If you do not need this publication after it has served your purpose, please return it to the Geological Survey, using the official mailing label at the end

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

Prepared in cooperation with the
IDAHO BUREAU OF MINES AND GEOLOGY
and the
IDAHO DEPARTMENT OF RECLAMATION

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 774

If you do not need this publication after it has served your purpose, please return it to the Geological Survey, using the official mailing label at the end

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

Prepared in cooperation with the
IDAHO BUREAU OF MINES AND GEOLOGY
and the
IDAHO DEPARTMENT OF RECLAMATION

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 774

UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Water-Supply Paper 774

GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

BY

HAROLD T. STEARNS, LYNN CRANDALL
AND WILLARD G. STEWARD

Prepared in cooperation with the
IDAHO BUREAU OF MINES AND GEOLOGY
and the
IDAHO DEPARTMENT OF RECLAMATION

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1938

For sale by the Superintendent of Documents, Washington, D. C. - - -

CONTENTS

	Page
Abstract	1
Introduction	2
Location and area	2
Purpose and history of the investigation	3
Acknowledgments	5
Geography	5
Surface features	5
Snake River Plain	5
Buttes	6
Falls of Snake River	7
Tributary streams	7
Climate	8
Temperature	8
Precipitation	10
Evaporation and transpiration	13
Jerome	13
Pioneer irrigation district	15
Milner	16
Sterling	17
American Falls and Michaud	18
Mud Lake region	18
Summary of evaporation losses	18
Possible effect of evaporation and transpiration on precipitation and stream flow	19
Tree rings in relation to climate	19
Soil	23
Crops and vegetation	24
Geology and water-bearing properties of the rocks	25
Summary	25
Rock formations and their water-bearing properties	32
Pre-Miocene rocks	32
Miocene (?) rocks	33
General character	33
Rhyolitic rocks in and near the Mud Lake region	35
Rhyolite of Big Southern Butte	35
Trachyte of East Twin Butte	36
Basalt of West Twin Butte	37
Shoshone Falls andesite	37
Pillar Falls mud flow	38
Rhyolitic rocks south of Snake River	39
Sources of rhyolitic and related rocks	41
Pliocene rocks	42
Occurrence and character	42
Lower Pliocene (?) rocks	43
Tertiary sediments in Clark County	43
Neeley lake beds	43
Eagle Rock tuff	
Massacre volcanics	

Geology and water-bearing properties of the rocks—Continued.
Rock formations and their water-bearing properties—Continued.
Pliocene rocks—Continued.
Middle (?) Pliocene rocks — Page 47
Rockland Valley basalt — 47
Raft lake beds — 48
Upper Pliocene rocks — 50
Banbury volcanics — 50
Flows — 50
Riverside Ferry cone — 51
Hagerman lake beds — 52
Pleistocene rocks — 56
Occurrence and character — 56
Sources of the eruptions — 56
Water in the Pleistocene basalt — 58
Undifferentiated basalt — 63
Sedimentary beds in the lava — 64
Pleistocene formations along the canyon of Snake River — 65
Lava fills — 65
Cedar Butte basalt — 69
American Falls lake beds — 69
Sedimentary beds — 69
Basalt member — 71
Madson basalt — 72
Malad basalt — 74
Thousand Springs basalt — 75
McKinney basalt — 76
Bliss volcanics — 78
Bliss cone — 78
Associated dikes — 78
The basalt flow — 80
Sand Springs basalt and Burley lake beds — 80
Minidoka basalt — 83
Wendell Grade basalt — 84
Pleistocene basalt in tributary valleys — 85
Salmon Falls Creek — 85
Goose Creek — 85
Raft River — 86
Portneuf River — 86
Blackfoot River — 87
Upper Snake River — 88
Lake beds near Terreton and Market Lake — 88
Glacial deposits — 89
Older alluvium — 89
Recent deposits — 93
Occurrence — 93
Black basalt and associated cones — 94
Water in the Recent basalt — 100
Wind-blown deposits — 102
Younger alluvium — 102
Landslides and talus — 104
Structure — 105

Page
Ground-water levels — 109
Method of investigation — 109
Form of the water table — 109
Relation of water table to land surface — 114
Relation of water table to irrigation — 116
Alluvial fan of Snake River — 116
Aberdeen-Springfield tract — 117
Fort Hall and Blackfoot tracts — 120
Minidoka project — 124
Twin Falls South Side project — 128
Twin Falls North Side tract — 135
Springs — 136
Occurrence and character — 136
Springs in the Fort Hall bottoms — 137
General features and discharge — 137
Sources — 139
Possible supply from Portneuf River Basin — 139
Possible supply from precipitation north of Snake River — 140
Possible supply from underflow of Snake River — 140
Springs between American Falls and King Hill — 142
Sources — 142
Spring coves — 144
Origin — 144
Cove piracy — 147
Springs between American Falls and Milner — 151
Rueger Spring — 151
Davis Springs — 151
Mary Franklin Mine Springs — 152
Mower Springs — 152
Springs near Lake Walcott — 152
Springs between Milner and Blue Lakes — 154
Minor springs — 154
Blue Lakes — 156
Springs between Blue Lakes and Crystal Springs — 157
Springs between Crystal Springs and Thousand Springs — 158
Crystal Springs — 158
Niagara Springs — 159
Clear Lake — 159
Briggs Spring — 160
Banbury Springs — 160
Box Canyon and Blind Canyon Springs — 160
Blue Springs — 161
Sand Springs — 161
Thousand Springs — 162
Springs between Thousand Springs and Bliss — 164
Springs in Hagerman Valley — 164
Malad Springs — 164
Miscellaneous small springs — 166
Thermal springs and wells — 166
White Arrow Hot Spring — 166
Blanche Crater Warm Spring — 167
Tschannen Warm Springs and hot well — 167
Banbury Hot Spring and hot wells — 167

Springs—Continued.
Thermal springs and wells—Continued. Page
Rings Hot Spring 168
Unnamed hot spring 168
Artesian City hot springs and hot wells 168
Bridger Hot Spring and wells 170
Frazier Hot Spring and well 170
Warm springs on south shore of Lake Walcott 171
Fall Creek warm springs 171
Indian Hot Springs 171
Lava Hot Springs 171
Heise Hot Springs 172
Condie Hot Springs 173
Lava Creek Hot Spring 173
Quality of water 173
Surface and ground waters in Snake River Plain above King Hill 176
Contributions from tributary valleys 176
Water discharged by Snake River as measured at King Hill 177
Water consumed by crops on irrigated lands 177
Water stored in surface reservoirs 178
Losses by evaporation from water surfaces 178
Ground-water storage 179
Summary of supply and disposal 180
Economic use of the water 181
Losses and gains in Snake River 182
General conditions 182
Method of computation 182
Losses between Heise and Lorenzo 182
Gains between Lorenzo and Shelley 185
Gains between Heise and Shelley 186
Losses between Shelley and Clough ranch 187
Gains between Clough ranch and Neeley 190
Losses between Neeley and Minidoka Dam 193
Gains between Minidoka Dam and Milner 197
Gains between Milner and Blue Lakes 198
Gains between Blue Lakes and Hagerman 199
Gains between Hagerman and King Hill 200
Losses from Henrys Fork of Snake River below mouth of Warm River 201
Future development of ground water 203
Tributary valleys 205
Ground-water supplies 205
Salmon Falls Creek Valley 206
Valleys between Salmon Falls Creek and Goose Creek 207
Goose Creek Valley 209
Marsh Creek Valley 209
Raft River Valley 210
Geography 210
Surface water 212
Well records 213
Water table 214
Quantity of ground water 216
Relation of surface water to ground water 218
Conclusions 220

Tributary valleys—Continued. Page
Rock Creek Valley 220
Bannock Creek Valley 221
Portneuf River Valley 222
Blackfoot River Valley 227
Valleys tributary to upper Snake River Plain from the east 228
Valleys north of Mud Lake region 230
Birch Creek Valley 231
Little Lost River Valley 232
Geography 232
Surface water 233
Ground water 234
Test drilling 236
Measurements of the spring-fed creeks 240
Available ground-water supply and method of recovery 241
Big Lost River Valley 243
Geography 243
Surface water 244
Ground water 245
Test wells 250
Wells near Moore Dam 250
Well near Arco 253
Conservation and recovery of water 255
Conclusions 258
Valleys between Big Lost River Valley and Carey Valley 258
Big Wood River and Little Wood River Valleys 258
Clover Creek Valley 262
Index 263

