings and contains thin beds of impure grayish green quartzite which grade upward into the basal quartzose beds of the Great Smoky quartzite.

In the Asheville quadrangle and in Snowbird Mountain in the Mt. Guyot quadrangle, and elsewhere, Keith used the name Snowbird formation for the graywacke that the writers have named Hurricane, and included in the Snowbird the overlying quartzite which the writers correlate with the Great Smoky. Also he classed the Snowbird formation as Lower Cambrian and applied the name to other rocks of well-established Cambrian age. For these reasons the writers have applied a new name to the graywacke at the base of the Ocoee series.

The writers retain Keith's[11] names Great Smoky and Nantahala for the units to which he applied them, but they place these formations in the late pre-Cambrian and not in the Lower Cambrian as they were classed by Keith. The Great Smoky quartzite is composed of a thick series of massive, poorly bedded, light- to dark-gray, impure quartzites made up in large part of angular grains of quartz and feldspar. Because conglomeratic beds occur only in the middle member, form only a small part of the formation, and few of the pebbles exceed half an inch in length, the writers use the name Great Smoky quartzite instead of conglomerate, emphasizing the siliceous character of the formation although, from its composition, it might well be called a quartzose graywacke.

The Ocoee series throughout its extent from the vicinity of Erwin, Tenn., southwestward into northern Georgia maintains a synclinal structure, the youngest formations being exposed in the centers of the synclines. At the northeast end of the series the Big Butt quartzite and Nantahala slate are enclosed in a syncline which follows the Bald Mountains in the Greeneville quadrangle southwestward to a point about 10 miles northeast of Hot Springs. There the syncline rises,

[11] Keith, Arthur: 1907, Geology of the Nantahala quadrangle, U. S. Geol. Survey, Geologic Atlas, Folio no. 143.

and southwestward to the vicinity of the Hot Springs window the Great Smoky quartzite is the youngest formation of the Ocoee series exposed. This quartzite (the upper part of the Snowbird formation of Keith) borders the north and northwest side of the window from a point on French Broad River near the mouth of Big Laurel Creek westward to the Brushy Mountains at the southwest corner of the window. On the southeast side of the Brushy Mountains the underlying Hurricane graywacke (basal part of the Snowbird formation of Keith) borders the window to the neighborhood of Locust Gap. At the gap the Hurricane graywacke trends southwest across the Asheville quadrangle and its basal contact with the injection complex follows the west foot of Max Patch Mountain. On the south side of the window from Locust Gap east to Slaty Knob, the injection complex (Max Patch granite of Keith) is at the sole of the thrust.

East of the window, east of the mouth of Big Laurel Creek, the Hurricane graywacke trends east, southeast, and then south, and, northwest of Barnard on French Broad River, it bends southwest. This curving trend follows the curve of the edge of the window eroded in the thrust block. In this region the graywacke is broken by several subsidiary thrust faults on which the injection complex overrides the graywacke. These faults are marked by granite mylonite.

THE FAULT THAT ENCIRCLES THE WINDOW.

The Hot Springs area has been recognized only recently as a window[12] with an encircling fault. Keith[13] mapped a fault partly around the area of the window but did not close it on the southeast side. He regarded the fault north of Hot Springs as an overthrust from the north, and states that it "is one of the most unusual in the Appalachians. Its outcrop forms a nearly complete oval and its planes, if extended upward, would almost unite in a dome. . . . Its plane dips successively toward all points of the compass . . . The area enclosed by the fault plane thus represents a downthrown mass upon which the adjoining rocks were piled high from all sides."

[12] Geological Map of the United States, 1933. U. S. Geol. Survey. Stose, G. W., and A. J.: 1944, op. cit., pp. 385-386.

[13] Keith, Arthur: 1904, op cit., p. 8.

