History of Snake River Canyon Indicated by Revised Stratigraphy of Snake River Group Near Hagerman and King Hill, Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 644-F

History of Snake River Canyon Indicated by Revised Stratigraphy of Snake River Group Near Hagerman and King Hill, Idaho

By HAROLD E. MALDE

With a section on PALEOMAGNETISM

By ALLAN COX

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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Lava flows and river deposits contemporaneous with entrenchment of the Snake River canyon indicate drainage changes that provide a basis for improved understanding of the late Pleistocene history

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HISTORY OF SNAKE RIVER CANYON INDICATED BY REVISED STRATIGRAPHY OF SNAKE RIVER GROUP NEAR HAGERMAN AND KING HILL, IDAHO

By Harold E. Malde

ABSTRACT

A discovery that debris left by the Bonneville Flood (Melon Gravel) overlies McKinney Basalt about 200 feet above the Snake River near King Hill requires that the stratigraphy of the Snake River Group be revised. In former usage, the McKinney Basalt and its immediately older companion, the Wendell Grade Basalt, were considered on the basis of equivocal field relations to be younger than the Melon Gravel and were assigned to the Recent. These lava flows are here reclassified as Pleistocene. The Bancroft Springs Basalt, which consists of both subaerial lava and pillow lava in a former Snake River canyon, was previously separated from the McKinney but is now combined with the McKinney. Accordingly, the name Bancroft Springs Basalt is here abandoned.

This revised stratigraphy is first described from geomorphic relations of the McKinney Basalt near King Hill and is then discussed in the light of drainage changes caused by local lava flows during entrenchment of the Snake River.

Near King Hill, a former Snake River canyon was completely filled by McKinney Basalt at the place called Bancroft Springs, but the depth of this lava in the next several miles of the canyon downstream (along a route that approximately coincides with the present canyon) steadily decreased. This ancestral geomorphology is inferred from the former canyon route and, also, from the continuity in gradient of the McKinney lava surface downstream from Bancroft Springs.

The drainage history recorded by various lava flows and river deposits of the Snake River Group indicates that the McKinney and Wendell Grade Basalts erupted after the Snake River canyon had reached its present depth of about 500 feet. The Snake River of that time, as far downstream as Bliss, flowed approximately along its present route. The Wood River of that time, however, skirted the north flank of Gooding Butte and joined the ancestral Snake at a junction, now concealed by lava, north of the present canyon about 3 miles west of Bliss. From that place the former Snake River canyon, also now concealed by lava, continued west to Bancroft Springs and thence along a route close to the present canyon to King Hill.

To become entrenched in a canyon 500 feet deep, the Snake River downstream from Hagerman became progressively more incised while its upstream route was pushed south in several earlier canyons by intermittent lava flows. Distinctive gravel deposits help to establish the episodes of progressive canyon cutting and to determine the routes of ancestral drainage, including the former position of the Wood River. As canyon cutting continued, springs began to emerge where lavas had filled the earlier canyons. When the Snake River canyon eventually attained its approximate present depth, the Wendell Grade Basalt erupted near Shoshone and, as several tongues, spread west to the canyon rim opposite Hagerman. One tongue crossed the future route of the Wood River, and another covered an upland area of Sand Springs Basalt that had previously reached the canyon floor at Hagerman.

The McKinney Basalt then erupted from McKinney Butte northeast of Bliss and spread southward as a subaerial flow, covering part of the Wendell Grade Basalt. It filled the ancestral Wood River canyon and the Snake River canyon of that time west of Bliss as far downstream as King Hill. The resulting dam of lava impounded a deep lake, which extended upstream in the canyon beyond Hagerman. Copious amounts of the McKinney spilled into this temporary lake and produced pillow lava. About 2 miles west of Bliss, pillow lava 500 feet thick completely fills the former canyon and is protected by rimrock of the subaerial McKinney Basalt. From Bliss, the pillow facies extends upstream as far as the McKinney rimrock—about 5 miles.

Eruption of the McKinney Basalt diverted the Wood River to a course along the southeast edge of this lava flow. The temporary lake that was dammed by McKinney Basalt west of Bliss spilled along the south edge of the McKinney and began to cut the present canyon of the Snake River. By the time of the Bonneville Flood of 30,000 years ago, the new canyon west of Bliss had reached its approximate present size and depth, for it was able to carry the computed flood discharge. Physiographic change along the canyon since this catastrophic event has been minor.

Paleomagnetic measurements show that the direction of remanent magnetism is the same for both the McKinney Basalt and the Bancroft Springs Basalt of former usage (each sampled in several places at three outcrops). Although it is possible that the earth's magnetic field had this direction at different times, this equivalence suggests that these outcrops are part of the same lava flow.

INTRODUCTION

In current studies by the U.S. Geological Survey along the Snake River from Hagerman to King Hill (fig. 1), one of the difficult stratigraphic problems in dividing the youngest rocks has been to determine the position of two local lava flows, the McKinney Basalt and its immediate predecessor the Wendell Grade Basalt, with respect to the Melon Gravel that was deposited by the catastrophic late Pleistocene Bonneville Flood. Until recently, these lava flows were interpreted on the basis of equivocal field relations to be younger than the Melon Gravel and were assigned to the Recent (Malde and Powers, 1962, p. 1217). Now, however, the McKinney and Wendell Grade Basalts are known to be older than the Melon Gravel and are accordingly dated as Pleistocene. Moreover, the McKinney is now believed to include lava previously classified separately as Bancroft Springs Basalt (Malde and Powers, 1962, p. 1216). (The revised age of the McKinney Basalt was briefly mentioned by Malde, 1964, footnote, p. 204.) This report explains the geologic and paleomagnetic evidence by which this revised stratigraphy has been learned and then applies this knowledge to a new analysis of late Pleistocene history along this segment of the Snake River.

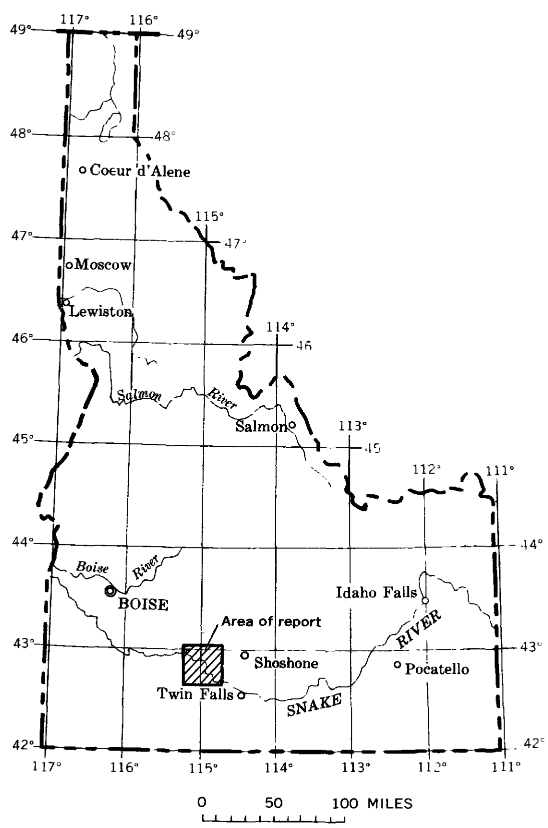


FIGURE 1.—Index map of Idaho showing area discussed.

The analysis of the river history deals with the entrenchment of the Snake River canyon and with the inferred routes of ancestral canyons that are recorded by various lava flows and river deposits of the Snake River Group. Thick deposits of pillow lava a few miles downstream from Hagerman are explained as a facies of the McKinney Basalt that accumulated in a temporary lake 500 feet deep; the lake was impounded by another part of the McKinney Basalt in the Snake River canyon of that time. This pillow lava, though previously known to be older than the Melon Gravel (part of the Bancroft Springs Basalt as used by Malde and Powers, 1962, p. 1216), has not been heretofore explained from a knowledge of the canyon history.

The former and present classifications of the Snake River Group are compared in figure 2.

ACKNOWLEDGMENTS

My work along the Snake River has been shared by Howard A. Powers, who first opened my eyes to the role played by local lava flows in modifying river history. He did much of the geologic mapping on which my present understanding of the Snake River Plain depends. We have spent so much time together discussing the perplexing matters that led to this report, both at the outcrops and in the office, that many of the ideas presented here are as much his as mine. Even so, especially because the features to be described stem mainly from geomorphology rather than volcanology, I take responsibility for whatever faulty deductions are found in these pages.

AGE OF THE McKINNEY AND WENDELL GRADE BASALTS

Surveys between the years 1954 and 1961 established that the McKinney Basalt erupted from McKinney

Former classification		Present classification	
Recent	McKinney Basalt Wendell Grade Basalt	Holocene	Lava flows
Upper Pleistocene	Melon Gravel *Bancroft Springs Basalt Sand Springs Basalt Crowsnest Gravel Thousand Springs Basalt Sugar Bowl Gravel Madson Basalt	Upper Pleistocene	Melon Gravel McKinney Basalt Wendell Grade Basalt Sand Springs Basalt Crowsnest Gravel Thousand Springs Basalt Sugar Bowl Gravel Madson Basalt

*Name now abandoned

FIGURE 2.—Stratigraphy of Snake River Group.

