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ORIGIN OF THE LARGE SPRINGS AND THEIR ALCOVES ALONG THE SNAKE RIVER IN SOUTHERN IDAHO[1]

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ABSTRACT

A group of large springs, eleven of which rank among the largest springs in the United States, discharge 5,000 cubic feet a second from the north side of the Snake River between Bliss and Twin Falls, Idaho. Most of the water issues from pillow lava at the base of basalt flows that fill ancestral canyons of the Snake River carved in the older lake beds of the region. Six different canyon fills of basalt, indicating six displacements of the Snake River in Pleistocene time, have been mapped in this area by the author.[2] Each of the flows that spilled into the Snake River Canyon caused a temporary lake on the upstream side of the lava dam and an alluvial fan containing huge blocks torn from the dam on the downstream side. Subsequent partial removal of the fans by the river has left concentrates of huge boulders in the form of trains, helpful in locating such displacements of the Snake River. Springs issue from these canyon fills of permeable basalt wherever the river has cut into them below the water table. Some of the springs issue from box-headed canyons or alcoves, which have been made by the springs, probably by solution of the basalt. It is believed that these springs are older than the others.

LOCATION AND DISCHARGE

Issuing from the north side of the Snake River Canyon in the 50-mile stretch between Twin Falls and Bliss, Idaho, are many large springs which have an aggregate discharge of more than 5,000 cubic

[1] Published with the permission of the Director of the U.S. Geological Survey.

[2] H. T. Stearns, L. Crandall, and W. G. Steward, "Geology and Ground-Water Resources of the Snake River Plain in Southeastern Idaho," *U.S. Geol. Surv. Water-Supply Paper* (in press).

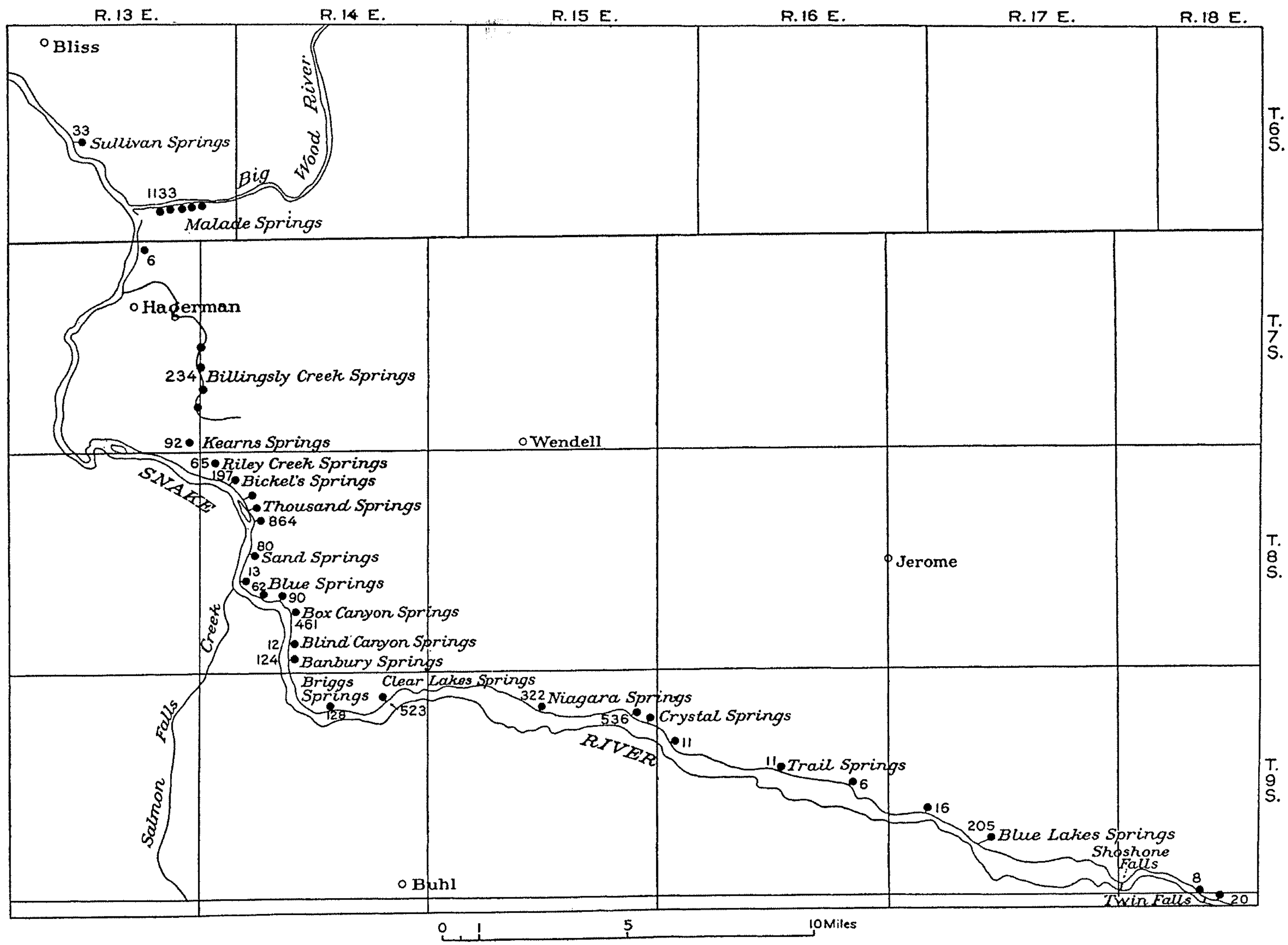

FIG. 1.—Map showing location and yield of the large springs on Snake River between Twin Falls and Bliss, Idaho. Numbers show yield of spring in second-feet. Most of the yields were measured in September or October, 1917, by Lynn Crandall, L. T. Burdick, and other engineers of the Twin Falls North Side Land and Water Co. Yield of Niagara and Sand Springs is that for September, 1918; of Thousand Springs, for August, 1920. (After Meinzer, *U.S. Geol. Surv. Water-Supply Paper 557*, p. 44, Fig. 12.)