ILLUSTRATIONS

Page

PLATE 1. Relief map of the Snake River Plain and adjacent valleys 6
2. Airplane view of Milner Lake, the Twin Falls canals, and the canyon of the Snake River 6
3. Twin Falls at a low stage of the river 6
4. Geologic sketch map of the Snake River Plain east of King Hill ..... In pocket
5. Geologic map of the canyon of the Snake River between Twin Falls and King Hill ..... In pocket
6. Geologic map of the canyon of the Snake River between American Falls and Steele Island ..... In pocket
7. Airplane view of Shoshone Falls on Snake River showing the massive andesite flow that forms the falls 6
8. Graphs showing width of rings in 11 trees from the Snake River Plain and a graph of the average ring width of 9 trees in comparison with precipitation at Boise and the flow of Snake River at Moran 22
9. Airplane view of rock bench bordering both sides of Snake River and forming a conspicuous feature near Kimberly 36
10. *A*, Typical exposure in the Hagerman lake beds on the west side of Snake River in Hagerman Valley; *B*, Bliss basalt containing talus blocks of a former cliff and overlain by vitreous volcanic sand and older alluvium 52
11. Relation between the use of irrigation water on the Twin Falls North Side tract and the flow of Blue Lakes and Clear Lakes Springs 62
12. *A*, Boulder deposit in Hagerman Valley laid down at the toe of a lava dam; *B*, View looking down Salmon Falls Creek showing entrenched meanders and inner bench formed by an intracanyon lava flow and outer bench of older lavas 86
13. Geologic map of the Craters of the Moon National Monument, Idaho ..... In pocket
14. *A*, View looking southeast from the summit of Big Cinder Butte showing the line of cones in the Great Rift zone; *B*, View looking northeast from the Idaho Central Highway near Grassy Cone across the dunelike topography to Sunset Cone 94
15. *A*, Perfect crater bowl in the summit of a very symmetrical cone at the north end of Two Point Butte; *B*, The line of spatter cones along Crystal Fissure 94
16. *A*, View of North Crater and the last pahoehoe flow which issued from it; *B*, View of Malad Spring Cove 94
17. *A*, Ropy lava on the surface of the North Crater pahoehoe flow; *B*, Aa lava flow at the Hoodoo Water Hole, near Round Knoll 94
18. Map of the Snake River Plain showing depths to ground water ..... In pocket

Page

PLATE 19. Map of the Snake River Plain, Idaho, and adjacent areas that contribute ground water to the Snake River, showing observation wells and contours of the water table in 1928 or 1929 ..... In pocket
20. Map of Snake River alluvial fan showing ground-water conditions 118
21. Sections of Snake River alluvial fan showing ground-water conditions 118
22. Water-table contour map of the North Side Minidoka project for 1910 126
23. Water-table contour map of the North Side Minidoka project for 1915 126
24. View looking toward Snake River from the head of Blue Lakes cove showing the general absence of talus aprons 142
25. Development of springs fed through lava-filled canyon, looking down Snake River 142
26. Thousand Springs before power development 142
27. Map of Snake River Valley above King Hill, Idaho, showing location of gaging stations 182
28. Map of the Raft River drainage basin 214
29. Map of Raft River Valley showing wells, water-table contours, and depths to ground water 214
30. Map showing ground-water conditions in the Spring Creek area of Little Lost River Valley, Idaho 238
31. Map of Big Lost River Valley showing depths to ground water 246

FIGURE 1. Map of southeastern Idaho showing distribution of precipitation 9
2. Average monthly precipitation on the Snake River Plain, Idaho 10
3. Average annual precipitation and run-off in the Snake River Plain, 1891–1927 11
4. Local unconformity between the Neeley lake beds and the Eagle Rock tuff 45
5. Hydrographs of the water level in certain wells in the Fort Hall-Blackfoot tract 120
6. Curves showing discharge of wasteways and drains from the Minidoka project for 1927 126
7. Hydrographs of three typical wells on the North Side Minidoka project 128
8. Rate of rise in wells on the South Side Twin Falls project 132
9. Longitudinal section of the Fargo drainage tunnel, Twin Falls 133
10. Diagrammatic section showing postulated conditions beneath the North Side Twin Falls tract 135
11. Sketch map showing the location of spring-measuring stations in the vicinity of the American Falls Reservoir 137
12. Map of the vicinity of Clear Lake, which is fed by large springs 158
13. Map of the Bickel Springs, or that part of the Thousand Springs group north of the Thousand Springs power plant 163
14. Relation between water temperature and rate of loss by seepage on the North Side Twin Falls project 184
15. Three profiles in Raft River Valley showing relation of the water table to the land surface 215
16. Map showing location of test wells and contours of the water table in the vicinity of Moore diversion dam, Big Lost River Valley 249

GEOLOGY AND GROUND-WATER RESOURCES OF THE SNAKE RIVER PLAIN IN SOUTHEASTERN IDAHO

By Harold T. Stearns, Lynn Crandall, and Willard G. Steward

ABSTRACT

The part of the Snake River Plain above King Hill, Idaho, is about 250 miles long and has a general eastward trend. This region and the alluvial valleys immediately tributary to it contain about 16,000 square miles. The principal cities in the region are Pocatello, Idaho Falls, and Twin Falls. The discharge of the Snake River at King Hill averages about 9,000,000 acre-feet a year.

The chief purpose of the investigation here recorded was to obtain data regarding the source, movement, and disposal of the ground-water supply of the lava plains that occupy most of the region. By assembling and correlating numerous well records obtained in this and related investigations, tied together by a system of levels, it has been possible to prepare a map of the region showing contours of the water table. This map (pl. 19) shows the direction of movement of ground water in all parts of the region and hence largely indicates the source and disposal of the water. As the altitude of most places in the region is known, this map makes it possible to predict the depth necessary for a well to obtain water. The total annual ground-water supply of the Snake River Plain is here estimated at 4,000,000 acre-feet, of which only a small part is now utilized for irrigation. One result of the study is the conclusion that, in order to conserve this supply, it is desirable so far as practicable to confine future irrigation development to the southeast side of the Snake River above Milner, so that the seepage water may return to a stretch of the river where it will be available for reuse. By heeding this hydrologic condition more land can be irrigated with the remaining available water supply than will be possible if the water is used on the northwest side of the river, because most of the return flow from the northwest side enters the river at too low an altitude to be used again.

The geology of the region in its relation to water supply has been studied with care, and much new information of many kinds has been obtained. One of the principal results of this study is the conclusion that the exceptionally large springs along the canyon of the Snake River owe their existence to the fact that the modern canyon intercepts a series of roughly parallel former canyons of the river that are now filled with especially permeable lava and hence serve as channels for ground water. The coves present where many of the springs emerge are thought to have been formed to some degree by solution. Light is thrown on other peculiarities of the behavior of ground water in basalt by a study of the exceptionally well exposed and very recent volcanic area of the Craters of the Moon National Monument.

The losses and gains in different stretches of the Snake River are estimated on the basis of available stream-flow records. An inventory of the water supply of the plain and its tributary valleys is made. The springs in and near the Snake River Plain are described, and all available records of their discharge are tabulated. Many of the heretofore unpublished ground-water conditions in both the plain and the tributary valleys are summarized.

INTRODUCTION

LOCATION AND AREA

The Snake River, the largest of the tributaries of the Columbia, is the drainage channel for the greater part of the State of Idaho. The South Fork enters southern Idaho from its source in Wyoming and contributes an average annual discharge of nearly 5,000,000 acre-feet. Henrys Fork, which rises in Henrys Lake and derives its waters chiefly from sources in Idaho, contributes an average of fully 1,250,000 acre-feet annually. Below the junction of the two forks the river takes first a southwestward and then a westward course through southeastern Idaho. In addition to the surface stream, a great quantity of water percolates underground, largely through the system of ancient channels of the Snake River that are now filled and covered with permeable lava, and reappears in many large springs in the canyon of the river above King Hill. The total discharge of these springs amounts to about 4,000,000 acre-feet a year. At Weiser, where the Snake River leaves southern Idaho, it has an average annual discharge of about 13,000,000 acre-feet. For more than 200 miles north of Weiser it forms the boundary between Idaho and the neighboring States of Oregon and Washington, and after receiving the inflow from the Salmon and Clearwater Rivers and from tributaries in Oregon and Washington, it leaves Idaho at Lewiston, where its average annual discharge is about 40,000,000 acre-feet. Plate 1 shows the major features of the topography of this part of Idaho. The waters of the Snake River have aptly been called the lifeblood of Idaho. The river with its tributaries furnishes water for irrigating about 2,000,000 acres of land in this State.