Butte 8 miles northwest of Gooding and that the Wendell Grade Basalt came from Notch Butte 4 miles south of Shoshone (Malde and others, 1963). As these events were then understood, the McKinney Basalt flowed south toward the Snake River, then west in the upland north of the canyon rim, and finally cascaded from the upland to present river level near King Hill; the Wendell Grade Basalt flowed west and reached the canyon rim at several places near Hagerman (fig. 3). Exposures 5 miles northeast of Hagerman along the Malad River (which is the local name for the lower reach of the Big Wood River) showed that the McKinney overlies the Wendell Grade. Because both the McKinney and the Wendell Grade lavas retain rough

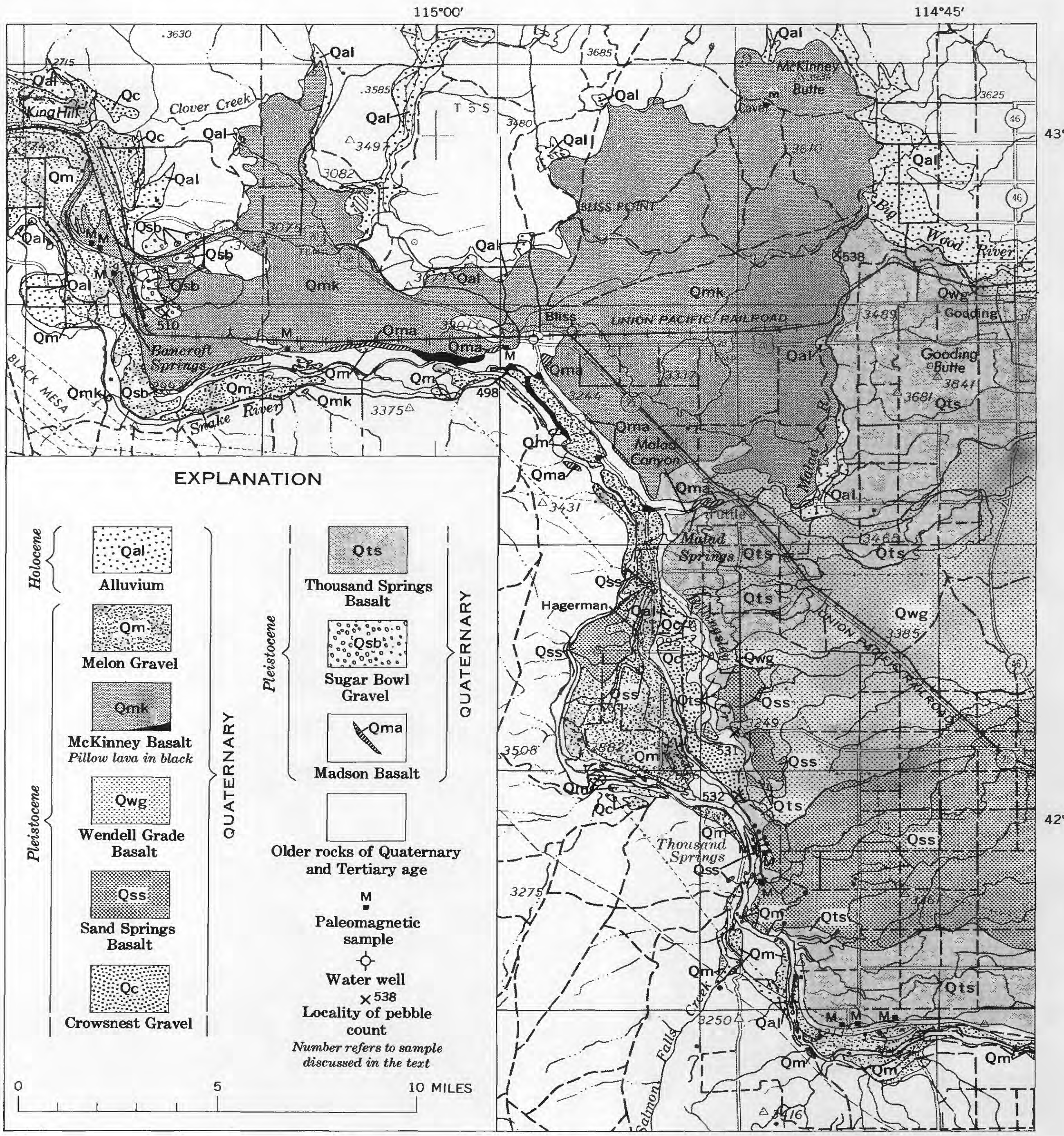


FIGURE 3.—Generalized geologic map of area between Hagerman and King Hill. Geology modified from Malde, Powers, and Marshall (1963). Base from U.S. Geological Survey Twin Falls quadrangle, 1955–63, and Hailey quadrangle, 1955–62.

surfaces that are only partly mantled by windblown surficial material (fig. 4)—in contrast to contiguous older lavas for which the original surface roughness has been almost entirely obliterated—and because of erroneous interpretations explained below, the McKinney and Wendell Grade were assigned to the Recent.

A discovery made in 1962 by George Stone, who was then collecting petrographic samples with Howard Powers, showed that the McKinney Basalt, and hence the Wendell Grade Basalt, is older than the Melon Gravel and is therefore of Pleistocene age, in spite of its youthful appearance. The decisive geology was found along the Union Pacific Railroad 4 miles southeast of King Hill at a site 200 feet above the Snake River. There, the Bonneville Flood scoured McKinney Basalt to make the intricate anomalous topography known as scabland (fig. 5), and it left well-rounded boulders of Melon Gravel on the eroded McKinney, some of which were more than 5 feet long (fig. 6). Prior to this discovery, I had recognized stream erosion of nearby McKinney Basalt no higher than 125 feet above the river and thought that this erosion could have been produced by overflow where the McKinney had dammed the Snake. My other previous interpretations about the relation of the McKinney Basalt to Melon Gravel, which I will now summarize, were also wrong. I had erred in two places.

First, along the Snake River 3 miles southeast of King Hill, the McKinney Basalt overlies basaltic cobbles and boulders formerly interpreted to be Melon Gravel (Malde and Powers, 1962, p. 1217)—the only local gravel deposit then known to consist solely of basaltic debris. The length of outcrop of this gravel amounts to less than a mile, much of it being obscured by talus from the overlying basalt, but sections of the gravel several feet thick are locally well exposed where protected by an overhang of lava (fig. 7). I now

FIGURE 4.—Pressure ridges of McKinney Basalt, which are partly covered with surficial material. View is north toward McKinney Butte from the railroad 5½ miles east of Bliss.

FIGURE 5.—Scabland surface of McKinney Basalt about 200 feet above the Snake River 4 miles southeast of King Hill. Part of the basalt was removed by the Bonneville Flood, and the remaining lava was extensively corraded, rounded, and polished.

discern subtle differences between this deposit and typical Melon Gravel. The basaltic gravel under the McKinney is subangular, rather well sorted, more cobbly than bouldery, and lacks interstitial sand. In contrast, the nearby Melon Gravel is rounded, poorly sorted, more bouldery than cobbly, and contains much basaltic sand. Because of the unequivocal evidence found by Stone and Powers (that is, boulders of Melon Gravel lying on McKinney Basalt), this gravel below the McKinney must be older than the Melon Gravel.

FIGURE 6.—Basalt boulder of Melon Gravel more than 5 feet long on McKinney Basalt 175 feet above the Snake River 4 miles southeast of King Hill. Another boulder, nearly buried by surficial sand, is at the right.

FIGURE 7.—Basaltic gravel under McKinney Basalt on right bank of the Snake River 3 miles southeast of King Hill. Pieces of the gravel are frozen in the base of the lava.

Second, the terminus of the McKinney Basalt near King Hill, in the area known as The Pasture (fig. 8), was formerly interpreted as several small tongues of lava that had descended shallow troughs in the Melon Gravel (Malde and Powers, 1962, p. 1217), but the physiography is now understood as subdued bars of Melon Gravel on the McKinney.

Observations by Powers (in Malde and Powers, 1962, p. 1217), about the stratigraphic position of the Wendell Grade Basalt with respect to Melon Gravel, in the light of present knowledge, were also deceptive. Powers found a place 2 miles east of Hagerman where Wendell Grade Basalt had cascaded from the canyon rim onto landslide debris. Because this landslide closely resembles another landslide 2–3 miles northwest that overlaps Melon Gravel (Malde, 1968, fig. 19), Powers decided that the Wendell Grade Basalt was also younger than Melon Gravel. From present evidence, this conclusion is false. The McKinney Basalt clearly overlies Wendell Grade Basalt on the Malad River, as previously mentioned, and both are older than the Melon Gravel.

CORRELATION OF LAVA PREVIOUSLY CALLED BANCROFT SPRINGS BASALT

Study since 1962 indicates that lava which fills a former canyon of the Snake River at Bancroft Springs, 5 miles south-southeast of King Hill (fig. 8), and which also forms the north rim of the present canyon as far upstream as the mouth of Malad Canyon, is McKinney Basalt as originally defined by Stearns (1936). The name, Bancroft Springs Basalt, which was previously applied to this lava (Malde and Powers, 1962, p. 1216),