feet a second and eleven of which rank among the largest springs in the United States (Fig. 1). Their aggregate flow would supply all the cities in the United States of more than 100,000 inhabitants with 120 gallons a day for each inhabitant.[3] Thousand Springs was the most spectacular of these springs before it was harnessed for water power (Figs. 2 and 3). Some issue from box-headed canyons or alcoves, only one of which receives surface drainage (Fig. 4). The water is

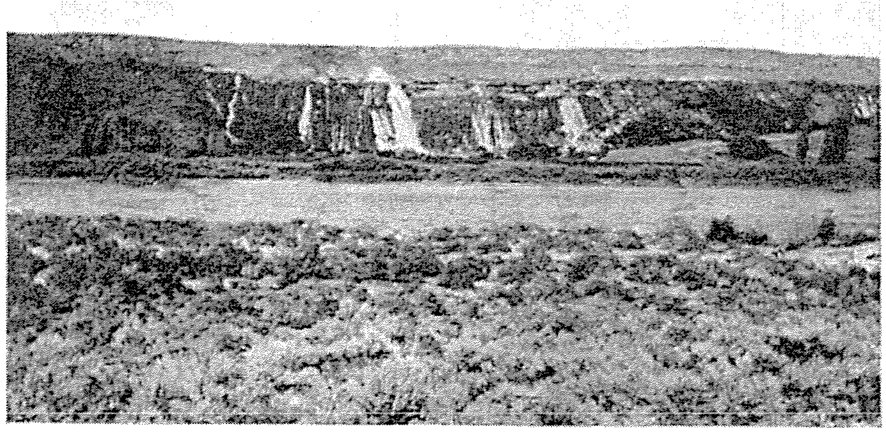

FIG. 2.—Thousand Springs before present power development. (Photograph by C. F. Bowen, *U.S. Geol. Surv. Water-Supply Paper 557*, Pl. 9.)

clear and has a temperature varying only a few degrees from 60° F. throughout the year.

PREVIOUS WORK AND PRESENT INVESTIGATION

Russell[4] was apparently the first to describe these springs in detail. He believed that they were supplied by water sinking in Big and Little Lost River sinks and from precipitation on the adjacent lava plain, and that the structure causing the springs was essentially that of horizontal lava sheets interstratified with sedimentary beds.[5]

[3] O. E. Meinzer, "Large Springs in the United States," *U.S. Geol. Surv. Water-Supply Paper 557* (1927), pp. 43–44, Fig. 12.

[4] I. C. Russell, "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull. 199* (1902), pp. 22–27, 162–66.

[5] *Ibid.*, p. 151 and Fig. 3.

Meinzer,[6] in his excellent description of these springs, summarizes the results of unpublished hydrographic surveys and the published account by Crandall.[7]

In 1928–30 the writer, with Lynn Crandall and W. G. Steward, made an investigation of the geology and underground-water resources of the Snake River Valley above King Hill for the United States Geological Survey, in financial co-operation with the Idaho

FIG. 3.—Near view of Thousand Springs, Idaho. (Photograph by C. F. Bowen, *U.S. Geol. Surv. Water-Supply Paper 557*, Pl. 9.)

Bureau of Mines and Geology, and the Idaho Department of Reclamation. The detailed report of this work awaits publication by the Geological Survey. The present article is a summary of one phase of the investigation and was presented as part of a symposium on ground water held by the Ground-Water Division of the United States Geological Survey in Washington in January, 1935. In the detailed report the writer has divided the rocks of the Snake River Basin of central southern Idaho into the units named in Table I.

[6] *Op. cit.*, pp. 42–51.

[7] Lynn Crandall, "The Springs of Snake River Canyon," *Idaho Irrig., Eng. and Agric. Societies Joint Conf. Proc.* (1918 and 1919), pp. 146–50.

GEOLOGY OF SPRING AREA

STRUCTURE AT SPRINGS

The numerous springs in almost all places issue from pillow lava or a peculiar glassy breccia at the base of a basalt layer, where it rests on older rocks. The pillows consist of spheroidal masses of lava of the same petrologic type as the basalt with which they are associated. They range from a few inches to 2 feet in diameter and con-

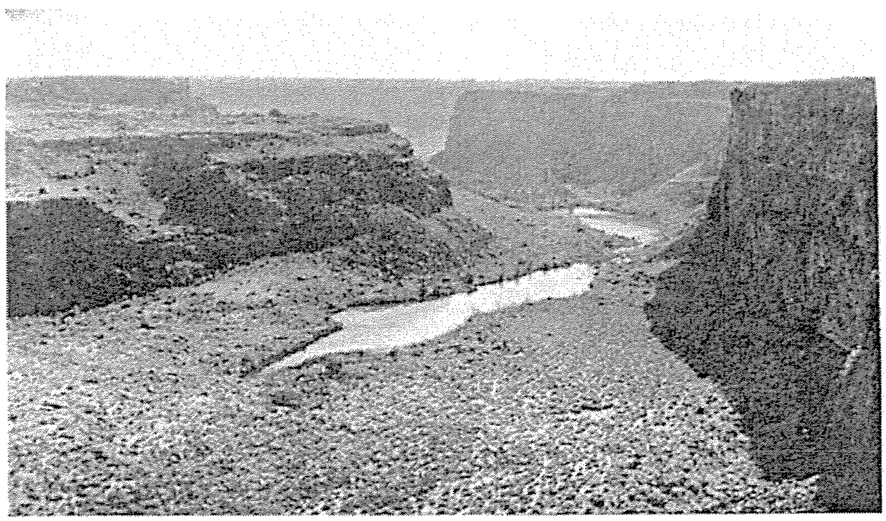

FIG. 4.—Blue Lake alcove, looking south into Snake River Canyon, Idaho. (Photograph by I. C. Russell, *U.S. Geol. Surv. Bull. 199*, Pl. 24.)

sist of a vesicular core changing outward to a dense glassy rind. Invariably they have numerous irregularly developed radial cooling cracks, especially near their surface, which make them break into small pieces. The pillows are loosely packed together in a matrix of comminuted friable basalt glass (Fig. 5). In many places much of this finer material has been carried out by spring water, and that which remains is commonly altered to a yellowish decomposition product resembling palagonite.