This report deals with the part of the Snake River Plain above the town of King Hill and with the valleys immediately tributary thereto. According to the official definition by the United States Geographic Board, this plain comprises the broad valley of the Snake River, which has a rather gently rolling surface mainly underlain by Snake River basalt and related sediments, beginning near the towns of Spencer, Kilgore, and Ashton, in northeastern Idaho, and extending south and west across the entire State to the point where the valley narrows sharply in the vicinity of Huntington, Oreg. In the region covered by this report the Snake River Plain is about 250 miles long, averages 70 miles in width, and covers about 12,500 square miles. The tributary valleys, whose conditions are described in this report, cover an additional area of about 3,000 square miles. The principal cities in the region and their population, according to the census of 1930, are Pocatello, 16,471; Idaho Falls, 9,429; and Twin Falls, 8,787. As shown in plate 4, the region is traversed by two main lines of the Union Pacific Railroad, one extending westward and one northward from Pocatello. Several branch lines connect with these two main

PURPOSE AND HISTORY OF THE INVESTIGATION

The main purpose of the present investigation was to determine the direction of movement of the ground water in the Snake River Plain above King Hill and the respective amounts of water contributed to the great underground reservoir by seepage from the Snake River and tributary streams, from precipitation on the plain itself, and from irrigation water that percolates below the root zone. Efforts were made also to ascertain where the water lost from certain stretches of the Snake River returns to the river and the time involved in the passage of this water underground. The geology of the region was studied to show the occurrence of the ground water and the geologic structure that affects its movement. (See pls. 4, 5, and 6.) To determine the direction in which the ground water is moving in different parts of the region, the position of the water table (or upper surface of the body of ground water) was found by measuring the depth to the water level in as many wells as possible and by connecting the reference points at the wells with a network of levels. From these data the contours of the water table given in plate 19 and the lines showing depth to ground water in plate 18 were drawn. All reliable records of wells were assembled and studied to determine the changes in the water levels in the wells as a result of differences in precipitation and irrigation development. Dye was used in open cuts and in wells to show the rate of ground-water movement. The movements of ground-water crests through certain areas were studied for the same purpose.

The investigation was begun by the United States Geological Survey May 1, 1928, and was under the general direction of O. E. Meinzer, geologist in charge of the division of ground water. It was conducted in cooperation with the Idaho Bureau of Mines and Geology and the Idaho Department of Reclamation. The North Side Canal Co., the Twin Falls Canal Co., the Minidoka and Burley irrigation districts, and the Idaho Power Co. cooperated financially through the Idaho Department of Reclamation.

During recent years investigations have been made by private and governmental agencies relating in large part to the ground-water conditions of this region, but practically none of the results of these investigations have yet been published. One of the main tasks of the present investigation was the assembling and interpretation of the data in the unpublished reports on these investigations.

Mr. Crandall, now district engineer of the United States Geological Survey at Idaho Falls, spent about 15 years investigating the duty of water, canal losses, and ground-water conditions on the North Side Twin Falls tract and in the Big Lost and Little Lost River Valleys. Much of his work is published here for the first time. He is the author of the text concerning losses and gains in the Snake River, the inventory of the water of tributary valleys, and the inventory of the surface

and ground waters in the Snake River Plain above King Hill, except the part relating to the economic use of water and portions of the text relating to consumptive use of water by crops, which were written by Mr. Steward. Mr. Crandall is joint author with Mr. Stearns of the text describing the valleys of the Big Lost, Little Lost, Big Wood, and Little Wood Rivers. In addition he wrote the part relating to the climate and the rate of flow of the ground water. He compiled most of the discharge measurements of the big springs in the Snake River Canyon.

Mr. Steward was responsible for the immense task of collecting, assembling, and checking all well data. In this work he was assisted by H. G. Haight, L. H. Perrine, John McDonnell, J. H. Boone, B. D. Alvord, Jr., and L. T. Burdick. Mr. Steward gave much valuable advice, based chiefly on his long experience in studying ground-water problems during the 20 years he was a member of the United States Bureau of Reclamation engaged largely in research problems in Idaho. He is also author of the text relating to ground water on the Minidoka project and part of that on the South Side Twin Falls tract.

The ground-water conditions on the Blackfoot-Fort Hall and Aberdeen-Springfield tracts were in part described by Mr. Haight. In addition he collected many of the trees and wrote much of the section on tree rings in relation to climate, although all three authors contributed to this section. He aided also in the preparation of the illustrations and in many other ways. C. L. Gazin contributed the data regarding fossils in the Hagerman lake beds. M. N. Short, formerly of the United States Geological Survey, examined the thin sections of the rocks in this region, and prepared a brief report on them which was utilized in this paper.

J. L. Saunders, of the United States Geological Survey, compiled the base maps and plotted the well data on them. This was a difficult task because the well records for each project had a different datum—a condition which required the adjustment of all measuring points to the sea-level datum of the United States Coast and Geodetic Survey.

Prior to this investigation Mr. Stearns spent most of 1921, 1922, and 1923 and parts of 1925 and 1926 in geologic field studies in and immediately adjacent to the region covered by the present report, and all pertinent results of his work during this period are incorporated herein except for the Soda Springs and Mud Lake areas. Mr. Stearns wrote all the text not specifically credited above to his collaborators. In connection with the present investigation, from 1928 to 1930, he mapped in detail the geologic formations along the canyon of the Snake River between King Hill and a point 10 miles downstream from Blackfoot in order to determine the relations of the older Pleistocene and Tertiary rocks, which in the greater part of the region are

hidden under a cover of later Pleistocene basalt and of loess. Because of the lack of adequate base maps for areas at a distance from the river, this work was confined to a strip generally less than 2 miles wide. All available geologic data are incorporated in generalized fashion on plate 4 and those portions of the canyon of the Snake River whose geology cannot be adequately shown on this small-scale map are represented in plates 5 and 6.

ACKNOWLEDGMENTS

The writers are indebted to the personnel of various irrigation projects in the region for many valuable well records and maps. The work was facilitated by the generous and helpful attitude of the late Mr. Burton Smith, former manager of the Twin Falls Canal Co.; Mr. E. B. Darlington, superintendent of the Minidoka Irrigation Project; Mr. R. E. Shepherd, manager of the North Side Canal Co.; and Mr. W. C. Paul, president of the Minidoka irrigation district—all of whom gave a considerable amount of their time and that of their staff. The Oregon Short Line Railroad, the Idaho Department of Public Welfare, the United States General Land Office, and the United States Forest Service furnished most of the data from which some of the base maps in this report were compiled. Numerous residents and drillers in the region supplied records of wells, and several of them donated fossils that were valuable for the determination of the age of the formations. Mr. Elmer Cook, of Hagerman, pointed out significant fossil localities in the Hagerman lake beds. Acknowledgments pertaining to particular areas are made in several places in this report.

Valuable criticisms of the manuscript were made by Messrs. O. E. Meinzer, C. P. Ross, and G. R. Mansfield of the United States Geological Survey.

GEOGRAPHY

SURFACE FEATURES

SNAKE RIVER PLAIN

The Snake River has its source on the Continental Divide, in the southern part of Yellowstone National Park. It flows southward through Wyoming for about 75 miles, enters Idaho, and at Heise emerges from its mountainous headwater area, into the great Snake River Plain. A short distance farther downstream it is joined by its major tributary, Henrys Fork, which drains the upper part of the Snake River Plain. This plain extends for more than 300 miles entirely across southern Idaho, roughly along the arc of a circle. The Snake River flows near the southern boundary of the plain, a position that has been forced upon it by lava flows, which cover the region between the present river and the northern edge of the plain and which have displaced the stream from its ancient channel in the axis of its valley. Plate 2 shows the locality where the river enters a canyon cut

in the lava at Milner. The canyon becomes deeper westward until near Twin Falls it is bounded by precipitous lava cliffs about 600 feet high. The Snake River continues in a canyon nearly to King Hill, a distance of about 90 miles. The topography of the region is illustrated by the relief map, plate 1.