The writers were led to suspect the presence of a window in the Hot Springs area because the rocks in the encircled area are largely Lower Cambrian strata of the Chilhowee group, whereas the sedimentary rocks that partly surround the area are of a different lithology and age, and also because this enclosing sedimentary series and the underlying injection complex are discordant in structure to the Lower Cambrian strata in the Hot Springs area. The further fact that cleavage or schistosity, and in places bedding, in the encircling rocks dip away from the area on all sides convinced them of this interpretation.

The fault is clearly evident on the north side of the window where, from the east side of French Broad River at Hot Springs westward to Wolf Creek, the quartzites of the Great Smoky dip northward away from the Shady dolomite and Rome formation. At a near contact of the thrust fault on U. S. Highway 25-70 a short distance east of the bridge over French Broad River, massive, light-gray, arkosic quartzite of the lower part of the Great Smoky strikes northwest and dips northeast away from brecciated Shady dolomite. Another poorly exposed thrust contact is farther west on this highway at a point half a mile south of the sharp bend at Grass Creek. There crushed, coarse-grained arkosic quartzite with north-dipping cleavage overlies ferruginous clay derived from the Shady dolomite which is exposed nearby. Just west of this place along Wolf Creek, Lower Cambrian quartzites in the western part of the window trend into and are cut off by the fault which there trends south to the vicinity of Locust Gap. At the gap the fault, as mapped by Keith, turns southeastward and continues in that direction on the south side of the window to a point half a mile north of Bluff. At that point, in a roadcut on North Carolina Highway 209, granite gneiss of the overriding block is sheared, slickened, and injected by quartz veins, and overlies contorted shale and soft arkose of the Vann formation. At several places in this vicinity the shattered granite gneiss and overridden Lower Cambrian rocks are replaced by irregular veins of barite. Keith[14] mentions that barite workings occur on Spring Creek east of the highway and says that "the barite-bearing quartzites are close to the thrust fault

[14] Keith, Arthur: 1904, op. cit., p. 9.

and there seems to be a distinct connection between the fault and the barite." On the map of the Asheville folio, in the region to the east between Spring Creek and French Broad River, Keith shows other barite prospects at the fault contact. At the river the encircling fault lies about 1½ miles east of Sandy Bottom and trends northward to the vicinity of King Creek where it curves northwestward and follows the creek to its mouth at Woolsey Branch; westward it extends to French Broad River, passing just north of Stackhouse and near the mouth of Big Laurel Creek. In exposures on King Creek, Woolsey Branch, and French Broad River north of Stackhouse, the structures in the Hurricane graywacke on the sole of the overthrust trend northwest and dip 50° to 70° NE. From the mouth of Big Laurel Creek the fault continues northwesterly to U. S. Highway 25-70 at a point just east of the bridge over the river, and cuts off the Lower Cambrian formations in the window which trend diagonally into the fault.

East and south of Stackhouse the granite gneiss in the window is mylonitized along shear zones adjacent to the trace of the overthrust. These mylonitized zones in the window trend southeast, then south and southwest, and are parallel to the encircling fault.

Where the road along Woolsey Creek to Stackhouse crosses the fault, the granite gneiss of the window is mylonitized on one of these subsidiary thrusts, and the plane of mylonitization strikes N. 60° W. and dips 40° NE. conforming to the structure in the sole of the adjacent fault. This mylonitized zone and others to the southeast contain veins of barite that has replaced the sheared granite gneiss with the addition of quartz and fluorspar. These veins have been mined for barite on Woolsey Branch just south of the mouth of King Creek, and to the southeast in Peter King Bottom near the forks of King Creek. The veins and granite mylonite in Peter King Bottom strike N. 20° E. and dip 55° SE., and represent shear zones parallel to the nearby encircling fault.