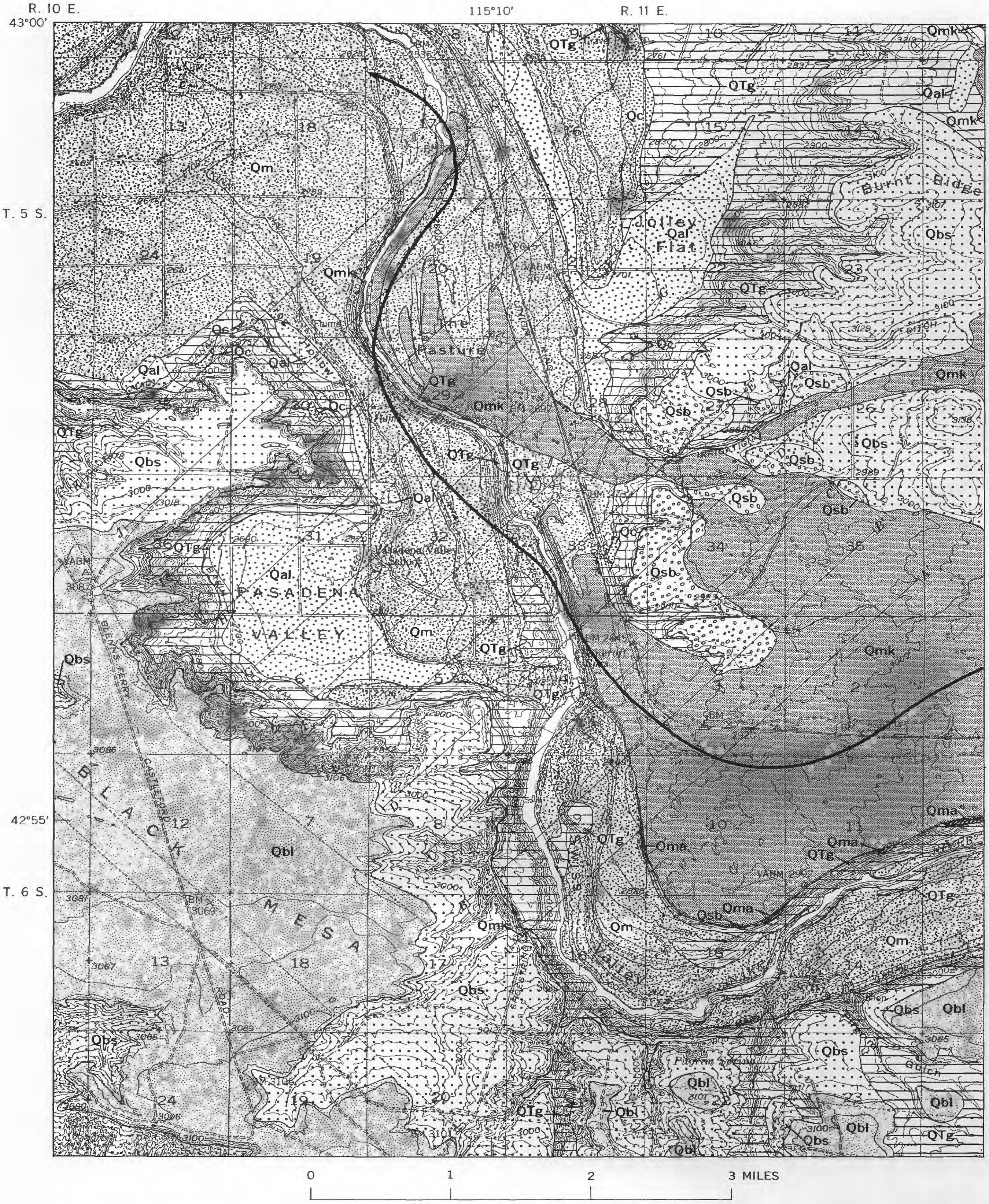


FIGURE 8.—Generalized geologic map of area along Snake River souheast of King Hill showing inferred route of former canyon of Snake River, which is filled with McKinney Basalt. Cross sections (*A–A′* to *K–K′*) are shown in figure 10. See map explanation on facing page.

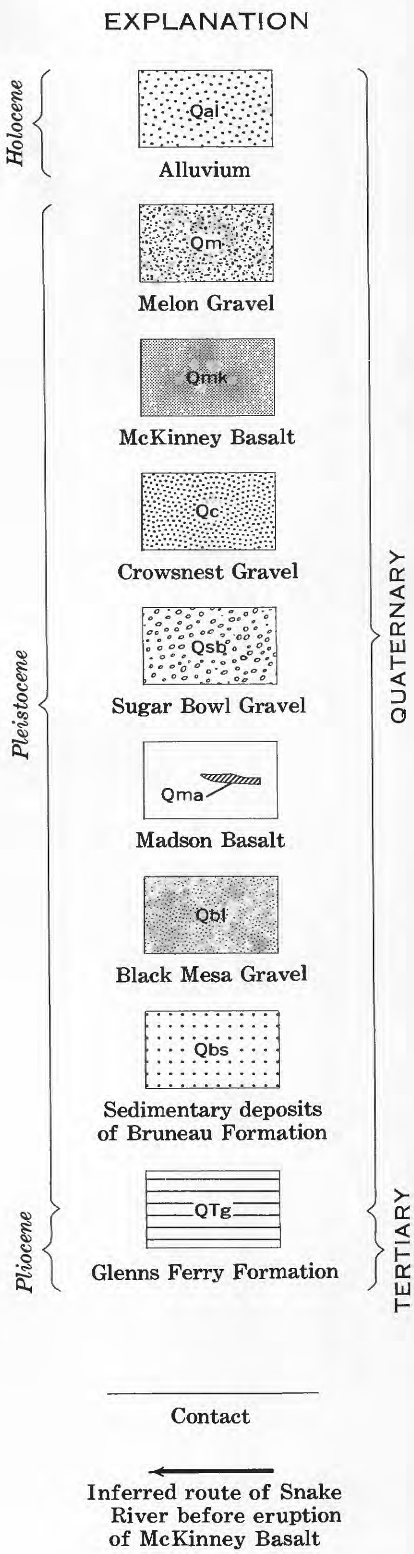


FIGURE 8.—Continued.

is hereby abandoned for reasons given in this discussion. Also, pillow lava between Bliss and Malad Canyon, which was formerly included in the Bancroft Springs Basalt, is here identified as a facies of the McKinney. This new assignment of the pillow lava is discussed in the next section, and the assignment is then incorporated in subsequent remarks on the river history. Paleomagnetic measurements compatible with this correlation are discussed in a separate section by Allan Cox.

Assignment of the canyon-filling lava at Bancroft Springs to the McKinney Basalt stems from my liberation from faulty concepts about the age of the McKinney and from a better comprehension of certain features of the ancestral physiography.

The canyon-filling lava forms an imposing basalt cliff 300 feet high at Bancroft Springs and is obviously older than the present canyon (fig. 9). The lava is also older than the Melon Gravel, which in places litters the lava surface with boulders as large as 15 feet. (See also, Malde, 1968, fig. 21.) Until George Stone and Howard Powers determined that a downstream lobe of McKinney Basalt that cascaded from the upland is also older than the Melon Gravel, I thought that this lobe represented an eruption younger than the lava at Bancroft Springs and that it reached the Snake River after the present canyon was cut. (The downstream lobe occupies the area called The Pasture in fig. 8.) This idea evidently was a misconception. I now infer that the lava at Bancroft Springs and the downstream lobe were formed concurrently by the eruption of McKinney Basalt and that both are older than the present canyon. The correlation of these bodies of lava cannot be proved from available outcrops because any possible link between them along the canyon is concealed by Melon Gravel. Nevertheless, their former connection can be inferred from the route of the ancestral canyon and, also, from the continuity of the surface gradient of the lava that extends downstream from Bancroft Springs. These features can be traced in a series of geologic sections drawn across the path of the ancestral canyon (fig. 10).

In section *A–A′*, the former canyon is shown to be completely filled with McKinney Basalt, which at one time undoubtedly extended across the area of the present canyon to the small remnant of lava on the southwest side. The former canyon, with a floor at an altitude of about 2,575 feet, is intersected by the present canyon at Bancroft Springs (section *D–D′*) and probably continues northwest into an area covered by Melon Gravel. Sections *F–F′* through *I–I′* show the possible presence of concealed remnants of the canyon-filling lava and indicate the inferred gradient of the former canyon floor. Beyond section *I–I′*, the former canyon is again

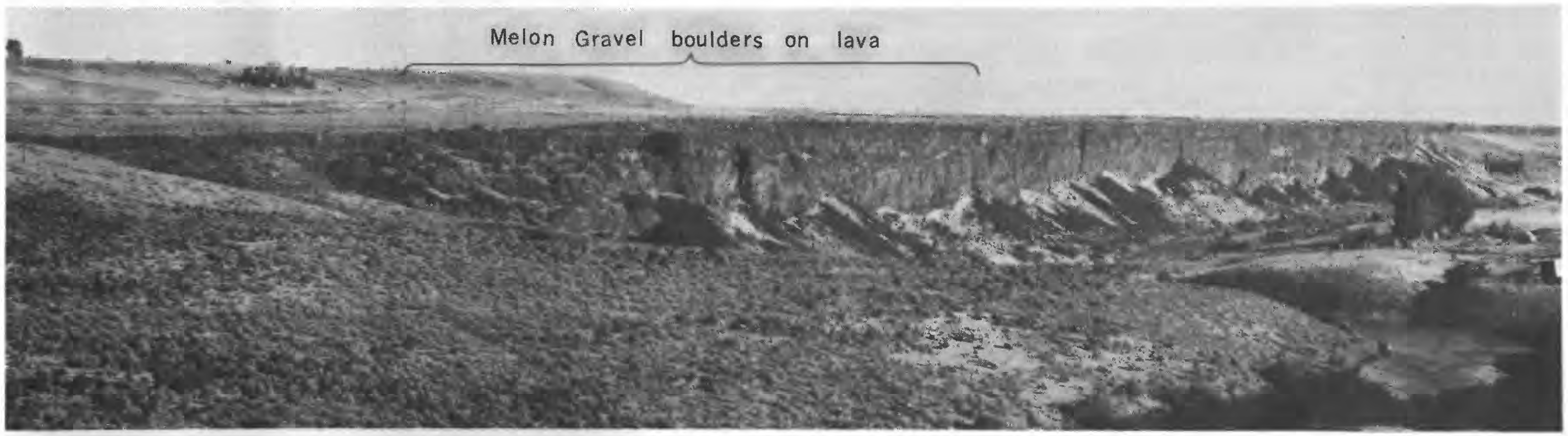


FIGURE 9.—Canyon-filling McKinney Basalt at Bancroft Springs. Boulders of Melon Gravel rest on the basalt surface 250 feet above river level, as marked. Melon Gravel also makes up the massive sagebrush-covered deposit in the foreground. Sugar Bowl Gravel 400 feet above river level forms the distant terrace at the left.

intersected by the present Snake River, and the McKinney Basalt is underlain by basaltic gravel, as previously mentioned. Finally, the former canyon approximately coincides with the present canyon near section *K–K′* where the McKinney reaches present river level.