Irrigated lands adjoin the river on both sides, extending for a distance of 10 or 12 miles and leaving the major part of the uninhabited plain as a great curved segment between the irrigated sections on the south and the mountains that border the plain on the north. Although this region presents from afar the appearance of a great level valley floor it has been built up by successive lava flows from numerous vents within the valley itself. Its topography is determined by the source and extent of these lava sheets and not by erosion, except that the Snake River and several tributary streams have cut deeply into it.

Though vegetation in one form or another covers much of the area, the desolate black lava flows, the drifting white sand dunes, and the bleak, bare lake beds serve to impress upon the traveler the desert character of the country. Throughout many square miles in the central part of the plain water can be found only in the ice caves in the lava flows or at some stock well at which the water is pumped hundreds of feet. With the increase in the area irrigated on the plain the people inhabiting the area have come more and more to refer to the irrigated part of the plain as the "Snake River Valley." About 1,000,000 acres is now under irrigation in "the valley," and not a small part of it lies hundreds of feet above the Snake River, on the surface of the plain. In the section of the report treating the irrigation development it is convenient to use the term "the valley" to refer to irrigated parts of the plain.

The altitude of the Snake River at Heise, where the stream first emerges from the foothills, is about 5,000 feet. At King Hill, about 250 miles downstream, the altitude is 2,500 feet. The stream thus descends at an average rate of about 10 feet to the mile. About 500 or 600 feet of this difference in altitude between Heise and King Hill, however, is concentrated in falls at Idaho Falls, American Falls, Twin Falls, Shoshone Falls, and other places, so that the average grade of the stream exclusive of these falls is about 8 feet to the mile. The altitude of the plain into which the river canyon is incised ranges from 5,100 feet at Ashton to 3,200 feet near King Hill and averages about 4,400 feet.

BUTTES

The generally flat appearance of the plain is relieved by several buttes, chief among which are Big Southern Butte, West Twin Butte, and East Twin Butte, which stand prominently above the general land surface about 30 miles northwest of Blackfoot. Big Southern Butte rises 2,350 feet above the surrounding plain. It is called by the

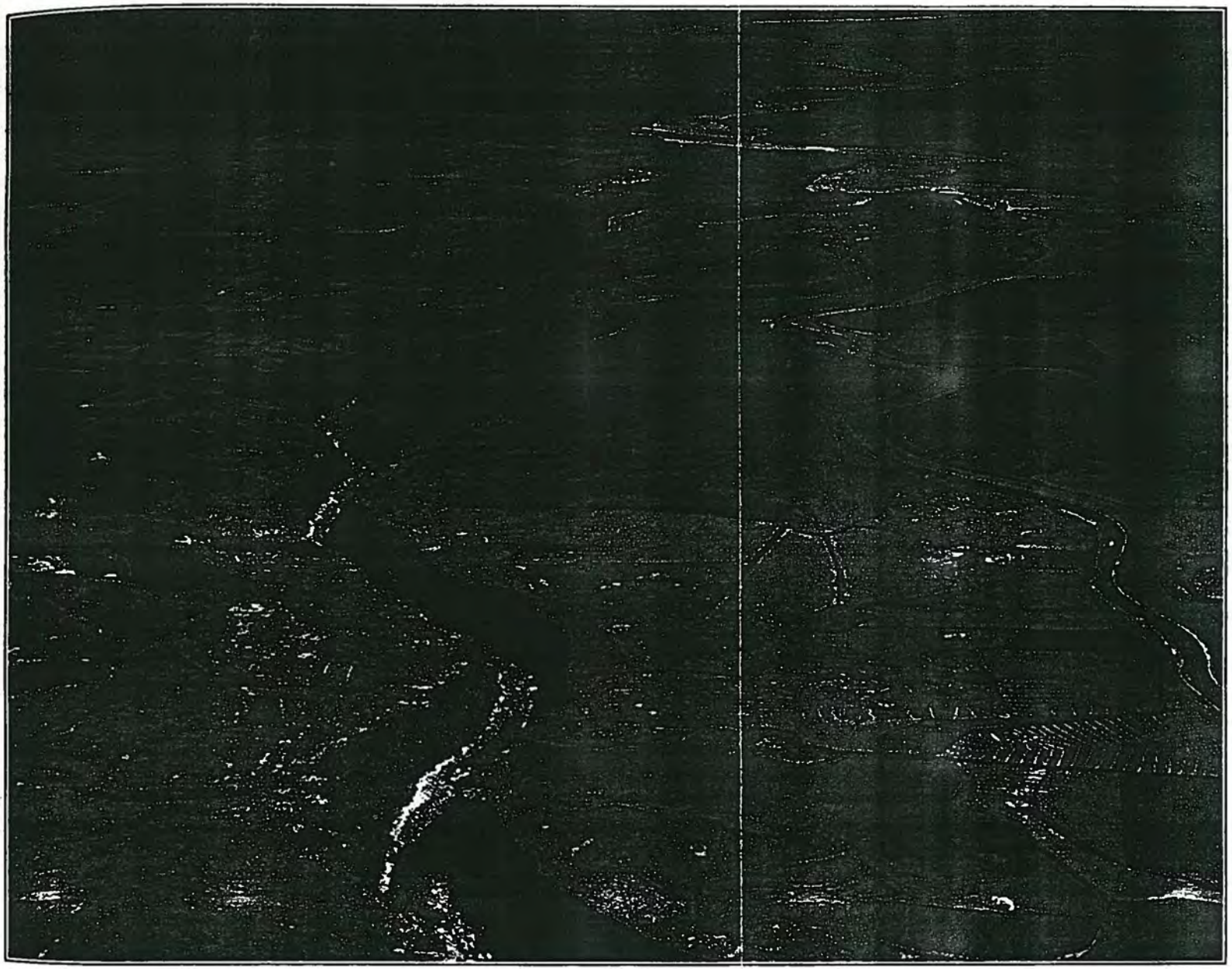
RELIEF MAP OF THE SNAKE RIVER PLAIN AND AD

per westward until
cliffs about 600 feet
early to King Hill,
of the region is il-

nding for a distance
ninhabited plain as
ns on the south and
h. Although this
t level valley floor
n numerous vents
ined by the source
n, except that the
deeply into it.
much of the area,
nd dunes, and the
raveler the desert
are miles in the
n the ice caves in
water is pumped
gated on the plain
ore to refer to the
Valley." About
lley," and not a
ke River, on the
ing the irrigation
alley" to refer to

the stream first
King Hill, about
The stream thus
ile. About 500
e and King Hill,
ican Falls, Twin
verage grade of
the mile. The
sed ranges from
averages about

ved by several
st Twin Butte,
he general land
Southern Butte
called by the



AIRPLANE VIEW OF MILNER LAKE, THE TWIN FALLS CANALS, AND THE CANYON OF THE SNAKE RIVER.

Photo by U. S. Army Air Corps.

AIRPLANE VIEW OF TWIN FALLS AT A LOW STAGE OF THE RIVER.

A resistant basalt bed 120 feet thick causes the falls. The sand banks in the gulch on the right are mined for flour gold and have yielded bones of extinct animals. Photo by U. S. Army Air Corps.

AIRPLANE VIEW OF SHOSHONE FALLS ON SNAKE RIVER SHOWING THE MASSIVE ANDESITE FLOW THAT FORMS THE FALLS.

The falls are dry because the entire flow of the river has been diverted for irrigation. The power plant on the left utilizes all the spring water and return flow that reaches the river below Milner. Photo by U. S. Army Air Corps.

Indians "Be-ah Car-did" (great stay), referring to its permanence. It may be seen from points over 100 miles distant. East Twin Butte rises about 1,100 feet and West Twin Butte about 800 feet above the adjacent plain.

There are many lower buttes scattered over the lava plain, all of which, unlike the three just mentioned, are extinct basaltic volcanoes (pl. 4). Among these may be mentioned Notched Butte; Sugar Loaf Butte, south of Shoshone; Big Cinder Butte, in the Craters of the Moon National Monument west of Arco; and the Menan Buttes, near Roberts. Besides the cones that are prominent enough to have been individually named, there are innumerable minor elevations that can be discerned if the surface of the plain is viewed against the sky line. These features rise to heights of 100 to 300 feet, but their bases, commonly 4 to 6 miles or more in diameter, are so broad that their slopes merge gradually into each other or into the surrounding plain. These minor elevations are also volcanic vents, and from those now visible as well as from many others buried by later eruptions, vast quantities of highly fluid lava formerly flowed in all directions.