On the southeast side of the window these shear zones offset the bordering fault, and in the vicinity of Slaty Knob pass southwestward into the overthrust block. These faults are parallel to similar subsidiary faults in the Great Smoky block east of the window. A zone of granite mylonite on a subsidiary thrust fault also in the overriding block extends southwestward from the edge of the window near Bluff. The rocks in this narrow linear area were mapped by Keith as a synclinal belt of Snowbird formation. They are not sedimentary rocks but are finely layered mylonite of felsitic texture, derived from cataclasis of granitic gneiss of the injection complex and are the result of movement on a fault in the overthrust block.

The subsidiary thrusts which have broken the overriding block and offset the fault that encircles the window are localized on the southeast side of the window. The west side of the window also is offset by a related thrust fault not shown on Figure 1. This fault passes through Locust Gap and extends northeastward along West Fork of Shutin Creek, so that granodiorite of the pre-Cambrian injection complex and overlying Hurricane graywack in the Great Smoky block are thrust over Nebo quartzite of the window.

It is clear that the lower Paleozoic rocks and underlying early pre-Cambrian gneisses in the Hot Springs area are encircled by a thrust fault and are in a window of a thrust plate composed of the Ocoee series and the underlying injection complex, and that this thrust plate is the Great Smoky overthrust block in which the structures near the encircling fault dip away in all directions from the rocks of the window. The rocks in the window were exposed by the erosion of the overthrust block along an axis of doming that occurred after the overthrust movement.

The Great Smoky overthrust emerges at the surface a short distance northwest of the window (Fig. 1). In that region a deep southward embayment in the general southwest trace of that overthrust is the result of uplift and erosion at the front of the overthrust block. For this reason the overthrust block on the northwest side of the window is narrow and, where it is crossed by U. S. Highway 25-70 south of the bend in the highway at Grass Creek, it is less than a mile wide.

In most of the area of the Great Smoky overthrust block the Ocoee series is in a wide synclinal area near the northwest front of the block, and the injection complex that underlies it is exposed at a considerable distance southeast of the front. In the vicinity of the window, on the west side, the exposure of the injection complex close to the front of the Great Smoky block is regarded as further evidence that erosion here has cut deeper into the thrust block because of uplift after overthrusting.

In the Asheville quadrangle and vicinity a series of en échelon thrust slices, composed of Lower Cambrian quartzites of the Chilhowee group and overlying Shady dolomite and Rome formation, lie in front of and are overridden by the

Figure 2. Hurricane graywacke overlying massive Shady dolomite on Paint Creek, 6 miles north of Hot Springs. The Hurricane graywacke (dark rock) has been thrust northwest on the Great Smoky overthrust over the Shady dolomite (light rock).

Great Smoky overthrust block (Fig. 2) and are in thrust relation to younger rocks of the Great Valley. It is evident that these thrust slices were derived from some point southeast of their present location and were pushed northwestward by the forward movement of the Great Smoky overthrust block. In the area north of the Hot Springs window, two such slices are north of the Great Smoky block; the southerly or Paint Rock slice, overrides the northerly or Meadow Creek Mountains slice on a fault shown in the Asheville folio to extend southwestward on the south side of Cove Creek to Laurel Branch.

The writers have extended this fault southwestward on Laurel Branch and through Moccasin Gap, where barite has been deposited in brecciated quartzite along the fault (Paint Rock quadrangle, T. V. A.).

For the reason that the rocks in both the Paint Rock slice and in the Hot Springs window contain quartzites of the Chilhowee group and the Shady dolomite, the rocks in the Paint Rock slice should pass southward beneath the narrow cover of the Great Smoky block into the rocks of the window with no stratigraphic break if the rocks of the window were part of the Paint Rock slice. However, the Shady dolomite on the north side of the window does not accord with the lower quartzites of the Chilhowee group in the Paint Rock slice just north of the emergence of the Great Smoky overthrust. Because of this discordance it seems probable that the rocks in the window are in a separate thrust slice, and the fault on its north border is covered by the Great Smoky overthrust block. If this assumption is correct, the injection complex that underlies the Chilhowee group in the window is not rooted *in situ* but, with the Lower Cambrian rocks that overlie it, has traveled northwestward in a separate slice.