The surface gradient of lava between Bancroft Springs and The Pasture can be measured from the cross sections and from the geologic map. For convenience, the altitudes and the indicated gradients are given in table 1. Because the original surface of the lava is preserved, except for a few feet of local stripping by flood erosion, the present altitudes closely indicate the original gradient. North of section *D–D′*, the lava surface descends rather uniformly at a gradient of about 2 percent, and the projected surface corresponds with the surface of the McKinney Basalt at section *G–G′*. Thereafter, the surface gradient descends more gradually.

In summary, the former canyon was deeply filled by McKinney Basalt at Bancroft Springs and was filled only to shallow depth downstream at The Pasture; the lava surface probably was graded continuously between these two localities. The differences in thickness of the McKinney Basalt between Bancroft Springs and The Pasture appear to be a consequence of the steep gradient of the lava surface. At The Pasture, McKinney Basalt in the canyon was joined by a lava cascade that spilled simultaneously from the adjacent upland.

EQUIVALENCE OF PILLOW LAVA NEAR BLISS TO McKINNEY BASALT

Another stratigraphic problem that has been clarified by studies made since 1962 concerns the age and origin of pillow lava that extends discontinuously upstream along the Snake River canyon from below Bliss to the mouth of Malad Canyon. The outcrops of pillow lava reach from present level near Bliss (about 2,650-ft. alt.) to places 500 feet higher and can be accounted for only by lava that entered a deep lake. Such a lake could have formed only behind a lava dam.

TABLE 1.—*Altitudes and gradients of surface of McKinney Basalt southeast of King Hill*

Section	Altitude (feet)	Relation to previous section: Difference in altitude (feet)	Relation to previous section: Intervening gradient (percent)
A–A′	2, 915		
B–B′	2, 885	30	1. 2
C–C′	2, 845	40	1. 7
D–D′	2, 800	45	1. 8
E–E′	2, 750	50	1. 9
F–F′	[1] (2, 700)	50	2. 0
G–G′	2, 650	50	2. 0
H–H′	2, 625	25	1. 0
I–I′	2, 600	25	1. 0
J–J′	2, 575	25	1. 0
K–K′	2, 540	35	. 6

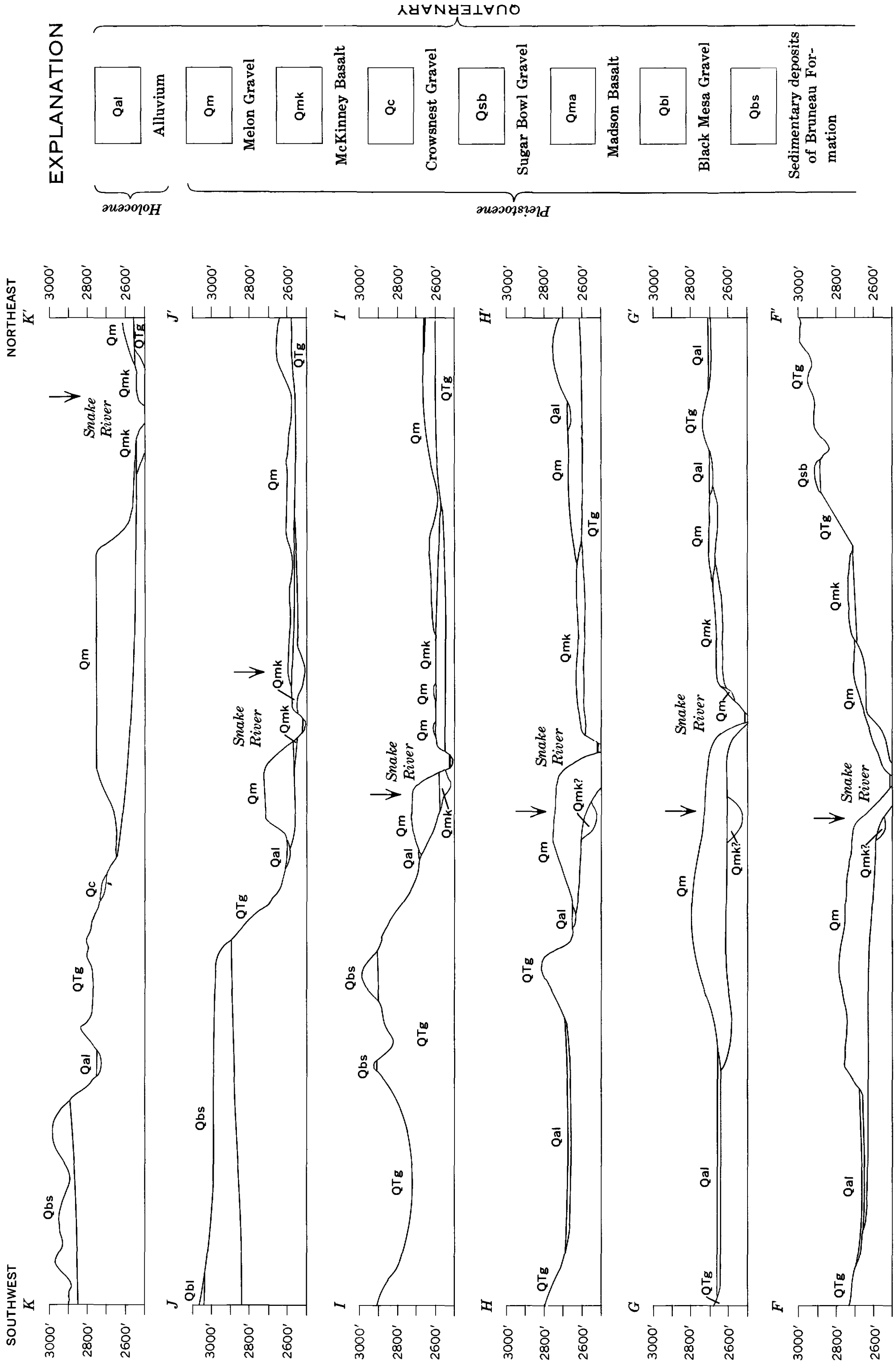
[1] Interpolated.

Russell (1902, p. 113–116) recognized pillow lava in the canyon at Bliss and compared these outcrops with subaqueous lavas in the Hawaiian Islands. Stearns (1936, p. 439–441), using the now-abandoned name of Bliss Basalt, considered the pillow lava as possibly a subaqueous phase of the McKinney Basalt. (See also, Stearns and others, 1938, p. 76–78). His stratigraphic placement of the McKinney, however, was incorrect. Malde and Powers (1962, p. 1216) assigned the pillow lava to a supposed early lava from McKinney Butte, the Bancroft Springs Basalt, but did not explain the canyon history that accounts for the deep lake in which the pillow lava was deposited.

As determined from petrography and geographic proximity, two possible sources of the pillow lava exist: McKinney Butte and Gooding Butte (fig. 3). The pillow lava, together with lava from both these vents, is fine-grained porphyritic plagioclase-olivine basalt, having plagioclase laths as much as 7 millimeters long that are clustered with olivine crystals 1–2 millimeters across. The petrography of these lavas differs from that of all others nearby. Gooding Butte, however, can be rejected as a potential source, because its time of eruption must have been earlier than the entrenchment of the ancestral Snake River to the depth represented by the pillow lava; the much younger McKinney Butte is therefore the only feasible source. This conclusion is derived from rather detailed knowledge of the canyon history, as described in the next section. Briefly, from an analysis of drainage history based on the effect of local lavas during canyon entrenchment, I infer that a dam of McKinney Basalt filled a former canyon of the Snake River and that the pillow lava accumulated simultaneously by the spilling of McKinney Basalt into the resulting lake. This interpretation can be easily tested by drilling about 3 miles west of Bliss, where the lava dam of McKinney Basalt is inferred to be concealed.

LATE PLEISTOCENE HISTORY OF SNAKE RIVER

The latest episodes of geologic history along the Snake River between Hagerman and King Hill, which are recorded by the various lava flows and river deposits of the Snake River Group, are portrayed on a series of paleogeologic sketch maps (fig. 11). The existing and inferred geologic features by which each of these maps has been constructed will be discussed in turn. The maps should be compared with the present geology shown in figure 3.


EXPLANATION
QUATERNARY
Holocene
Pleistocene
Qal Alluvium
Qm Melon Gravel
Qmk McKinney Basalt
Qc Crowsnest Gravel
Qsb Sugar Bowl Gravel
Qma Madson Basalt
Qbl Black Mesa Gravel
Qbs Sedimentary deposits of Bruneau Formation
SOUTHWEST
NORTHEAST
K K'
J J'
I I'
H H'
G G'
F F'
3000'
2800'
2600'
Snake River
QTg
Qmk?