FALLS OF SNAKE RIVER

There are many falls along the Snake River, some of which are large and spectacular. However, so much of the water is being used for irrigation that many of them are dry in the summer. The locations of most of the falls and principal rapids are shown on plates 4, 5, and 6. Shoshone and Twin Falls are by far the largest. The former is 200 feet high and results from the superposition of the river on the Shoshone Falls andesite as a result of displacement from its former channel by the Sand Springs basalt. The fall at a period of low water is shown in plate 7. Twin Falls is caused by the river's tumbling over a massive bed of basalt 120 feet thick (pl. 3). The other falls along the Snake River within the region studied are 45 feet or less in height.

TRIBUTARY STREAMS

Many perennial streams, of which the largest are the Blackfoot and Portneuf Rivers, flow into the Snake River from the south, but between the mouth of Henrys Fork, in the extreme northeastern part of the area, and the mouth of the Big Wood River, near Bliss, in the southwestern part, a distance of about 250 miles measured along the stream, the Snake River does not receive a single surface tributary from the north. The drainage area north of the plain is occupied by lofty mountains which rise to altitudes as great as 12,500 feet and the run-off from which forms many streams that sink at the north edge of the lava plain. Part of this run-off flows beneath the lava sheets near the mouths of the valleys through the gravel deposits which were laid down by the ancestral tributary streams and which underlie or are

interstratified with the lavas, and a part passes through the lavas that fill these ancient valleys. The flood waters usually form shallow ponds or lakes in depressions on the surface of the Snake River Plain, from which the water not lost by evaporation sinks to the deep underlying water table. Big Wood and Little Wood Rivers are the only streams that succeed in crossing the lava plain, principally because of the more favorable topography along these rivers and the narrowness of that part of the belt of lavas that separates the mountains from the Snake River.

CLIMATE

TEMPERATURE

The mean annual temperature of the Snake River Plain east of King Hill ranges from 41° F. at Ashton (altitude 5,100 feet) to 50° at Bliss (altitude 3,270 feet). In parts of the mountainous areas bordering the plain the mean annual temperature is probably lower. A table showing the mean monthly and annual temperatures at 16 stations on the Snake River Plain is given below.

Temperatures in southern Idaho (° F.)

[From records of the U. S. Weather Bureau]

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
Arco	.....	14.8	20.1	29.9	36.3	58.9	61.1	65.0	64.0	54.7	44.8	31.6	18.6	41.7
Blackfoot	32	21.9	26.5	38.9	44.9	53.2	61.6	65.3	66.1	56.5	45.4	34.5	22.8	44.7
Boise	65	29.4	34.9	42.7	50.4	57.1	65.3	72.9	71.8	61.9	51.1	41.0	32.1	52.3
Bubl	21	28.0	33.3	40.1	48.1	55.8	64.3	72.9	66.2	60.2	49.6	39.6	28.4	49.2
Burley	11	27.3	32.3	38.8	45.6	55.9	64.3	72.5	69.0	59.5	48.4	38.0	27.7	48.2
Caldwell	24	28.7	35.4	43.2	50.5	57.4	65.3	73.1	68.8	60.7	50.3	39.5	30.7	50.3
Emmett	22	29.3	36.3	44.0	51.5	58.8	67.0	75.1	72.6	63.3	52.2	40.8	30.2	52.4
Fort Hall	14	21.2	28.6	36.2	44.4	53.4	61.8	69.9	66.4	57.0	46.4	35.0	23.4	45.3
Glenns Ferry	20	27.7	35.5	44.0	50.7	58.9	69.0	78.5	74.6	62.5	49.8	39.3	28.7	51.6
Gooding	19	24.2	29.2	39.0	46.7	55.2	63.3	71.4	68.5	58.8	48.1	37.4	25.7	47.3
Idaho Falls	34	19.6	23.4	33.6	44.4	53.9	60.5	68.5	66.5	56.8	45.9	43.5	22.2	44.0
Mackay	.....	17.2	20.9	31.0	41.8	51.0	59.4	67.2	64.6	55.3	44.6	31.0	19.6	42.1
Milner Dam	18	27.1	31.0	39.8	47.0	55.0	61.7	70.0	69.5	60.4	48.6	[1] 37.8	26.4	47.9
Oakley	35	28.6	31.8	38.7	46.2	53.9	62.4	70.7	69.2	59.4	49.2	38.8	28.7	48.2
Rupert	22	25.5	30.7	38.6	46.6	54.7	61.9	70.9	67.7	58.1	48.4	37.7	26.5	47.4
Twin Falls	23	27.8	32.4	39.5	47.2	54.9	62.4	70.6	67.9	58.9	48.3	38.0	27.9	47.9
Mean	25.7	26.2	31.5	39.6	47.4	55.6	63.7	71.7	68.9	59.8	48.7	38.6	27.2	48.3

[1] Mean of Burley and Rupert.

At Ashton the average date of the last killing frost in the spring is June 7 and that of the first killing frost in the fall is September 11. At Bliss the dates are May 10 and October 4. July is the month of maximum temperature, the mean for that month ranging from 71° at the lower altitudes to 63° at the higher altitudes on the plain. January is generally the month of minimum temperature, with a range in the mean temperature from 28° to 18° at different stations on the plain.

Like other continental interior areas of fairly high altitude, the Snake River Plain has a large daily range of temperature. The difference between the mean daily maximum and mean daily minimum is about 20° during the winter and about 38° during the summer, but occasionally much greater variations are experienced. The summers are characterized by hot days and cool nights. Now and then the temperature is 100° or more for a few days at a time, and it has reached a maximum of 106°. On account of the dryness of the atmosphere, however, the daytime heat is less oppressive than it is in more

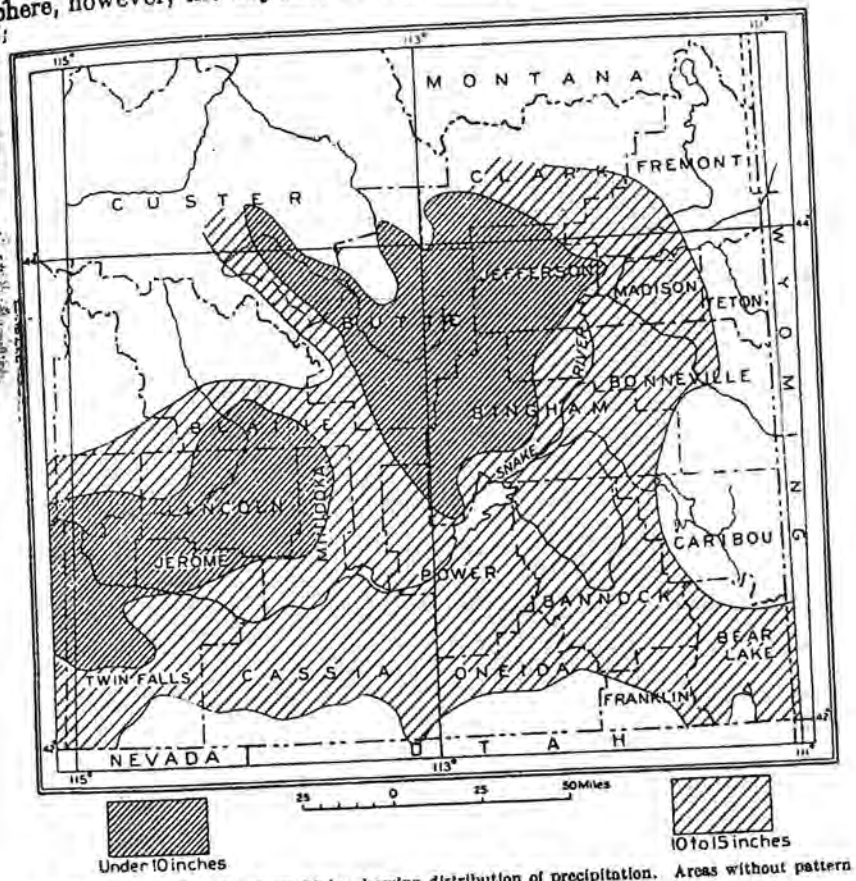


FIGURE 1.—Map of southeastern Idaho showing distribution of precipitation. Areas without pattern have an average annual precipitation of more than 15 inches.

humid regions, and as the clear summer nights allow rapid radiation from the heated land surface, the temperatures become comfortably cool shortly after darkness falls. During the winter the temperature frequently falls below zero and has dropped as low as 40° below zero at the entrances to some of the tributary valleys. In ordinary winters the minimum temperature reached on the plain is from 10° to 20° below zero. In the small area within the Snake River Canyon below Twin Falls and including the Hagerman Valley the temperature at all

times is noticeably higher than on the adjacent uplands, doubtl because of the sheltered location and lower altitude of these lands.