Downstream from the Thousand Springs the rock underlying the pillow lava in most places is the impermeable clay of the Hagerman lake beds (late Pliocene). At Thousand Springs the underlying rock is relatively impermeable stratified tuff in this same formation, but

TABLE I

GEOLOGIC FORMATIONS OF SNAKE RIVER BASIN, CENTRAL SOUTHERN IDAHO

Recent	Landslides and talus Alluvium, 0–20+ feet Loess, 10± feet
	Black lavas and cones, 100± feet
Pleistocene	Old alluvium, 100± feet Late Pleistocene basalt, 100± feet Wendell Grade basalt, 25± feet (black, aphanitic pahoehoe). *Type*, Wendell Grade, in road in Gooding Co., N.W. of town of Wendell.
	Minidoka basalt, 30± feet (vesicular, blue pahoehoe). *Type*, Minidoka dam; probably issued from one of cones near Minidoka. Burley lake beds, 150 feet in wells; not exposed. Deposited in ancient Lake Burley.
	Sand Springs basalt, 500± feet (massive pahoehoe flow). Exposed for 14 miles up Snake River, or to point where Sand Springs cascade into Snake River, in Gooding County. *Type*, wall of Snake River Canyon at Sand Springs cascade.
	Bliss basalt, 100± feet (chiefly vitreous porphyritic basalt; brecciated subaqueous flow). May be subaqueous phase of McKinney basalt or, possibly, of Sand Springs basalt. *Type*, Bliss Cone and Bliss Bridge, Sec. 11, T. 6 S., R. 12 E., Twin Falls County; also Bliss Spring, Gooding County.
	McKinney basalt, 20 feet on plains, 500 feet in Snake River Canyon (porphyritic, grayish-black pahoehoe). Issued from McKinney Butte, N.W. of Gooding. *Type*, McKinney Butte.
	Thousand Springs basalt, 100± feet (feldspar-olivine pahoehoe; filled with tubes and open contacts). Thousand Springs, S.W. of Wendell, in Gooding County, issue from this basalt. *Type*, bluff above Thousand Springs.
	Malad basalt, 400± feet (black pahoehoe). *Type*, cliff in Malad Canyon near Malad Power Plant.
	Madson basalt, 200+ feet (dense, black, jointed). Fills former canyon of Snake River carved in Hagerman lake beds. Madson Spring issues from this basalt. *Type*, cliff above Madson Spring.
	American Falls lake beds, 150± feet (buff, horizontal, evenly bedded, partly consolidated, clay, sand, and silt, including a 10±-foot member of gray pahoehoe basalt). *Type*, bluffs along Snake River from American Falls dam, Power County to narrows, 5± miles distant.
	Cedar Butte basalt, 200+ feet (aphanitic, blue, pahoehoe). *Type*, Cedar Butte, T. 8 S., R. 29 E. Power County. ~~~~~~local~~~~~~ Early undifferentiated basalt, 500+ feet.

TABLE I—*Continued*

Pliocene	Hagerman lake beds (upper Pliocene), 600± feet (nearly horizontal, partly consolidated, buff to white clay and silt, with, in most places, a gravel cap 20 feet thick; some pebbly lenses and sandy beds near top; in places some basic tuffs and flows; one thin basalt flow 200 feet below top is conspicuous for several miles along Snake River; contains a 20-foot bed of diatomite near mouth of Salmon Falls Creek). Late Pliocene fossils. Forms prominent bluffs along Snake River in Hagerman Valley, Gooding, and Twin Falls counties. *Type*, West bank Snake River at Hagerman.
	Banbury volcanics, 360± feet (massive, dark-brown weathered basalt flows and coarse and fine tuff beds). *Type*, exposures near Banbury Hot Springs, Sec. 33, T. 8 S., R. 14 E., Twin Falls County (*Upper Pliocene*).
	Raft lake beds (Middle[?] Pliocene), 200± feet (buff-colored clay, silt, and sand; in places filled with concretions; partly consolidated). In places unconformable on Paleozoic limestone. *Type*, exposures along Raft River, near mouth.
	Rockland Valley basalt (Middle[?] Pliocene), 250± feet (even-bedded blue and black, partly weathered; contains at least one bed of clay 15 feet thick in Rock Creek Canyon). *Type*, exposures on north side of Rockland Valley.
——(?)——	
Pliocene (?)	Massacre volcanics (Pliocene[?]; Lower [?] Pliocene), 150± feet (well-consolidated, red to brown, cindery basaltic tuff, in places containing angular fragments of underlying formations; at many places a persistent flow, 23± feet thick, of fine-grained blue basalt at base). *Type*, Massacre Rocks, Sec. 6, T. 9 S., R. 30 E. Power County, is the feeder from which these tuffs and lavas were erupted.
	Eagle Rock tuff (Pliocene[?]; Lower [?] Pliocene), 35± feet (rhyolite tuffs, in part welded obsidian). *Type*, Eagle Rock, northeast of Massacre Rocks, Power County.
	Neeley lake beds (Pliocene[?]; Lower[?] Pliocene), 100+ feet (flesh-colored to brown sandy lacustrine deposits, partly reworked tuffs). *Type*, in bluffs of Snake River in vicinity of village of Neeley, 5 miles southwest of American Falls.
——(?)——	
Miocene (?)	Pillar Falls mud flow (Miocene[?]; Upper[?] Miocene), 0–40± feet (well-rounded gravel and huge boulders several feet in diameter; andesitic pebbles and boulders intermingled with ash and soil). *Type*, exposures at Pillar Falls.
	Shoshone Falls andesite (Miocene[?]; Upper[?] Miocene), 200+ feet (purple and black, massive, vitreous, porphyritic). Forms Shoshone Falls and Pillar Falls. Rests on Paleozoic limestone. *Type*, Shoshone Falls.

upstream as far as Blue Lakes it is in most places the underlying slightly permeable Banbury volcanics. From Blue Lakes to Twin Falls it is massive andesite.