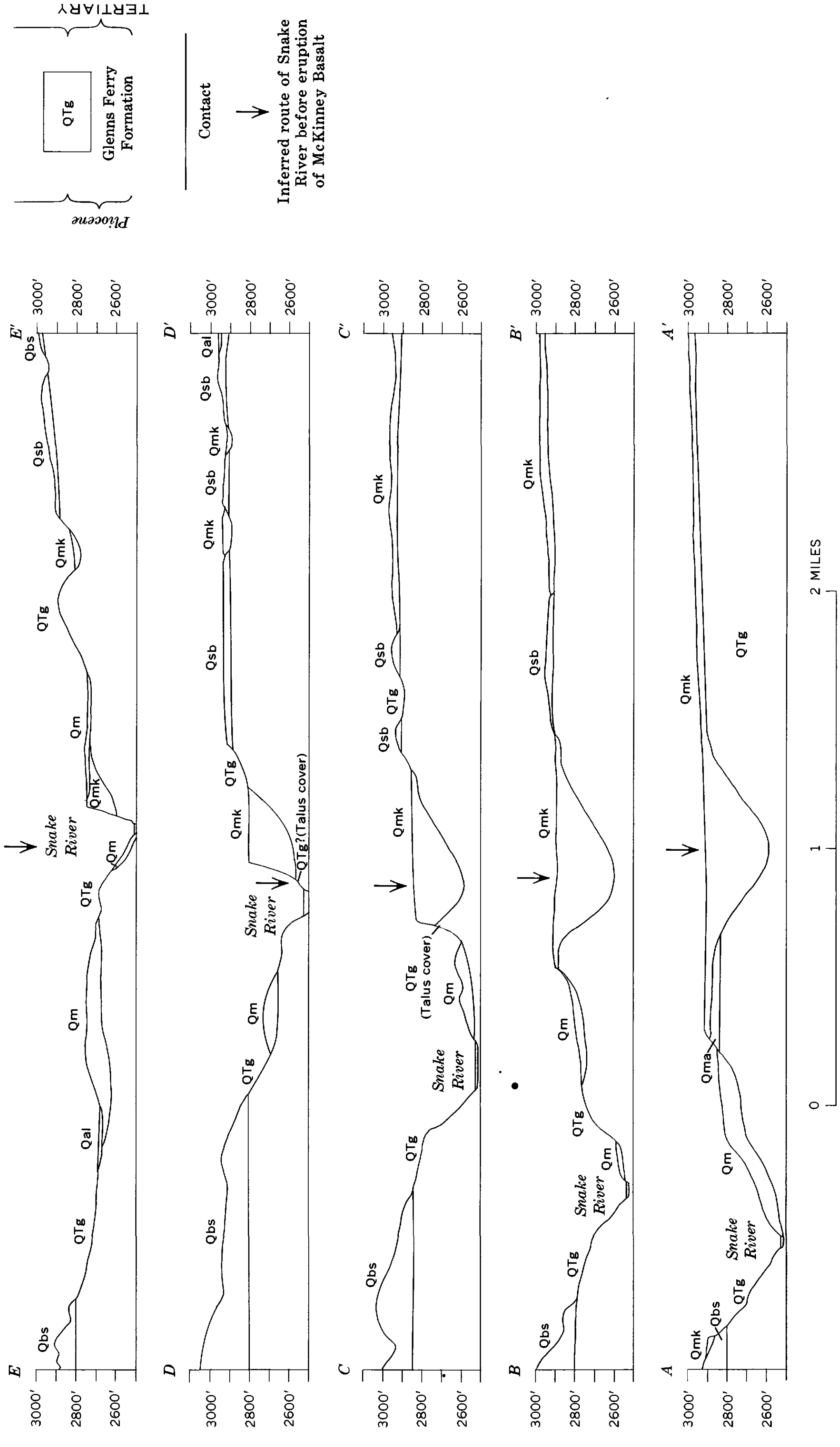


FIGURE 10.—Geologic sections across former canyon of the Snake River southeast of King Hill. For location of sections, see figure 8.

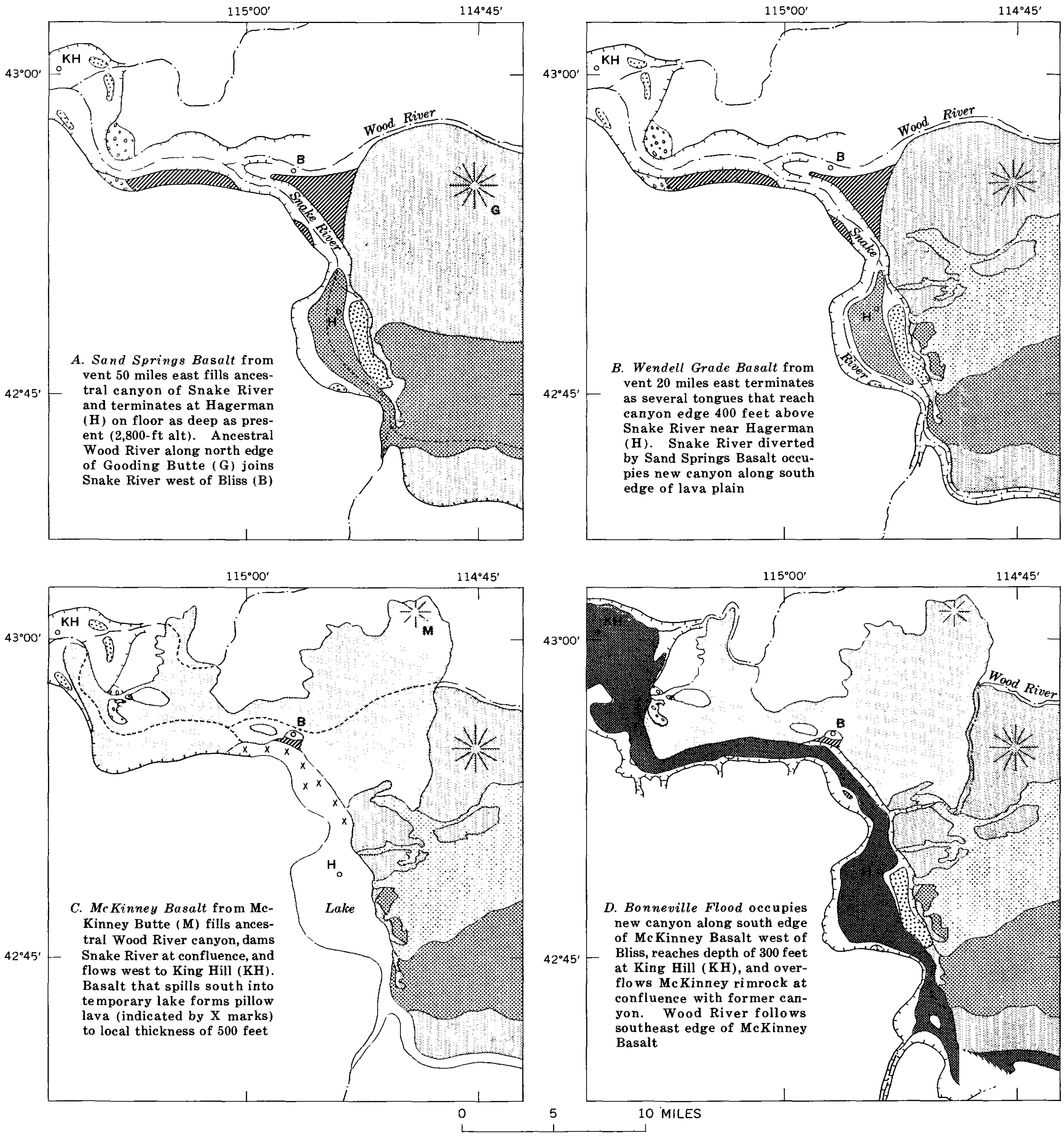


FIGURE 11.—Maps of area between Hagerman and King Hill showing late Pleistocene drainage changes caused by local lava flows.

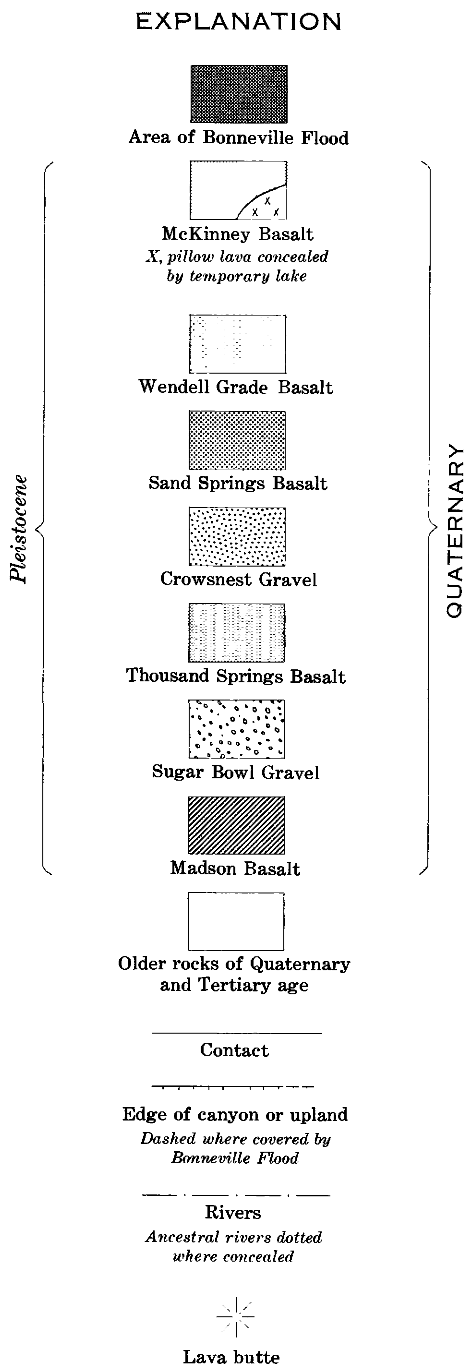


FIGURE 11.—Continued.