PRECIPITATION

Precipitation on the Snake River Plain ranges from an annual ave age of less than 9 inches in some areas of the north-central and weste parts to about 14 inches in some of the eastern, southern, and nort eastern areas. Toward the mountain areas that contain the head

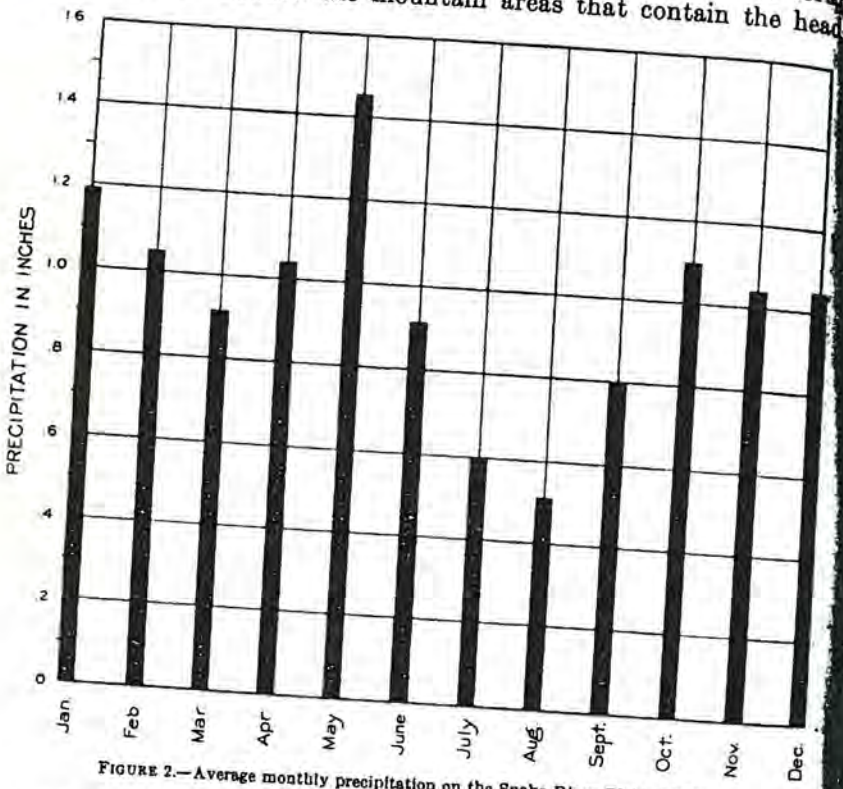


FIGURE 2.—Average monthly precipitation on the Snake River Plain, Idaho.

waters of the river on the northeast and east, the precipitation increases, exceeding 20 inches at high altitudes.

The general distribution of the precipitation is shown in figure 1. Records are lacking to show the precipitation at high points between the tributary valleys, hence there are probably local areas of higher precipitation than are indicated on this map. Unlike many other semiarid regions, the Snake River Plain is favored with a fairly uniform distribution of precipitation throughout the season, as shown by figure 2. The relatively high precipitation during the spring and early summer is probably in large part of local origin and supplied by the reprecipitation of the moisture evaporated from the melting snow fields in the foothills and mountains during these months.

Continuous records of precipitation in the upper part of the plain are not available for the years prior to 1891, but the average annual precipitation at American Falls, Ashton, Blackfoot, Idaho Falls, Oakley, and Pocatello, six stations with long-time records, is shown in figure 3

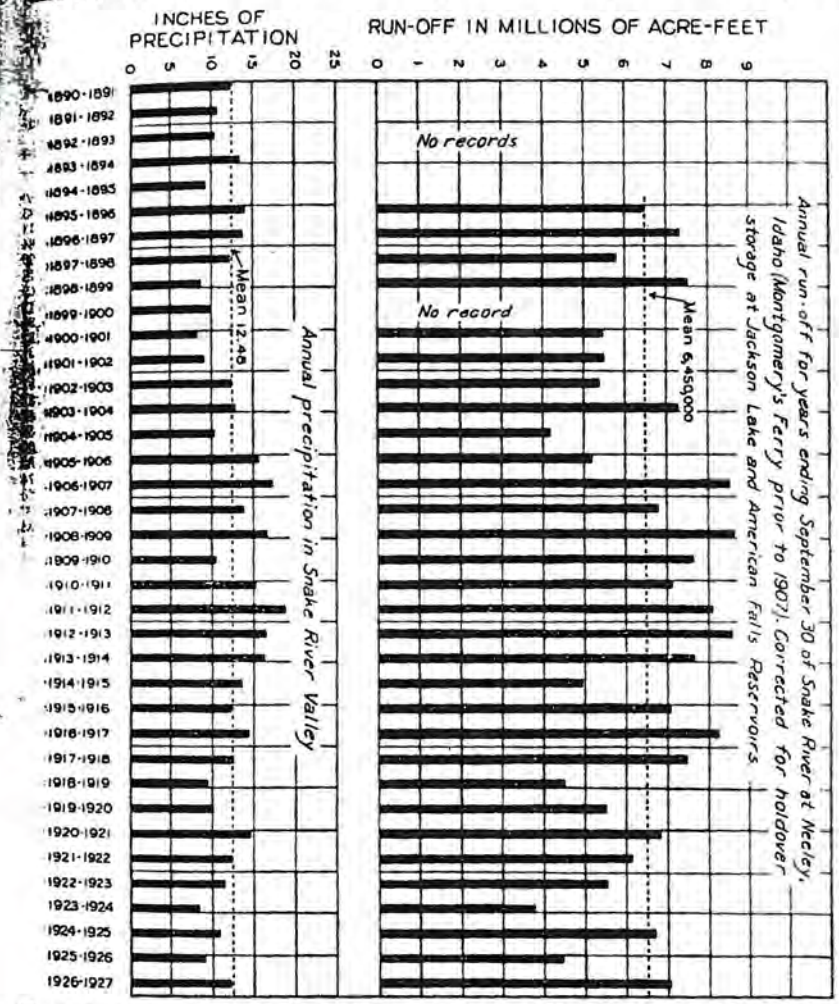


FIGURE 3.—Average annual precipitation and run-off in the Snake River Plain, by years ending September 30, 1891–1927.

together with the discharge of the Snake River at Neeley, corrected for storage hold-over at Jackson Lake and American Falls during the years of record. The table on page 12 gives the mean monthly and annual precipitation at these and other stations for years of record from 1891 to 1927.

The years of high precipitation from 1906 to 1917 constituted the period of great development of dry-farm wheat lands on the Snake River Plain, especially north of the Snake River between Idaho Falls

and Minidoka. Most of these lands have been abandoned since 19[illegible] owing to inadequate rainfall and it would thus appear that an a[illegible] age annual precipitation of about 15 inches is essential to succes[illegible] dry farming in this region.

Mean monthly and annual precipitation, in inches, at stations in the Snake R[illegible] Plain and tributary areas, 1891–1927