THE SPRINGS.*

The thermal springs come to the surface at the edge of the floodplain on the southwest side of French Broad River in the northern part of the town of Hot Springs. A retaining wall about 20 feet high has been built at the river's edge, and the source of the springs has been enclosed in a spring house. A hotel, now called Montaqua Hotel, A. S. Wheeler, manager, and bath house are situated on the adjacent floodplain. The spring house contains a concrete tank, 6½ feet by 7¼ feet, which the water enters at the bottom between concrete slabs an inch apart. The adjoining bath house is approximately 84 feet by 50 feet and contains 16 concrete bathing tanks 6 feet by 9 feet. The water from the spring house is pumped to the bath house and enters the bathing tanks between concrete slabs at the bottom, and overflows through pipes to the river.

* Statistical data supplied by D. C. Murrow, Engineer, Water Resources Branch, U. S. Geol. Survey, Ashvelile, N. C., Dec., 1946.

The temperature of the water in the spring house is 104°. It is reported by the engineer of the Water Resources Branch that the temperature is not affected by seasons, but during dry spells the flow of the spring diminishes and the temperature falls slightly. The temperature of the water in the bath house varies from 97°, in the tanks nearest the source, to 86°, farthest from the source. Water piped from the spring house direct to baths in the hotel, after running freely, is 103°. The flow of water at the spring house was calculated to be 6.02 gallons per minute.

The temperature of this spring is considerably higher than most thermal springs in the southern Appalachians. In a recent report on the thermal springs of Virginia, Reeves[15] lists 326 thermal springs in Virginia and West Virginia, most of which have temperatures below 70°. The springs with highest temperatures are in Bath County, Va. In that county the temperature of the water at Healing Springs attains a maximum of 76°; at Warm Springs, 96.2°; and at Hot Springs the recorded maximum temperature is 105.8°, comparable with that at Hot Springs, N. C. Reeves (pp. 28, 33) reached the conclusion that the thermal 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 water being an expression of the normal earth-temperature in the deep synclinal basins through which the waters circulated. . . . It is evident that at a depth of 5,000 feet the earth temperature exceeds that of the hottest spring in the region." Such an explanation is not applicable to the thermal springs at Hot Springs, N. C. These springs emerge at the surface at an altitude of 1,332 feet from the Shady dolomite, which is on the south limb of a syncline. This formation is not known to outcrop at a higher altitude in the nearby region, from which an artesian flow could be derived. The water evidently reaches the surface from a deep source beneath the Shady dolomite, along a fracture in the rocks. This fracture cannot be the Great Smoky overthrust, which emerges 1,500-2,000 feet to the north of the spring and about

[15] Reeves, Frank: 1932, Thermal springs of Virginia: Va. Geol. Survey Bull. **36**, pp. 37-52.

200 feet higher in altitude, and is known to have a gentle dip and therefore does not reach great depths in the vicinity of the springs.

Figure 3 shows the distribution of the outcrops of the Paleozoic rocks near the springs. The Hesse and the Nebo