PREDECESSORS OF SAND SPRINGS BASALT

The eruption of Sand Springs Basalt occurred after the Snake River had become entrenched to its present depth (fig. 11*A*). Before then, the entrenchment had been interrupted at various times by lava flows that had caused minor diversions of the river. The first of these older lavas, Madson Basalt, came from an eastern source and reached nearly as far west as King Hill. It occupied a shallow ancestral valley of the Snake River at about 3,000 feet in altitude at the approximate latitude of Gooding Butte. This valley, which is now mainly concealed north of the present mouth of the Big Wood River (Malad Canyon), passed just south of Bliss (where it is intercepted by the present canyon) and then turned west. Gravel under the Madson Basalt is exposed in Malad Canyon (fig. 3) and is a type that differs from the porphyry-rich gravel that is now carried to the Snake River Plain by the Big Wood River from central Idaho (Howard Powers, written commun., May 19, 1967). The lack of porphyry in this gravel suggests that the Wood River at that time was probably along the north edge of the Madson Basalt. The Sugar Bowl Gravel that overlaps the terminus of the Madson Basalt (locality 510 in fig. 3) resembles the modern gravel of the Big Wood River (locality 538) by being rich in porphyry and other rocks from central Idaho (table 2).

The Madson Basalt pushed the ancestral Snake River south to the latitude of Hagerman. Lava from Gooding Butte, one of the sources of the Thousand Springs Basalt, then covered the eastern part of the Madson, restricted the Wood River to a course north of Gooding Butte, occupied the site of the Snake River that was then east of Hagerman, and diverted the Snake into

TABLE 2.—*Selected pebble counts, in percent, of gravel pertaining to ancestral river history between Hagerman and King Hill*

	Sugar Bowl Gravel	Gravel on Thousand Springs Basalt	Crowsnest Gravel	Crowsnest Gravel	Melon Gravel	Modern Gravel of Big Wood River
Locality No	510	531	532	[1] 513	498	538
Source chiefly in central Idaho:						
Porphyry	22	--	--	24½	31	40½
Granite	13	½	2	3	6½	3
Conglomerate	6½	--	--	5	--	2½
Vein quartz	1	--	--	--	--	1
Quartzite [2]	41	14½	11½	41	46	43
Source nearby:						
Latite	5½	73	65	10½	6	2
Rhyolite	7	3	6	2	½	--
Basalt	2	½	1½	6½	9	1
Source indeterminate:						
Chert	2	8½	14	7½	1	7
Number of pebbles counted	279	311	313	281	272	372

[1] This locality is 7 miles southwest of King Hill and 1 mile south of Glenns Ferry.
[2] Includes as much as 3 percent fine-grained dark rock, counted as argillite.

a course still farther south at the approximate latitude of 42°45′. Gravel southeast of Hagerman on this Thousand Springs Basalt (locally 531) reflects material that was transported by the ancestral Snake River and is more than 400 feet above the present Snake River. The gravel evidently closely marks the depth of canyon cutting at that time.

As entrenchment by the Snake River progressed, the base of the Thousand Springs Basalt from Gooding Butte in the former canyon east of Hagerman was exposed and began to discharge spring water. This discharge initiated the small spring-fed tributary (Billingsley Creek) that parallels the east wall of the canyon. The springs at the base of the basalt range in altitude from 3,100 to 3,150 feet.

A younger part of the Thousand Springs Basalt from vents about 20 miles east of Hagerman was then deposited on the floor of a shallow canyon 100 feet below the south edge of the basalt from Gooding Butte. This canyon was at the latitude of 42°45′, as previously mentioned. Ground water carried by basalt in this former canyon is thought to account for the large discharge at Thousand Springs, 5 miles southeast of Hagerman (Nace and others, 1958, p. 45–48). Because of this younger Thousand Springs Basalt, the ancestral Snake River was pushed a little farther south to the position of the concealed canyon sketched as a dotted line in figure 11*A*.

The canyon was next partly filled with about 50 feet of Crowsnest Gravel, which overlaps the younger part of the Thousand Springs Basalt near Hagerman. Along Billingsley Creek, the base of this gravel is from 3,050 to 3,080 feet in altitude, which is 30–80 feet below the springs at the base of the basalt from Gooding Butte. If the Crowsnest Gravel extended eastward under the basalt, the springs would issue from a level equal to the base of the gravel. Their absence at this level confirms that the basalt from Gooding Butte is older than the Crowsnest Gravel, as the physiographic relations already described indicate.

The Crowsnest Gravel southeast of Hagerman (locality 532) closely resembles in composition the gravel on the basalt from Gooding Butte (locality 531), and this composition reflects nearby sources. The outcrops of Crowsnest Gravel downstream near King Hill, however, include a large component transported by the ancestral Wood River from central Idaho (locality 513). The Crowsnest Gravel near King Hill lies about 200 feet below the Sugar Bowl Gravel and thus indicates the depth of canyon entrenchment by this time.

Canyon cutting then resumed, eventually reaching a depth of more than 400 feet at Hagerman (250 ft. below Crowsnest Gravel) and probably a comparable depth near King Hill. In the lava plain southeast of Hagerman, the Snake River canyon was approximately in the position it had occupied since eruption of the last Thousand Springs Basalt (dotted line in fig. 11*A*). From Hagerman to Bliss, as indicated by confining outcrops of Madson Basalt and older rocks still preserved along the canyon rim, the ancestral canyon was approximately in its present position. At Bliss it was separated from the Wood River canyon on the north by a divide of old Quaternary and Tertiary deposits, as recorded in the log of well 6S–13E–6dc1 (table 3). West of Bliss the canyon must have been approximately in the position it occupied during the subsequent eruption of McKinney Basalt, as will be explained later.

When the Snake River canyon reached its present depth at Hagerman (2,800-ft alt), it was filled as far downstream as Hagerman by the Sand Springs Basalt, which erupted from a vent 50 miles east. The narrow ancestral canyon is now exposed in profile along the present canyon 7 miles southeast of Hagerman (fig. 12). In the wide part of the canyon at Hagerman—an area bounded on the west by weakly consolidated basin deposits (older Quaternary and Tertiary)—the Sand Springs Basalt spread as a thin terminal tongue. (For a map of outcrops of Sand Springs Basalt farther east, see Malde and others, 1963.)

With emplacement of the Sand Springs Basalt, the geology resembled that shown in figure 11*A*.

WENDELL GRADE BASALT

The Wendell Grade Basalt (fig. 11*B*) was the immediate predecessor of the McKinney Basalt. Both display a rough surface of pressure ridges that project above a thin cover of surficial material. Glassy skins on ropy surfaces of these lavas are locally preserved, and the lavas are fresh. (The McKinney Basalt, however, at a single locality 7 miles east of King Hill, displays patterned ground, a curious landform characteristic of older weathered basalt and gravel in this region; see Malde, 1964, p. 204.)

TABLE 3.—*Log of water well 6S–13E–6dc1 at Bliss*

[From files of U.S. Geological Survey, Water Resources Division Boise, Idaho. Alt. 3,620 ft. Assignment of lithologic units based on map by Malde, Powers, and Marshall (1963)]

Material	*Thickness (feet)*	*Depth (feet)*
Glenns Ferry Formation (Pleistocene and Pliocene):		
Clay, yellow	84	84
Lava, gray, hard; water at 188 feet	34	118
Clay, yellow	92	210
Clay, blue	52	262
Clay, yellow	147	409
Clay, blue	21	430
Clay and black sand	22	452
Banbury Basalt (Pliocene):		
Lava, black	40	492
Sand, black	3	495
Clay, blue	17	512

FIGURE 12.—Canyon fill of Sand Springs Basalt about 7 miles southeast of Hagerman. The lava cliff rises 210 feet above the Snake River.

Before the eruption of Wendell Grade Basalt, a thin mantle of windblown sand and silt had accumulated on the Sand Springs Basalt to form a smoothly rolling lava plain. The Snake River had been diverted at a place 30 miles upstream from Hagerman by the Sand Springs Basalt and had carved a new canyon southeast of Hagerman where the Thousand Springs Basalt had previously abutted an upland of basin deposits. This part of the Snake River canyon of that time was virtually in the position of the present canyon. (Small outcrops of Thousand Springs Basalt at the south rim of the present canyon are mapped 1–3 miles east of the area of fig. 11; see Malde and others, 1963.) Where the new canyon intercepted the former canyon 5–7 miles southeast of Hagerman, the Sand Springs Basalt had been removed. Near Hagerman the Snake River probably followed the west edge of the terminal tongue of Sand Springs Basalt, as it does now. Billingsley Creek probably was a little deeper than it had been during the eruption of Sand Springs Basalt and was flanked on the east by landslide and talus debris derived from the basalt rimrock. Downstream from Hagerman, the canyon probably had become deeper, as indicated by outcrops of pillow lava assigned to the McKinney Basalt that occur 100 feet lower than the terminus of the Sand Springs Basalt.

The Wendell Grade Basalt flowed west as several thin tongues on the old lava plain. One tongue crossed the future path of the Wood River southwest of Gooding Butte, and others opposite Hagerman reached the canyon edge. At least one of these ended as a lava cascade on landslide debris along the east wall of Billingsley Creek. The preservation of this cascade indicates that subsequent erosion from spring discharge along Billingsley Creek has been minor.

McKINNEY BASALT

When the McKinney Basalt erupted from McKinney Butte (fig. 11*C*), the Snake River canyon from Hagerman to Bliss was as deep as it is now (about 500 ft) and occupied its approximate present position. At a place about 2 miles west of Bliss, where the only important gap in the continuity of the Madson Basalt occurs, I infer that the former canyon continued northwest a short distance to its confluence with the ancestral Wood River and then turned west. The canyon route to the west can be approximately located by the presence of confining upland areas of older rocks and by the lava-filled canyon intersected at Bancroft Springs (fig. 8). Similarly, the route of the ancestral canyon of the Wood River north of Bliss can be determined by its adjoining uplands (including the divide of older rocks under the site of Bliss); its path from the east must have been along the north flank of Gooding Butte.