Station	Length of record (years)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	A[illegible]
Albion	13	1.20	1.35	1.18	1.28	1.60	1.09	0.64	0.40	0.71	1.58	1.48	1.29	[illegible]
Almo	8	1.58	1.43	.37	.92	1.95	2.88	1.63	1.01	1.25	2.09	1.42	.80	[illegible]
Aberdeen	14	.53	.71	.65	1.07	1.28	.63	.62	.47	.82	1.02	.74	.59	[illegible]
American Falls	35	1.50	1.21	1.43	1.33	1.66	.94	.64	.54	.70	1.25	1.23	1.41	[illegible]
Arco	25	1.13	.59	.92	.83	1.38	1.16	.59	.53	.58	.67	.65	.87	[illegible]
Ashton	24	1.90	1.41	1.22	1.20	2.02	1.35	.91	.58	1.16	1.51	1.26	1.66	[illegible]
Blackfoot	31	.93	.79	.86	.94	1.41	.80	.74	.64	.83	1.11	.79	.85	[illegible]
Bliss	11	1.25	1.12	.63	.90	1.06	.26	.13	.17	.44	.90	1.27	.99	[illegible]
Buhl	20	.99	.96	.59	.96	1.23	1.01	.48	.22	.54	1.02	.99	.96	[illegible]
Burley	10	.78	.80	.45	1.54	1.02	.81	.41	.78	.74	1.12	.98	.89	[illegible]
Fort Hall	13	.58	.65	.92	1.34	1.34	.60	.71	.74	.92	1.12	.72	.67	[illegible]
Gooding	18	1.18	1.16	.53	.95	.83	.51	.40	.25	.52	.97	1.57	.98	[illegible]
Hailey	24	2.53	2.16	1.34	1.08	1.51	.91	.51	.46	.79	1.12	1.60	1.86	[illegible]
Hazleton	10	.99	1.27	.77	1.01	2.05	.58	.22	.61	.59	1.03	1.10	1.25	[illegible]
Hollister	16	.70	.88	.47	1.19	1.29	.80	.42	.44	.61	1.09	.81	.78	[illegible]
Idaho Falls	33	1.37	1.07	1.25	1.01	1.49	1.18	.65	.69	.90	.95	.85	1.15	[illegible]
Irwin	25	1.35	1.12	1.13	.98	1.87	1.22	1.00	.91	1.33	1.34	1.15	1.20	[illegible]
Jerome	12	.90	1.06	.65	1.03	.92	.45	.18	.32	.40	.95	1.01	.99	[illegible]
Mackay	19	.95	.84	.45	.69	1.18	1.06	.93	.78	.92	.70	.51	.73	[illegible]
Martin	6	2.06	1.28	3.14	.91	2.16	.80	.20	.32	.77	.63	1.79	1.54	[illegible]
Mud Lake	5	.60	.35	.53	.49	1.43	.61	.76	.81	.61	.72	.24	.85	[illegible]
Oakley	34	.81	.76	.85	1.13	1.36	1.05	.64	.63	.81	.98	.78	.58	[illegible]
Pocatello	28	.66	.95	1.65	2.02	2.20	.99	.63	.56	.88	.98	.55	.86	[illegible]
Richfield	13	1.40	.97	.67	.92	1.02	.70	.27	.20	.63	.91	1.22	.93	[illegible]
Rupert	21	1.20	1.04	.82	1.09	1.26	.87	.54	.53	.78	1.16	1.18	1.17	[illegible]
Shoshone	13	1.57	1.17	.55	.68	.91	.51	.24	.11	.70	.95	1.45	1.03	[illegible]
Spencer	6	1.38	1.64	1.38	1.06	2.48	.75	1.48	.80	1.68	1.61	.91	1.76	[illegible]
Springfield	19	1.02	.81	.64	1.03	1.31	.74	.69	.47	.87	1.13	.94	.85	[illegible]
Sugar	20	1.13	.82	.61	.84	1.71	1.13	.78	.46	1.10	1.16	.57	1.18	[illegible]
Twin Falls	22	1.24	1.01	.84	.97	1.14	.90	.43	.26	.70	.93	1.17	1.10	[illegible]
Wendell	18	1.46	1.15	.66	.99	.93	.81	.26	.21	.51	1.19	1.41	.86	[illegible]
Average		1.19	1.05	.91	1.04	1.45	.91	.60	.51	.80	1.09	1.04	1.05	[illegible]

The stream run-off reflects in a general way the fluctuations in precipitation from year to year, but the relation is not definite, probably in part because precipitation at the stations within the valley is not always an index to precipitation on the headwater areas, from which the stream run-off is principally supplied. The precipitation generally takes the form of snow during December, January, and February, and at the higher altitudes often also in November, March, and even April. The snow cover during the winter ranges from a few inches to several feet or more at different places and in different seasons and often melts during warm weather in the winter, particularly at the lower altitudes. The deep snows in the high mountains melt during May, June, and July and then form the source of the water supply that is used for irrigation in the valley.

The mean relative humidity at Pocatello averages about 50 percent for the year, with a daily range from 25 to 60 percent during the summer and 70 to 80 percent during the winter. The average wind velocity at Pocatello is 8.8 miles an hour, and the recorded maximum 58 miles an hour.

EVAPORATION AND TRANSPIRATION

Records of evaporation from water surfaces have been obtained at [illegible]veral stations in the region, principally in connection with studies [illegible]lossos from reservoirs. Some are records from floating lake pans, [illegible]hers from pans of the standard class A type of the United States [illegible]eather Bureau. The annual evaporation as disclosed by these [illegible]ords ranges from less than 3 feet to about 6 feet, according to the [illegible]cation and type of the evaporation pan. The accompanying tables [illegible]ow total evaporation—that is, the sum of the measured loss plus [illegible] rainfall.

JEROME

Fragmentary records of evaporation during 1916 are available for [illegible]erome, in Jerome County. Beginning in 1917 records were obtained [illegible]om a standard class A Weather Bureau land pan in an irrigated [illegible]lue-grass pasture in the vicinity of Jerome, in sec. 18, T. 8 S., R. 17 E. [illegible]oise meridian.

Evaporation data at Jerome, 1916–27

[Altitude 3,780 feet. From records of North Side Canal Co., Jerome]

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation (inches): Land pan 6 feet in diameter, top flush with ground	Evaporation (inches): Pan 27 inches square, floating in canal
1916				
[illegible]ne	60.4	0.01	6.60	5.30
[illegible]ly	69.9	.40	7.60	4.95
[illegible]gust	68.2	.00	6.35	4.50
[illegible]ptember	59.8	.00	5.07	3.36
Total or average	64.6	.41	25.62	18.11

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month): Top of 20-foot building	Wind velocity (miles a month): Ground surface	Mean relative humidity (percent)
1917						
[illegible]pril	42.2	2.43	4.23			
[illegible]ay	52.9	1.34	6.40			
[illegible]ne	62.2	.00	9.17			
[illegible]ly	74.3	.09	8.20			
[illegible]gust	69.8	.00	7.03			
[illegible]ptember	62.5	.54	3.60			
[illegible]ctober	49.6	.00	2.40			
Total or average	59.1	4.40	41.03			
1918						
[illegible]pril 17-30	46.7	0.82	3.15	[1] 16,544		46
[illegible]ay	53.0	1.37	9.39	5,827		48
[illegible]ne	71.2	1.15	8.92	4,060		51
[illegible]ly	73.8	.42	10.17	4,040		56
[illegible]gust	66.0	.42	7.53	4,965		58
[illegible]ptember	61.8	.95	4.23	4,015		57
[illegible]ctober	50.4	.96	2.13	4,730		72
[illegible]vember	36.0	.42	1.41	6,420		69
[illegible]cember	30.6	.54	.70	4,766		72
Total or average	54.4	7.05	47.63	5,041		59

[1] For full month.

Evaporation data at Jerome, 1916–27—Continued

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month)		Mean relative humidity (percent)
				Top of 20-foot building	Ground surface	
1919						
January	29.9	0.39	0.52	5,925		
February	30.7	1.47	.45	6,199		
March	38.6	1.21	1.65	6,625		
April	50.0	.69	5.09	6,382		
May	59.0	.05	7.50	6,739	2,510	
June	66.0	.00	10.51	4,300	1,860	
July	73.7	.00	9.37	4,805	1,550	
August	72.9	.00	9.64	4,604	1,655	
September	62.4	.70	5.35	5,383	2,081	
October	42.6	.92	1.89	4,799		
November	35.8	.97	1.09		2,320	
Total or average	51.1	6.40	53.06	5,576	1,996	
1920						
February	34.7	0.48	0.67	4,628		
March	38.8	.68	2.65	4,223		
April	44.3	1.15	4.31	7,995		
May	54.8	.00	6.34		2,539	
June	63.8	.44	6.97	4,653	1,523	
July	74.9	.05	9.90	4,450	1,530	
August	70.5	.28	6.42	4,040	1,490	
September	61.8	.48	2.73		1,040	
October	48.2	1.81	1.83		1,360	
Total or average	54.6	5.37	41.82	5,098	1,580	
1921						
April	44.3	1.16	3.96		2,876	
May	55.4	3.16	4.88		1,726	
June	65.6	.46	6.29		860	
July	72.0	.03	7.71		941	
August	70.9	.06	5.02		958	
September	54.8	.06	2.61		1,289	
October	52.2	.03	1.61		1,137	
Total or average	59.3	4.96	32.08		1,398	
1922						
April	42.6	1.64	3.89		3,127	
May	54.1	.74	6.63		2,449	
June	67.0	.87	6.65		683	
July	70.8	.05	6.51		966	
August	71.8	1.07	3.77		748	
September	61.6	.01	2.65		923	
October	53.1	.34	1.75		1,275	
Total or average	60.1	4.72	31.85		1,453	
1923						
April	47.1	1.35	3.72		1,384	
May	56.4	1.30	6.51		1,140	
June	61.2	1.03	6.50		701	
July	74.4	.08	9.79		691	
August	70.1	.27	7.64		484	
September	63.4	1.37	5.76		541	
October	47.2	2.02	3.10		983	
Total or average	60.0	7.42	43.02		847	
1924						
April	47.3	0.03	5.69		1,522	
May	61.6	.15	10.08		1,367	
June	65.8	.20	[1] 9.02		1,277	
July	73.8	.00	9.54		945	
August	71.0	.00	8.28		765	
September	63.5	.02	4.98		877	
Total or average	63.8	.40	47.59		1,125	

[1] Partly estimated.