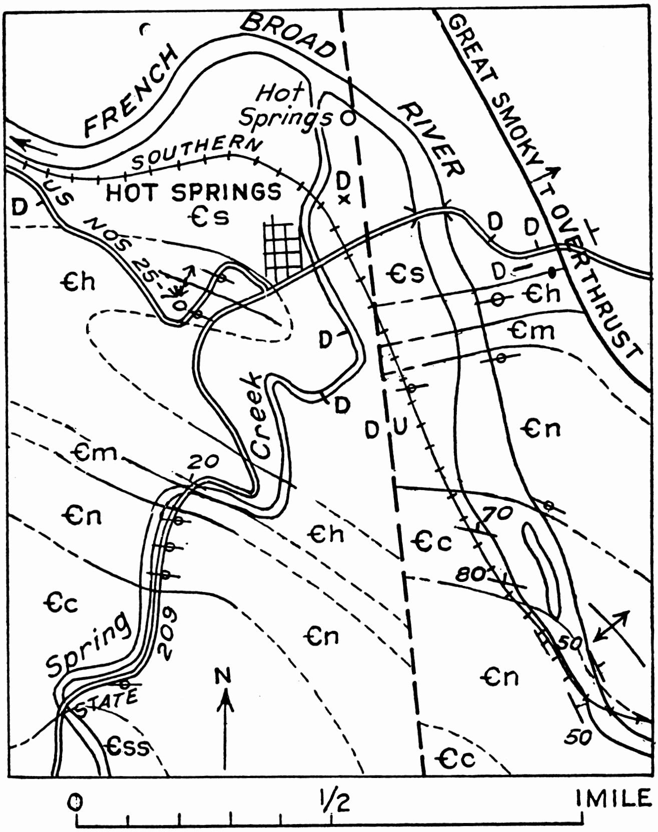

Figure 3. Geological map of the vicinity of Hot Springs, N. C. Showing offset of existing outcrops (solid lines) and a postulated cross fault through the springs to account for the offset.

Ꞓs, Shady dolomite. Ꞓh, Hesse quartzite. Ꞓm, Murray shale. Ꞓn, Nebo quartzite. Ꞓc, Cochran quartzite. Ꞓss, Sandsuck shale. D, dolomite.

quartzites exposed on French Broad River are vertical and strike almost due west into the limestone lowland at Hot Springs. The Hesse quartzite on Spring Creek strikes S. 70° E. and dips 20° NE. and the Nebo quartzite strikes

E.-W. and is vertical. These outcrops of the two formations are not stratigraphically continuous and are offset across the strike about half a mile. The writers have concluded that a fault, shown on Fig. 3, accounts for this offset. If the white quartzite that crops out west and north of the bridge of the Southern Railway over French Broad River is Nebo and the Cochran quartzite in the railroad cut to the north of it is in an anticline, as the writers have suggested, this uplift is probably the anticline that exposes Hesse quartzite on U. S. Highway 25-70 in Hot Springs which, east of the inferred fault, has been raised sufficiently to expose the Cochran quartzite at the axis. The structures on opposite sides of the inferred fault thus match, the rocks east of the fault have been relatively uplifted, and the anticlinal axis east of the fault has been shifted half a mile south. This fault cuts directly across the structure and trends nearly due north through the springs. In the Appalachian Mountains and the Piedmont upland, cross faults of this type are commonly tension faults with nearly vertical planes. A vertical fault would reach deep-seated horizons in the syncline below the Shady dolomite and would tap artesian water in the beds deep in the syncline.

The map (Fig. 1) shows the extent of thick-bedded arkosic quartzite in the lower part of the Cambrian sequence exposed, with gentle dips, in the vicinity of Vann Cliff, Long Mountain, and Stony Spur. These beds are not dense compact quartzites but are more or less porous, and would be an ideal aquifer. The section (Fig. 4) shows that these rocks descend to a depth of over 5,000 feet in the syncline, beneath the Shady dolomite exposed in the lowland, and could be the source of the hot water. The altitude of the upland around Vann Cliff and the crest of Long Mountain west of the cliff is considerably above 2,123 feet, which is the altitude of the nearest bench-mark on North Carolina Highway 209, and the elevation of the lowland at the spring is 1,332 feet. The difference in altitude of these two points gives an adequate head for the artesian flow at the spring.