WATER-BEARING ROCKS

Although on casual examination the water-bearing basalt seemed to be a more or less continuous layer, detailed study showed that there were at least six and possibly seven different basalts that are conduits for the spring water between Twin Falls and King Hill. Most

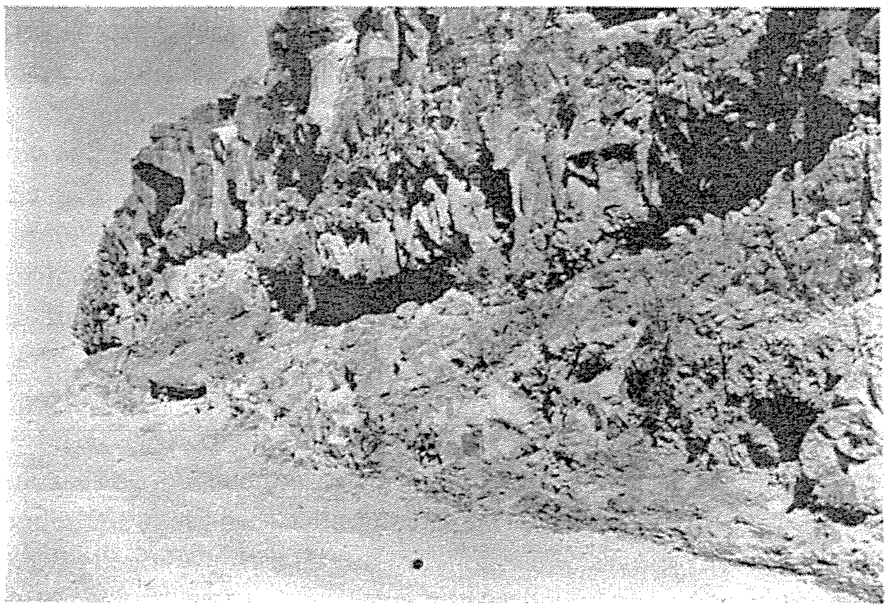

FIG. 5.—Pillow lava at base of Sand Springs basalt, top of Clear Lakes grade. Note pillow in lower right foreground. (Photograph by H. T. Stearns, Neg. No. 729.)

of these basalts differ only slightly in petrologic characteristics, but all of them, with possibly one exception, differ sufficiently in field occurrence to make them readily susceptible of mapping. These basalts, named in order of their age from oldest to youngest, are (1) Madson basalt, (2) Malad basalt, (3) Thousand Springs basalt, (4) McKinney basalt, (5) Bliss basalt, and (6) Sand Springs basalt. The Sand Springs basalt may consist of two flows poured out at different times, and the Bliss basalt may be a subaqueous phase of the McKinney basalt. Mapping of each of these basalts showed that they fill or partly fill ancestral canyons of the Snake River adjacent to the present canyon (Fig. 6). The best place to see one of these canyon fills of basalt is on the main highway opposite and upstream from the Thousand Springs power plant. The observer looking across the river at this point gets a magnificent view of a broad V-shaped section of the Sand Springs basalt, more than 300 feet thick, resting unconformably on older rocks. The bottom of the lava fill extends below the river surface, indicating that the old canyon was deeper than the present one. At this point the Sand Springs basalt is almost completely drained, but upstream numerous large springs issue from it. The manner in which lava-filled canyons serve as extensive collecting systems for underground water, discharging huge springs where tapped by erosion, has been described by the writer elsewhere.[8]

Madson basalt.—The Madson basalt, a dense, black, jointed basalt, crops out beneath the Malad and McKinney basalts in the east wall of the Snake River Canyon half a mile downstream from the mouth of the Malad River. It probably reached the Snake River by flowing down an ancestral canyon of the Malad. Steele and Madson Springs, and possibly Bliss Spring, are fed from this basalt, which has an exposed thickness of 200 feet.

Malad basalt.—Closely following the extrusion of the Madson basalt came a very voluminous flow of black pahoehoe lava that displaced the Snake River for at least 9 miles between the Malad River and Thousand Springs. This flow dies out as a thin wedge between the Madson and McKinney basalts near Steele Spring. It has been named the "Malad basalt" because it forms a 400-foot cliff in Malad Canyon. The Hagerman and Kearn tunnels, near Hagerman, expose 20–25 feet of pillow lava at its base. This basalt supplies all the water in Billingsly and Cove creeks and also the voluminous Malad Springs, which, because they yield more than 1,000 cubic feet a second, rank among the largest springs of the world.

Thousand Springs basalt.—The canyon carved in the older sediments by the Snake River after its displacement by the Malad basalt was filled with a very permeable porphyritic feldspar pahoehoe. Pillow lava or a related phase of comminuted glassy basalt characterizes the basal contact. This basalt, which is about 200 feet thick, is

[8] "Geology and Water Resources of the Upper McKenzie Valley, Oregon," *U.S. Geol. Surv. Water-Supply Paper 597* (1928), pp. 171–88.