The buried Wood River canyon is evidently encountered in a water well three-quarters of a mile east of Bliss, which penetrates a lava fill described in log 6S–13E–5dd1 (table 4). The bottom of this well is at an altitude of about 2,750 feet and probably marks the approximate floor of the filled canyon. Howard Powers (written commun., May 19, 1967) infers that the confluence of this filled canyon with the ancestral Snake River was west of Bliss because no permeable connection exists between the well and pillow lava 100 feet lower at Bliss; this is discussed more fully on page F17.

It is unlikely that any lava in the filled canyon of the ancestral Wood River came from Gooding Butte. The Thousand Springs Basalt from this vent dates from a time before the ancestral drainage was deeply entrenched, as previously explained, and the filling of the canyon during more than a single eruptive episode would have caused diversions of drainage that are not recorded by known geologic features. I conclude that the ancestral Wood River canyon was filled solely by basalt from McKinney Butte, which simultaneously descended the Snake River canyon of that time nearly as far as King Hill. Most of the McKinney Basalt in the ancestral Wood River canyon, and farther west in the ancient Snake River canyon, probably is subaerial basalt; the flow of river water, which would have favored the formation of pillow lava, probably was interrupted early during the eruption of the basalt. A few feet of pillow lava locally occurs below subaerial basalt at The Pasture, near the terminus of the flow, and some "clay" and "sand" reported in the water well east of Bliss may represent basalt that fragmented in water; however, the massive lava fill of McKinney Basalt at Bancroft Springs displays only columnar layers that evidently cooled in air (fig. 9). This evidence indicates that Bancroft Springs lies downstream from the site where the McKinney first entered and dammed the ancestral Snake River.

TABLE 4.—*Log of water well 6S–13E–5dd1, three-quarters of a mile east of Bliss*

[From files of U.S. Geological Survey, Water Resources Division, Boise, Idaho. Alt. 3,270 ft. All beds penetrated are here assigned to McKinney Basalt]

Material	*Thickness (feet)*	*Depth (feet)*
Clay	4	4
Basalt	32	36
Clay	9	45
Basalt	11	56
Clay (sloughs)	229	285
Clay, blue	10	295
Sand	30	325
Clay	83	408
Basalt, hard, black	32	440
Clay	16	456
Sand rock, water-bearing	6	462
Clay	4	466
Sand, water-bearing	4	470
Clay, blue	35	505
Basalt, sand	12	517

As the McKinney Basalt filled the Snake River canyon west of Bliss, a lake formed in the canyon upstream. Eventually, the lava dam reached an altitude of 3,150 feet, thus impounding a lake 500 feet deep that extended upstream along the Snake River beyond Hagerman. Basalt that reached the lake formed pillow lava, the first of it being deposited on old talus that had been derived from Madson Basalt (Malde and Powers, 1962, p. 1216). Angular pieces of Madson Basalt (not necessarily talus) are also found under the McKinney Basalt at The Pasture near King Hill. Much of the basalt that became pillow lava probably arrived at Bliss by overflowing the ancestral Wood River canyon when the Snake River canyon downstream was already deeply blocked by lava. The copious amounts of McKinney Basalt that spilled into the temporary lake produced the massive subaqueous volcanic features described by Stearns (in Stearns and others, 1938, p. 78–80) as the "Bliss cone," "brecciated lava," and "dikes."

In the old lava plain southeast of Bliss, subaerial McKinney Basalt spread south and covered the Madson Basalt as well as some of the Thousand Springs Basalt from Gooding Butte and a small part of the Wendell Grade Basalt. Some McKinney Basalt on the lava plain undoubtedly spilled west into the lake held by the ancestral Snake River canyon, because outcrops of pillow lava in the canyon extend upstream along the east side as far as the McKinney rimrock (Stearns and others, 1938, p. 79). Discernible bedding in the pillow lava dips west.

The McKinney Basalt near the canyon rim southeast of Bliss has a relatively smooth surface and was formerly mapped separately from lava on the plain 1–3 miles east, which has a rough surface. (See Malde and others, 1963.) Detailed work might show that the smooth McKinney is a local physiographic effect produced by a mantle of loess, but the two contrasting areas may also represent different flows from McKinney Butte that were perhaps separated by a considerable span of time. Whatever the cause of the local differences, such a contrast cannot be recognized west of Bliss, where the McKinney surface is uniformly rough. All basalt from McKinney Butte is therefore classed as a unit even though its eruption may have been prolonged.

The McKinney Basalt west of Bliss, after filling the ancestral Snake River canyon, spread south as a subaerial flow over Madson Basalt to the edge of an upland formed by older basin deposits. In the gap between outcrops of the Madson about 2 miles west of Bliss, which marks the former canyon, the subaerial McKinney evidently rests on the pillow lava facies, which completely fills the former canyon to a depth of 500 feet. Although continuous exposures of pillow lava in the former canyon have been found no more than 250 feet above the canyon floor, the subaerial McKinney rimrock at the east edge of this ancestral canyon is separated from the Madson Basalt below by 25 feet of pillow lava, which reaches 500 feet above the canyon floor—that is, to an altitude of 3,150 feet. Identical pillow lava at a comparable height underlies McKinney rimrock 2 miles southeast of Bliss. The height of these outcrops implies that the dam of McKinney Basalt is concealed about 3 miles west of Bliss, near the buried confluence of the ancestral Wood and Snake Rivers, as shown in figure 11*C*. If the present canyon had then existed downstream from Bliss, it necessarily would have been filled with McKinney Basalt, thus providing a means for the spread of the McKinney to its two outcrops now preserved on the south rim (fig. 11*D*). No sign of such a lava fill in the present canyon can be found; as explained in the discussion which follows, the present canyon west of Bliss surely formed after McKinney time.

Aspects of ground water support the inference that the ancestral Wood and Snake Rivers joined a short distance west of Bliss and indicate that the area between the Snake and the buried Wood River canyon is a drainage divide consisting of rather impermeable basin deposits (older Quaternary and Tertiary). These conclusions are deduced from a lack of springs in the McKinney pillow lava, whereas most other basalts of the Snake River Group in this area are notable aquifers. Small springs that appear to issue from pillow lava along the canyon wall southeast of Bliss, at altitudes between 2,825 and 2,875 feet, are possibly supplied by water that migrates along a concealed surface of Banbury Basalt. (See log of well 6S–13E–6dc1 and map by Malde and others, 1963.) Stearns also thought that this meager flow of spring water could not represent discharge from the pillow lava (Stearns and others, 1938, p. 164), but he attributed the discharge to water carried by the Madson Basalt. Because the former valley filled with Madson Basalt is intercepted upstream by the present Wood River in Malad Canyon, where it yields a phenomenal discharge of about 1,000 cubic feet per second at Malad Springs (Nace and others, 1958, p. 55–58), the amount of water carried by the Madson Basalt in the downstream area of pillow lava must be negligible. In summary, a lack of springs in the pillow lava indicates that this lava is isolated from ground water in the buried ancestral Wood River canyon by an impermeable barrier. Thus, the talus-covered canyon wall southeast of Bliss, which was previously mapped mostly as pillow lava (Malde and others, 1963), surely consists of older Quaternary and Tertiary basin deposits (fig. 3). The necessary corollary is that the dry pillow lava in the ancestral Snake River canyon connects with lava in the filled canyon of the Wood River at a somewhat lower altitude at a concealed junction west of Bliss.

A small amount of ground water, however, issues from the canyon-filling McKinney Basalt at Bancroft Springs, which is near the terminus of the flow. Although Bancroft Springs connects with the present Wood River via the filled ancestral Wood River canyon and also with the Snake River near Bliss via the canyon fill of McKinney pillow lava, its discharge is curiously small. Howard Powers (written commun., Sept. 25, 1967) suggested the following explanation. For the McKinney Basalt at Bancroft Springs to have solidified as columnar subaerial layers, its dam upstream must have been virtually watertight, a circumstance that may persist today. That is, under present conditions, the water carried by the Snake River flows readily down the existing channel, and the water pressure on the concealed lava dam is not great enough to cause substantial leaks. Also, contributions to Bancroft Springs from the Big Wood River must be small because this stream maintains its flow across the lava plain and seemingly loses little water by seepage.

BONNEVILLE FLOOD

After the eruption of McKinney Basalt, lake water impounded by the lava dam west of Bliss spilled along the south edge of the McKinney lava, where it abutted the upland of basin deposits, and thus established the Snake River in its present course (fig. 11*D*). As noted by Stearns (in Stearns and others, 1938, p. 77), this overflow descended 700 feet in 7 miles (actually more nearly 13 miles) and must have cut rapidly into the soft basin deposits. In the reach from 3 to 10 miles west of Bliss, a canyon about 1 mile wide exposed Madson Basalt (locally overlain by Sugar Bowl Gravel) below McKinney rimrock. When downcutting reached a depth 300 feet below the north rim, the river was confined to a narrow inner gorge in Tertiary basalt and eventually reached an additional depth of 200 feet (Malde and others, 1963). By the time of the Bonneville Flood of 30,000 years ago (Malde, 1968), the canyon had virtually attained its modern dimensions.

Two remnants of McKinney Basalt are preserved on the south rim of the new canyon. One of these, 11 miles west of Bliss, is subaerial basalt at the altitude of McKinney rimrock on the north side (fig. 10, section *A–A′*). The other remnant, 6 miles west of Bliss, consists only of basalt boulders 2–3 feet in diameter, which are slightly below the altitude of McKinney rimrock on the north, 1 mile distant. These boulders obviously match the distinctive McKinney lithology and must have been deposited near the edge of the McKinney Basalt during initial overflow of the temporary lake. Their size demonstrates the transport power of the turbulent water discharged from the lake.