The increase in temperature in depth within the earth in the southern Appalachians is 1° F. for every 60.8 to 71.4 feet in depth.[16] The mean annual temperature of the air at

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

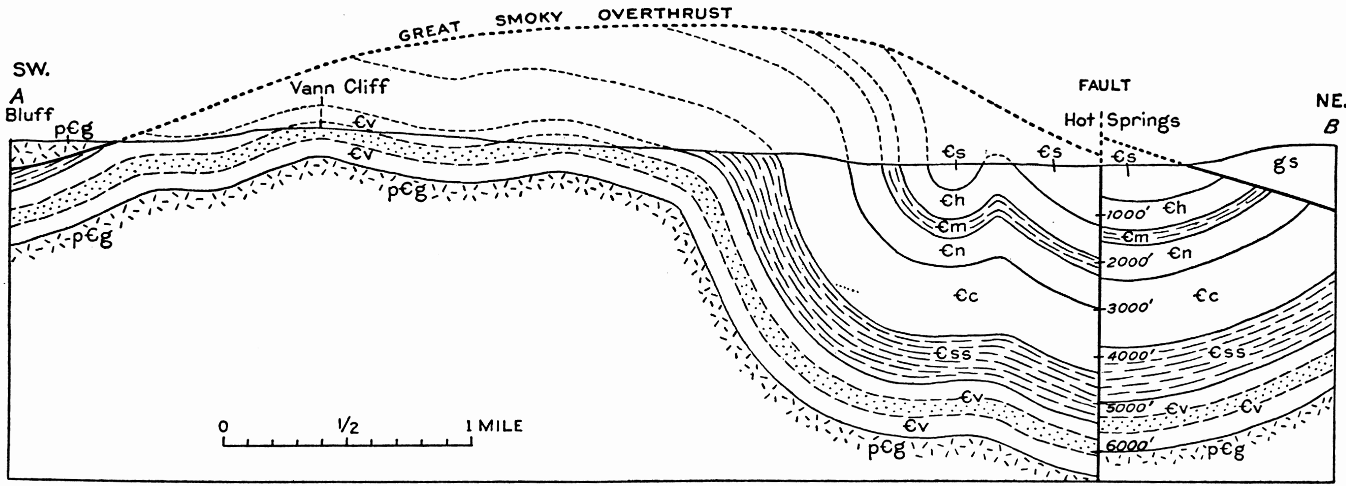

Figure 4. Section along line AB on Figure 1, showing porous sandy strata in the Vann quartzite outcropping on the upland at Vann Cliff and descending to more than 5,000 feet in depth in the syncline beneath the spring. The hot water ascends along the cross fault which taps this aquifer.

Єs, Shady dolomite. Єh, Hesse quartzite. Єm, Murray shale. Єn, Nebo quartzite. Єc, Cochran quartzite. Єss, Sandsuck shale. Єv, Vann quartzite, containing porous sandy beds. pЄg, granite gneiss of the early pre-Cambrian injection complex. gs, Great Smoky quartzite.

the surface in the Hot Springs region is 50°. At the rate of 71.4 feet for 1° increase in temperature, a depth of 3,900 feet would produce a temperature of 104°, that of the water of the hot springs. Groundwater at shallow depth, shielded from the sun's rays, is generally cooler than the air at the surface, so that water must be heated more than the difference between the temperature of the spring and the mean annual temperature of the air. Furthermore, some heat probably is lost in the slow ascent of the water in the conduit of the spring. However, with the necessary allowance for these factors, a depth of over 5,000 feet, as indicated by the section, would supply enough earth-heat to account for the temperature of the water at the hot springs.

CONCLUSION.

A cross fault that passes through the springs has been demonstrated as necessary to explain the observed outcrops of the formations and their structure. That this cross fault is a nearly vertical tension fault along which ground water can freely circulate is a reasonable assumption. The writers suggest, therefore, that the artesian conditions and the high temperature of the springs arise from the fact that water enters porous beds of the Lower Cambrian quartzites in the vicinity of Vann Cliff and Long Mountain, descends into the syncline beneath the lowland around Hot Springs, and rises on a normal cross fault.

WASHINGTON, D. C.