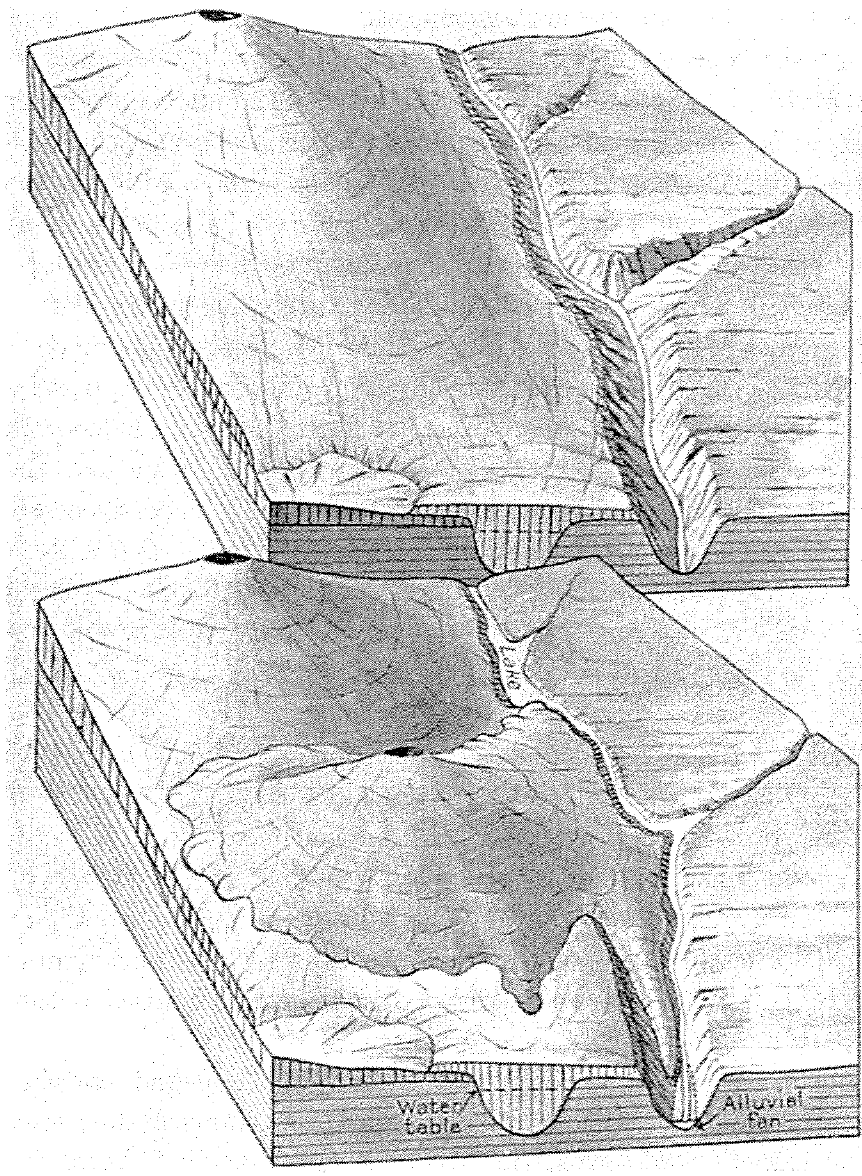

FIG. 6.—Diagram showing displacement of Snake River by lava flows

a great aquifer; all the large springs along the Snake River from Sand Springs to Riley Springs issue from it.

McKinney basalt.—McKinney Butte, at the foot of the mountains on the north, sent three streams of porphyritic lava into the Snake River Canyon. One of these lava flows made a fill in the canyon about 500 feet thick and displaced the river for a distance of 6 miles between Bliss and King Hill. Although extremely permeable, it carries very little water. Its supply is entirely dependent upon local rainfall because upstream leakage into it from the Snake River is prevented by a barrier of relatively impermeable basalt. Apparently lateral movement of water into it from the opposite side of the buried canyon is cut off by the same impermeable formation. The McKinney basalt, a prophyritic, grayish-black pahoehoe, named for McKinney Butte, supplies a small spring in Section 4, T. 6 S., R. 11 E. It has been described here because it crops out in the big-spring area and hence is part of the series of canyon fills. It is younger than the Malad basalt and is believed to be older than the Sand Springs basalt.

Bliss basalt.—A brecciated, vitreous, porphyritic basalt that was probably laid down under water crops out for about 7 miles downstream from the mouth of the Malad River. Several dikes and a large cone (Bliss Cone) are associated with it. It is very permeable, and from it issue several springs, notably Bliss Spring and the unnamed spring an eighth of a mile southeast. Its age is uncertain except that it is later than the Malad and Thousand Springs basalts. It is about 100 feet thick.

Sand Springs basalt.—Just upstream from Thousand Springs a V-shaped canyon fill of lava about 500 feet thick shows in the present Snake canyon wall. This, the "Sand Springs basalt," forms flat-topped, detached benches for 14 miles down the Snake River from the point where the Sand Springs cascade into the river, and completely fills an ancient canyon of the river for a long but unknown distance upstream. About $2\frac{1}{2}$ miles downstream from Blue Lakes another V-shaped section of basalt is exposed in the wall of the Snake River Canyon. This may be another canyon fill of lava, but it could not be definitely established as different from the Sand Springs basalt, and may be only a large exposure of the side of the

Sand Springs canyon fill. If so, the Sand Springs basalt fills a former canyon of the Snake River for about 50 miles and supplies all the large springs from Twin Falls to Thousand Springs.

CAUSE OF PILLOW LAVA

From a few feet to 25 feet or more of pillow lava lies at the contact between these canyon-filling basalts and the older rock. It is most readily seen at the north end of the Twin Falls bridge across the Snake River, where the Sand Springs basalt rests on an older subaërial basalt. In Kearn tunnel 25 feet of pillow lava at the base of the Malad basalt rests on dry, mealy loess. In other places the pillow lava lies on tuffs, on older basalts, or on eroded lake beds. It seems to bear no relation to the character of the underlying formation. Moreover, pillow lavas were not observed at the base of the basalt sheets that do not fill canyons of the Snake River. Obviously this peculiar pillow phase is in some way connected with the conditions associated with the burial of the canyons.

Pillow lava of this type generally has been thought to be caused by lava flowing into water, but it is obvious from the conditions at most if not at all the outcrops in this area that the lava was spread over dry ground similar to the present surface. The following hypothesis is given to account for the presence of the pillow lava.

When a lava flow entered the Snake River Canyon it dammed the river and buried extensive saturated gravel deposits in the river bottom and also numerous pools of water. Much of this water trapped under the lava was converted into steam, which probably escaped chiefly at the contact of the lava with the canyon wall. It is highly probable that percolation from the ponded river continued through the gravel and brecciated base of the basalt throughout the period of eruption, and hence there was no lack of water. It is believed that the steam formed in this manner and escaping from the margins of the basalt gave rise to conditions essentially the same as those under which the usual subaqueous pillow lavas are produced and hence enabled pillow lavas to form at the base of these canyon-filling basalts far above the river bed.

GEOLOGIC HISTORY

Following the draining of the lake in which the Hagerman sediments were laid down voluminous basalt flows spread northward from vents south of the present Snake River. These lava beds underlie the Twin Falls irrigation project and extend from Burley to the mouth of Salmon Falls Creek. During this volcanic epoch the Snake River probably flowed north of its present course, near the axis of the present Snake River Valley. After the cessation of the lava outpourings on the south side of the valley, sporadic eruptions on the north side began to crowd the river southwestward in this area (Fig. 6). The earliest known of these lavas is the Madson basalt, which was probably of insufficient volume to affect the position of the river materially. Erosion followed, during which the Snake River cut a canyon at least 400 feet deep. Then came the voluminous Malad basalt, entirely filling this canyon for at least 9 miles and displacing the river southwestward. The river then cut a new canyon farther southwest in the lake beds, but this canyon was only about 200 feet deep when erosion was halted by the outpouring of the Thousand Springs basalt. Another time of canyon-cutting at the southwest edge of this basalt came next, during which a canyon deeper than the present one was cut. This canyon later became filled in the stretch between Bliss and King Hill by the McKinney basalt, partly filled between Bliss and Malad Springs by the Bliss basalt, and upstream from Malad Springs probably as far as the town of Paul (near Rupert) by the Sand Springs basalt. After the Sand Springs eruption the river took a new course, partly along the south margin of the Sand Springs basalt, and carved the present canyon between Burley and Thousand Springs. Near Thousand Springs it tumbled back into its previous partly lava-filled canyon and began the task of removing these rocks.