The Wood River that had been blocked by the McKinney Basalt was diverted into its present route (the Malad River) along the southeast edge of the McKinney lava. Downcutting by the ancestral Wood River along this marginal path required removal of thick layers of basalt and need not have been especially rapid until erosion reached the base of the Madson Basalt, 200 feet below the lava plain. The rate of cutting must have then increased, primarily because the soft basin deposits below the Madson were easily erodible, but partly because streamflow was thereby augmented by discharge from Malad Springs (p. F17). It is remarkable that the present Malad Canyon upstream from the base of the Madson Basalt (the site of Malad Springs) abruptly narrows and becomes shallow, whereas the canyon in basin deposits downstream to its mouth, 2 miles distant, rapidly widens and deepens. Even so, Malad Canyon is short and narrow when compared with the Snake River canyon of equivalent age west of Bliss. This difference is probably a function of contrasts in river gradients, discharge, and the resistance of rocks to erosion. As explained below, the comparatively large canyon west of Bliss was not a circumstance of the Bonneville Flood.

The Bonneville Flood deposited large amounts of basaltic debris, particularly in wide parts of the canyon (Melon Gravel of fig. 3). For a short distance downstream from the mouth of the Malad River, however, the flood debris contains gravel derived from the headwaters of the Big Wood River in central Idaho (locality 498). This fact alone, even if other geologic relations were lacking, would suggest that the Bonneville Flood occurred after diversion of the Wood River and was, therefore, younger than the McKinney Basalt. (This gravel was previously discounted as pertaining to the age of the McKinney because I assumed it was younger than the Bonneville Flood.) The basaltic flood debris elsewhere along the canyon, although mostly produced by spectacular erosion near Twin Falls 35 miles upstream from Hagerman, partly represents local smoothing of canyon walls by flood erosion. Such smoothing by the flood, however, had little effect on the previous size of the canyon, for calculations of flood discharge and canyon capacity indicate that the canyon had already attained its approximate present dimensions by the time of the flood. The movement of boulders 10 feet in diameter 9 miles west of Bliss, for instance, demonstrate a velocity of floodwater that required a canyon of the present dimensions to accommodate the Bonneville Flood at its known height and discharge (Malde, 1968, p. 34, 46).

Part of the erosional effect of the Bonneville Flood presumably was the removal of some McKinney pillow lava that had survived during the cutting of the canyon west of Bliss and also the removal of any lacustrine deposits that may have formed at the head of the temporary lake that was dammed by the McKinney Basalt. Such lake deposits, if they had been present, would have been mainly in a narrow part of the canyon upstream from Hagerman and therefore would have been in the direct path of the floodwater.

In descending the Snake River canyon, the Bonneville Flood overtopped rimrock of Sand Springs Basalt 250 feet above the canyon floor south of Hagerman (Malde, 1968, p. 32). Floodwater again overtopped the canyon rim at Bancroft Springs and partly covered the toe of the McKinney Basalt with Melon Gravel.

Since the Bonneville Flood, the Snake River canyon has changed little and still plainly bears marks of this catastrophic event.

CONCLUSION

The foregoing account of the volcanic eruptions and associated drainage changes that produced the present Snake River canyon between Hagerman and King Hill leaves some matters still incompletely explained.

Not all the ground water, for example, that emerges as springs from lava flows along this part of the canyon exactly fits the changing pattern of drainage outlined here, even though the positions of most springs are understandable in these terms. The cause of the small discharge from McKinney Basalt at Bancroft Springs, in particular, will remain a mystery until drilling penetrates the concealed lava dam west of Bliss and reveals its character.

A progressive increase in the roughness of lava flows that erupted at various time during entrenchment of the Snake River corresponds with their decreasing age (the older flows being smooth and the younger ones being rough), but the McKinney Basalt is locally an exception. Smooth McKinney rimrock southeast of Bliss, which must be related to pillow lava in the canyon below, contrasts with rough McKinney elsewhere.

In a larger sense, the slightly weathered appearance of the McKinney Basalt (and the Wendell Grade Basalt) must be reconciled not only with the 30,000 years that has elapsed since the Bonneville Flood but also with whatever additional time was required to cut the Snake River canyon west of Bliss. Even though the McKinney locally displays patterned ground, a mark of the Pleistocene, its physiography is that of a lava flow which has erupted recently. Thus, together with the Wendell Grade Basalt of similar appearance, the McKinney provides an example of how little geomorphic change might be shown by other upper Pleistocene lavas in this region.

Preservation of the cascade of Wendell Grade Basalt along the canyon wall east of Hagerman is quite unexpected, especially because of the erosion that would be anticipated at neighboring sites of springs. Perhaps, however, this lava cascade is not at all anomalous; perhaps it demonstrates clearly enough that erosion along canyon walls rimmed with basalt—even a canyon supplied with local springs—is slow.

PALEOMAGNETISM

By Allan Cox

Paleomagnetic measurements can help to determine whether isolated outcrops of lava may represent the same eruption because they accurately indicate the direction of the earth's magnetic field when the lava cooled. For example, studies of historic lava flows on Hawaii have established that the mean direction of remanent magnetization of an individual flow is nearly parallel to the earth's magnetic field of its time, as recorded at magnetic observatories close to the site where the lava solidified. These results show that the angular difference between the measured direction of magnetization of a flow and the observed direction of the earth's field, which may be regarded as the irreducible error of the paleomagnetic method, is not more than 4° if at least eight oriented samples are collected from each flow. Multiple sampling is necessary because directions of magnetization of individual samples commonly vary from 5° to 15°.

Remanent magnetization is useful for stratigraphic purposes, because the geomagnetic field that controls the magnetization changes direction with time. If plotted on a sphere, or on a spherical projection, the changing pole of the earth's magnetic field determined at a given locality appears as a point that traces out an irregular path around some mean direction. Observatory records show that the velocity of motion and the amplitude of the swing of the magnetic pole vary widely from place to place. A shift in pole position as great as 40° has occurred during a mere 200 years at some observatories, whereas the change has been less than 2° at others. On the basis of such data, it is obvious that the path traced out by the shifting magnetic pole may cross and recross itself many times during an interval as long as 100,000 years. This conclusion is of considerable importance in applying paleomagnetism to stratigraphy.

Two outcrops of volcanic rock that differ in direction of magnetization by several tens of degrees, for instance, must have cooled several hundred years apart, if we assume that the ancient geomagnetic field changed at the maximum rate observed today. A time interval of 10,000 years or 100,000 years would also be consistent with such measurements.

On the other hand, because the geomagnetic field can coincide with a former position, two outcrops of volcanic rock that have the same direction of magnetization may have cooled at different times, but such a coincidence is very unlikely. It is more probable that the outcrops solidified simultaneously.

The directions of magnetization of several basalt flows in the Snake River Group are plotted in figure 13. Each point is the direction of magnetization of an oriented sample after partial demagnetization in an alternating magnetic field to remove the effects of possible lightning strikes (Cox, 1960; Graham, 1961). The samples for a particular flow represent several outcrops and show that the direction of magnetization is the same throughout an individual basalt unit. For example, the samples from the Sand Springs Basalt are from three outcrops that span a distance of 22 miles. At the 95-percent confidence level, the mean directions of magnetization of these three outcrops are the same. On the other hand, samples from different basalts (compare Sand Springs and Thousand Springs) are magnetically distinct.

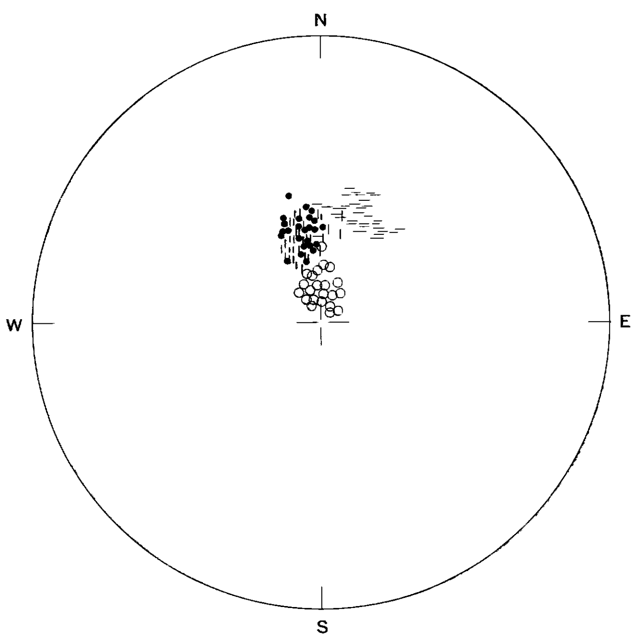


FIGURE 13.—Directions of remanent magnetization of selected basalts from the Snake River Group: Thousand Springs Basalt (open circles); Sand Springs Basalt (horizontal bars); Bancroft Springs Basalt of former usage (vertical bars), and McKinney Basalt (solid circles). All directions are plotted on the lower hemisphere of an equal-area projection.

For the Bancroft Springs Basalt of former usage and the McKinney Basalt, however, both of which were sampled at three outcrops (fig. 3), the directions of magnetization overlap; at the 95-percent confidence level, their mean directions are not significantly different. From the foregoing remarks about the meaning of magnetic data, this result suggests that the Bancroft Springs and McKinney are almost surely the same flow. However, coincidence in direction of magnetization, as already explained, does not rule out the remote possibility that the Bancroft Springs and McKinney are different. Moreover, the measured direction of magnetization is close to the direction of an axial dipole field (Cox and Doell, 1960) that occurs more commonly than any other direction in young rocks, as determined in many regions. Even in the Snake River Plain, two other basalts (not shown in fig. 13 because they are remote from the area described here) have nearly the same direction of magnetization as the Bancroft Springs and McKinney. Coincidence in the direction of magnetization is clearly a necessary condition, but not a sufficient condition, for establishing equivalent age. Nonetheless, when these paleomagnetic results are combined with the knowledge of geology given earlier in this report, the conclusion is virtually inescapable that the Bancroft Springs Basalt and the McKinney Basalt are identical.

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