EFFECTS OF DISPLACEMENT OF SNAKE RIVER BY LAVA FLOWS

The damming and displacement of the Snake River by these lava flows had four effects: (1) lake-bed sediments were deposited on the upstream side of the lava dams, giving rise to such deposits as the Burley and American Falls lake beds; (2) a new canyon was cut along the margin of the basalt where the lava was in sufficient volume to displace the river completely; (3) at the downstream end of the lava dam a fan was built containing huge blocks torn from the dam during its destruction. The formation of the fan at the toe of the dam resulted from the abrupt decrease in gradient at the point where the river reached its old graded channel. (4) Finally, most of this fan deposit was removed, leaving a concentrate of the largest boulders as a train at the toe of the former dam, because, as the dam was cut away, the river changed from an aggrading to a degrading stream but lacked sufficient velocity to remove the big boulders. Such boulder trains are important criteria for recognizing volcanic accidents in the history of a river.

Irrigation projects are situated on both sides of the Snake River Canyon in the area of these springs. Because these lava-filled canyons on the north side of the river act as great underground drains, the irrigated lands on that side do not need artificial drainage, whereas those on the south side do. In a few places on the south side the water table has risen as much as 800 feet because of the lack of adequate drainage in the underlying rocks.

SPRINGS

TYPES OF SPRINGS

Two distinct types of springs were observed—those which discharge from the ends of canyon fills of lava where they have been cut through by the river and those which discharge from window-like exposures on the sides of the canyon fills. For example, a spring issues from the Thousand Springs basalt at each low spot or sag in the impermeable divide that separates this saturated basalt from the Snake River. Thus, these springs may be considered as discharging from spillways at successively lower levels downstream. Commonly these spillways are sufficiently numerous to drain the basalt fill almost completely, so that where it is finally cut entirely across by the river it yields little water.

SOURCE OF SPRING WATER

The water-table map prepared during the investigation indicates that the springs are supplied chiefly from water lost in the upper stretches of the Snake River Valley and from irrigation on the north side of the river. Additional water is derived from the surface drainage sinking in the lava beds on the north side of the valley and from precipitation on the lava plains.

The discharge of the springs increased from 3,885 second-feet in 1902, before any irrigation developments had been made on the north side, to 5,085 second-feet in 1918, after the north-side irrigation project had been developed.[9] The hydrograph of Blue Lakes Spring indicates that ground water flows through the basalt in the 15-mile stretch between the Wilson Lake region and this spring at an average rate of 750 feet a day.

TABLE II

APPROXIMATE AVERAGE ANNUAL CONTRIBUTIONS TO THE SPRINGS IN SNAKE RIVER VALLEY ABOVE KING HILL

(Based on studies of run-off prior to 1930)

	Acre-Feet
Big and Little Wood River areas	354,000
Big Lost River	226,000
Other creeks between Big Lost River and Henrys Fork	200,000
Henrys Fork	698,000
Snake River between Heise and Shelley	922,000
Losses from Lake Walcott Reservoir	100,000
Minidoka project	240,000
Twin Falls North Side project	600,000
Rainfall on lava plains	700,000
Total	4,040,000

POSSIBLE DEVELOPMENTS

The fact that the water supplying these springs flows through definite canyon fills of lava makes it possible to recover this water at certain points for the development of power. For example, by drilling a line of holes north of the river at Shoshone Falls it may be possible to locate one or more of these lava-filled canyons and partly drain them by a tunnel. Other similar developments might be made at power sites farther downstream. However, it should not be expected that such tunnels will recover all the water now discharging from these lava-filled canyons, because they probably receive contributions at numerous places from parallel lava-filled canyons to the north.

[9] Meinzer, *op. cit.*, p. 43.

SPRING ALCOVES

ORIGIN

Many of the big springs discharge from box-headed canyons or alcoves that receive no surface drainage and hence must have been made by the springs themselves. The most notable are Blue Lakes, Box (Fig. 7), Blind, and Malad canyons. Some are dry, like the unnamed ones near Shoshone Falls and those in the Lake Channel region southwest of American Falls, and are partly filled with talus, alluvium, or wind-blown sand. Russell, who first recognized these alcoves as due to spring action, describes them as follows:

FIG. 7.—Head of Box Canyon showing absence of talus in spring pool. (Photograph by H. T. Stearns, Neg. No. 727.)

At Blue Lakes, about 5 miles below Shoshone Falls, where the walls of Snake River Canyon are about 700 feet high and nearly vertical, except for the talus lodged against their bases, there is a tributary canyonlike alcove in the north wall which is about 2 miles long and about 2,000 feet across at the top and which heads in a semicircular amphitheater with vertical walls about 300 feet high. There is no stream entering the alcove from the surface of the neighboring plain, but springs discharging probably several hundred cubic feet of water per second boil up in the amphitheater at its head. One of the striking features in this alcove is the small quantity of talus at the bases of the bordering cliffs. This is most noticeable in the semi-circular expansion of the alcove at its head. In the view of the Blue Lake alcove presented on plate 24 [Fig. 4 of this article] some of the features referred to may be recognized. . . . .

These pools and others fed by springs in and near the four alcoves referred to have white bottoms composed of clean white sand which is brought to the surface of the springs themselves. . . . . No exposures of the material on which the basalt rests are known to me, but as the springs are bringing out white silt and fine white quartz sand it is evident that beds of similar material exist beneath the basalt.

The origin of the side canyons which receive no surface streams, such as Little and Box Canyons and the one in which the Blue Lakes are situated, is plainly due to the action of the great springs which come out at their heads. The lower portion of the canyon of the Malad has a like history, modified by the fact that a surface stream is also concerned in the work. The great springs undermine the basalt by removing the soft material on which it rests. Thus blocks of the usually more or less vertically jointed rock break away and fall into the spring and sooner or later sink into the soft bed beneath, as the emerging waters remove the silt and sand from beneath them. By this process vertical walls without talus slopes are produced. This process continuing, the cliff recedes, leaving a side cut or alcove in the wall of the main canyon, which becomes lengthened into a lateral canyon. The process would seem to be cumulative, as the farther the head of a side canyon receded the greater would be the tendency of the escaping waters to converge toward it. The marked tendency to an enlargement into an amphitheater, observable especially at the head of the Blue Lakes alcove, is apparently due to this cause.[10]

Three hypotheses for the origin of the alcoves are considered—sand burial, erosion, and solution.

The sand-burial hypothesis calls for a layer of sand at the bottom of each alcove sufficiently thick to engulf the basalt removed in the development of the alcove. Careful search proved that the white sand in Blue Lakes was typical blow sand from the adjacent river flood plain, also that the basement beneath the Blue Lakes alcove consists of the relatively impermeable Banbury basalt, and not strata of quartz sand. Furthermore, Shoshone Falls andesite forms the basement of the Devils Corral alcove, in Section 32, T. 9 S., R. 18 E., and of several others in the stretch of the Snake River Canyon between Twin Falls and Blue Lakes. Some of these alcoves are dry and now lie high above the level of the Snake River, hence their basement can be examined. The talus postulated by Russell[11] in the floors of these alcoves is absent, and a sharp contact between the ba-

[10] *Op. cit.*, pp. 127, 128.

[11] *Ibid.*, p. 130.

salt and andesite is visible. The postulated presence of soft sand or silt strata of sufficient thickness to engulf a block of basalt 400 feet thick and equivalent in size to the alcove, without any exposure in the adjacent Snake River Canyon, is one of the weak features of this hypothesis. Tunnels driven to tap the spring water in several places along the Snake River Canyon have found the spring water moving through interstices in basalt where it rests on impermeable rock formations.

The conspicuous feature about these alcoves is the scantiness of talus at their heads and its abundance along the alcove walls downstream, as shown in Figure 7. Inasmuch as the spring at its point of issue is clear and has a low velocity, the second hypothesis or that of erosion does not seem adequate to explain these alcoves. In many of the alcoves the water flows swiftly between the spring pool and the Snake River and is armed with quartz sand blown from the river valley, yet the talus is not being removed as rapidly as at the head of the alcove.

The third hypothesis requires the slow solution or chemical weathering of the basalt in the clear water of the spring pool. Chemical weathering results in the breaking-down of the minerals of the basalt into carbonates, chlorides, and sulphates and in the solution of these salts. The nature of these changes is discussed at length by Clarke.[12] As Wentworth[13] expressed it: "Basalt is generally recognized as offering rather slight resistance to chemical weathering, because of the relative instability of such minerals as augite, olivine, and plagioclase feldspar as compared with quartz and orthoclase."

The mean temperature of the spring water is only 10° F. below the mean temperature in the Hawaiian Islands, where basalt boulders fluted by rainwater solution are common. Analyses of the water from several of these springs and adjacent wells were made. The samples were too few to give a conclusive answer to the problem, but were sufficient to indicate that the spring water is not appreciably

[12] F. W. Clarke, "The Data of Geochemistry," *U.S. Geol. Surv. Bull. 770* (5th ed., 1924), pp. 479–542.

[13] C. K. Wentworth, "Principles of Stream Erosion in Hawaii," *Jour. Geol.*, Vol. XXXVI (1928), p. 390.

higher in mineral content than the tributary ground water. However, the volume of water discharged by these springs is so great that if the water dissolved only 5 parts per million of solids after it issued, solution would be competent to form the alcoves in the estimated time since they originated.

ALCOVE PIRACY

The presence of numerous dry alcoves suggests the question: Why and how did they dry up? It is at once evident that an explanation which will fit one group of dry alcoves may not fit others, because of the differences in the kinds of rock involved and in the form of the land surface flooded by the basalt. Another question is: Why do some springs have alcoves and others not?

The following hypothesis is offered to account for the variation in size and shape of the alcoves and the variation in the amount of water rising in those supplied by the Sand Springs basalt.

When the Sand Springs basalt was erupted the Snake River was displaced from half a mile to 5 miles south of its old canyon and forced to find a new channel. Then the river began to erode a canyon to the baselevel of the river bed at the downstream end of the Sand Springs basalt, near the mouth of the Malad River. The water table in the Sand Springs basalt adjusted itself to the point of discharge, which at first was where the river tumbled back into its former partly lava-filled canyon. This place was shown by geologic mapping to be at the mouth of Salmon Falls Creek, near Thousand Springs. Here the first springs should have developed, because upstream from this point the river was presumably flowing above the water table on the surface of the lava plain. It therefore is not surprising to find at this point the best-developed alcoves—namely, Box and Blind canyons, each over a mile long. Between this place and Blue Lakes numerous large springs, such as Clear Lake, issue, but they have not formed alcoves or have made only slight indentations in the valley wall. It is believed that the absence of alcoves at these springs indicates that they are relatively young. This explanation is supported by the fact that the divide between the Snake River and the Sand Springs basalt-filled valley in this stretch is the relatively impermeable Banbury volcanics. At Blue Lakes the divide is formed by permeable basalts, and hence ground water had an opportunity to enter the river at this point early in the history of the present canyon. Accordingly, at this point a large alcove exists similar to Box and Blind canyons.

A series of diagrammatic cross sections are given in Figure 8 to explain these differences in history. Section 1 of Clear Lake represents the geologic conditions in the vicinity of Clear Lake, Niagara, or Crystal Springs prior to the extrusion of the Sand Springs basalt and shows the Snake River Canyon incised in the relatively impermeable Banbury volcanics at the margin of younger basalt. Section 1 of Blue Lakes shows geologic conditions at the same stage in the vicinity of Blue Lakes. The important difference between the two sections is the thick series of permeable basalt beds overlying the relatively impermeable Banbury volcanics at Blue Lakes.

Section 2 at Clear Lake shows the geologic conditions after the canyon was filled with the Sand Springs basalt and before the Snake River had established a new course. The water table is close to the surface in the lava fill, because the baselevel of ground-water flow was established by the outlet of this water at Box Canyon Spring, near Hagerman Valley. The water-table conditions at Blue Lakes at this time were very similar.

Section 3 at Clear Lake shows the conditions after the river had cut a canyon about 100 feet deep at the southern margin of the Sand Springs basalt. The banks of the river consist of the relatively impermeable Banbury volcanics, hence the ground water moving through the lava-filled channel is not affected by the new canyon and continues to flow westward toward Box Canyon, its nearest outlet. At the same stage in the vicinity of Blue Lakes ground water in the lava-filled valley had already begun to escape into the river through the permeable basalt divide.

Section 4 shows a still later stage of river-cutting. In the vicinity of Clear Lake the water table was still in the same position, undisturbed by the presence of a fairly deep canyon adjacent to it because of the impermeable divide between them. At the same stage at Blue Lakes an alcove had already formed because water readily entered through the permeable divide between the old and new canyons. Considerable water was still moving westward through the lava fill,

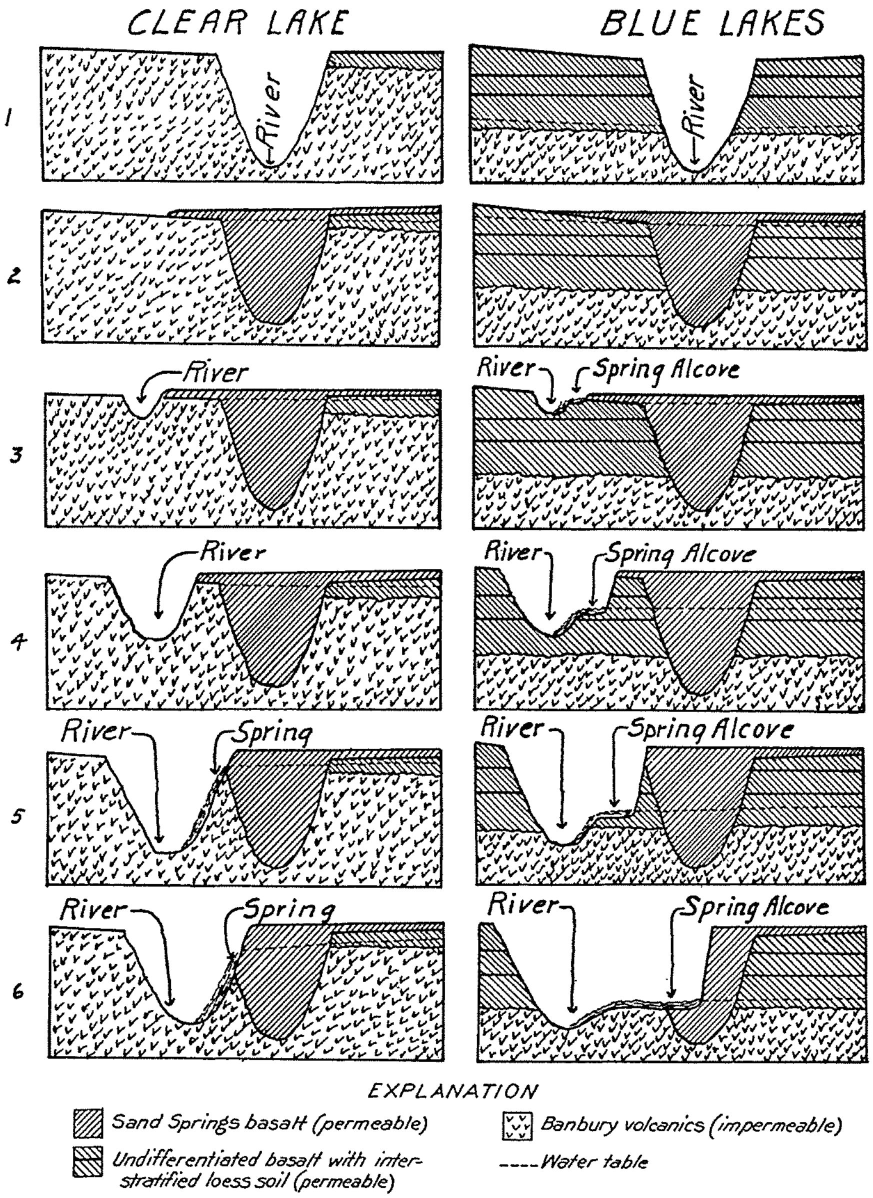

FIG. 8.—Diagram showing formation of Clear Lake and Blue Lakes springs, looking downstream.

because the Blue Lakes outlet was still considerably higher than the bottom of the ancient canyon. West of Blue Lakes additional ground water probably entered the lava fill from the north, and this recharge accounted for the high level of the water table as shown in the section.

Section 5 shows the Snake River Canyon at Clear Lake in a more advanced stage than in section 4. In the process of deepening, the canyon had been widened sufficiently to reduce the impermeable divide slightly between the old and new canyons. Water in the lava fill found an outlet and began to overflow at low points in this divide in the stretch between Blue Lakes and Box Canyon, leading to the formation of Clear Lake and the adjacent springs. The level of the water table was consequently lowered by this overflow of ground water into the river. In the meantime, the Blue Lakes alcove was deepened slightly and migrated northward, as shown in section 5. The old basalt divide has practically disappeared, but the deepening of the alcove was arrested by the spring cutting down to the Banbury volcanics.

Section 6 shows the present stage of the Snake River Canyon at Clear Lake. The long erosional epoch has widened the canyon, thereby reducing the height of the impermeable inverted wedge-shaped divide between the old and new canyons. The springs have increased considerably in discharge, and the water table has been lowered. Probably the increase in the flow of these springs accounts in part for the drying-up of Blind Canyon, which was less favored by the underlying structural conditions than the adjacent Box Canyon. At Blue Lakes the alcove has receded northward until a considerable part of the lava fill in the old canyon has been removed, as shown in section 6. In spite of its steep gradient, the Clear Lake water, being unarmed with abrasive sand, was not able to cut through the Banbury volcanics and keep the spring channel at the same level as the Snake River. For this reason considerable water is still moving westward through the unexposed parts of the lava fill and helping to supply the springs farther west. The deepening of the Blue Lakes alcove dried up the numerous alcoves upstream from it, because at these alcoves the impermeable Shoshone Falls andesite occurred at much higher levels than that of the Banbury volcanics at the Blue Lakes.