Evaporation data at Jerome, 1916–27—Continued

Month	Mean air temperature (° F.)	Precipitation (inches)	Evaporation from U. S. Weather Bureau class A pan (inches)	Wind velocity (miles a month)		Mean relative humidity (percent)
				Top of 20-foot building	Ground surface	
1925						
[illegible]	64.3	0.70	7.87		544	
[illegible]	76.8	.41	8.64		479	
July	69.7	1.17	7.12		683	
August	60.4	.35	4.16		601	
September						
Total or average	67.8	2.63	27.79		577	
1926						
[illegible]	59.4	0.19	4.39		964	
May	70.4	.03	6.87		1,314	
June	76.0	.52	8.56		1,030	
July	73.5	.15	8.82		826	
August	56.2	.04	7.43		1,039	
September	51.8	.25	4.83		955	
October						
Total or average	64.5	1.18	40.90		1,021	
1927						
[illegible]	66.4	0.02	8.85		898	
[illegible]	74.2	.00	8.42		658	
July	70.6	.05	6.46		474	
August	59.0	.41	5.49		753	
September						
Total or average	67.5	.48	29.22		696	

Average evaporation at Jerome, 1917-27 from U. S. Weather Bureau class A evaporation pan

[Records from North Side Canal Co., Jerome]

Month	Relative humidity (percent)	Mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)	Wind velocity (miles a month)	
					20 feet above ground surface	Ground surface
January	67	26.7	0.90	0.52	5,925	
February	73	32.2	1.06	.56	5,414	
March	67	38.3	.65	2.15	5,424	
April	57	47.2	1.03	4.26	6,974	2,227
May	47	56.4	.92	6.90	6,283	1,814
June	45	65.7	.45	7.96	4,338	1,073
July	47	73.7	.18	8.80	4,432	977
August	47	70.5	.32	7.07	4,736	898
September	57	60.4	.40	4.45	4,699	1,016
October	69	49.8	.95	2.44	4,764	1,142
November	69	38.5	1.01	1.25	6,420	2,320
December	72	28.0	.99	.70	4,766	
Total or average	60	49.0	8.86	47.06	5,348	1,433

PIONEER IRRIGATION DISTRICT

Evaporation and transpiration data are available for the Pioneer irrigation district, near Caldwell, in Canyon County. Pan A was a galvanized-iron tank 4 feet square and 3 feet deep, set about 2 feet in the ground in a swamp and surrounded by water from 0.3 to 0.4

foot deep. The space within the pan was planted to cattails or tules which grew abundantly in the surrounding area. The pan was filled with water twice a week to maintain conditions similar to those in the surrounding swamp.

Pan B was of the same dimensions as pan A. It was set in the ground about 2.8 feet, in a water-logged area, and was filled with soil to the same level as the surrounding ground. In the pan were planted strips of blue grass about 8 inches wide, with intervening 8-inch strips of bare soil. The water level in the pan was maintained from 1.5 to feet below the surface by means of pipes that supplied the water from beneath, so that it rose in the soil from below, as under ordinary field conditions in water-logged areas.

Pan C was a standard Weather Bureau class A evaporation pan, 4 feet in diameter and 10 inches deep, set on a platform of 2- by 4-inch planks resting on the ground.

Evaporation and transpiration in the Pioneer irrigation district, 4 miles southeast of Caldwell, Boise Valley, Idaho [1]

[Altitude 2,370 feet]

Date	Mean temperature (° F.)	Precipitation (inches)	Evaporation and transpiration from soil (inches)		Evaporation from free water surface (pan C) (inches)
			Pan A	Pan B	
1918					
June 12-30	73.6	0.25	6.01	4.23	4.60
July	73.8	.50	13.00	6.23	7.26
August	67.2	.24	14.10	4.13	4.70
September	64.8	1.87	7.20	2.91	2.63
October	54.0	1.47	3.25	1.28	1.28
The period	66.7	4.33	43.56	18.78	20.67
1919					
April 3-30	53	0.85	4.84	4.09	4.77
May	57	.00	6.70	5.60	8.27
June	67	.00	8.92	5.80	8.15
July	74	.00	14.27	6.37	8.30
August	72	.00	13.10	4.20	6.10
September	63	.37	7.86	2.38	3.83
October	45	.52	2.99	2.14	2.29
The period	62	1.74	58.68	30.58	41.71

[1] Steward, W. O., and Coffin, M. H., Experiments conducted to show the comparative evaporation from swamped areas in the Pioneer irrigation district": U. S. Bur. Reclamation unpublished report, Boise, Idaho, 1920.

MILNER

Records of evaporation have been obtained at Milner, in Twin Falls County, in sec. 29, T. 10 S., R. 21 E. The land pan at this point is a standard class A Weather Bureau pan surrounded by bare uncultivated soil. The lake pan is 4 feet in diameter and 10 inches deep, floated on a raft in Milner Lake.

Evaporation at Milner [1]

[Altitude 4,200 feet. From records of Twin Falls Canal Co.]

Month	Monthly mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)		Wind movement per month (miles)
			Land	Floating pan	
1927					
April	45.0	1.02	4.53	4.02	2,790
May	52.0	2.14	6.24	5.79	2,940
June	64.8	.40	8.48	7.27	1,832
July	73.7	.00	10.60	9.20	1,631
August	68.6	.19	8.09	7.20	1,015
September	58.8	.92	5.31	6.69	1,247
October	51.2	.48	3.71	4.11	1,569
November	42.2	1.08	1.41		2,124
Total or average	57.0	6.23	48.37	44.28	1,893
1928					
March 17-31	41.1	0.99	1.00		
April	44.1	.41	6.43	5.60	3,445
May	61.0	.14	8.14	7.38	2,013
June	60.2	1.43	8.34	7.27	2,241
July	72.8	.00	8.70	10.14	1,226
August	67.7	.00	9.00	10.06	1,230
September	61.9	.00	5.49		927
October	49.6	.72	2.53		
Total or average	57.3	3.69	49.63	40.51	1,847

[1] During several of the months shown in the table the lake-pan results at this station are higher than the land-pan results, owing to some undetermined cause. The land-pan results are believed to be more reliable during such periods than those from the lake pan. During the period from Dec. 1, 1927, to Mar. 17, 1928, the land pan was frozen and received precipitation of 1.65 inches, mostly in the form of snow. When the snow and ice had melted, on Mar. 17, 1928, the amount of water remaining in the pan indicated a total evaporation since Dec. 1, 1927, of 0.71 inch. This result may have been affected by snow blown in or out of the pan by winds.

STERLING

Records of evaporation were obtained at Sterling, in sec. 33, T. 4 S., R. 32 E., adjacent to the American Falls Reservoir, in Bingham County. The land pan was a standard United States Weather Bureau class A evaporation pan resting on a frame of 2- by 4-inch planks fully exposed to sun and wind and surrounded by bare ground. The lake pan was 4 feet in diameter and was placed on a small raft chained within a larger raft near the west shore of the American Falls Reservoir near Sterling.

Evaporation at Sterling [1]

[Altitude 4,400 feet]

Month	Mean temperature (° F.)	Precipitation (inches)	Evaporation (inches)	
			Land pan	Lake pan
1927				
May	50.2	1.80	7.95	
June	61.8	.28	10.95	7.73
July	69.1	.11	13.03	9.72
August	64.6	.74	9.83	7.70
September	55.2	1.43	6.65	4.78
October 1-15	47.4	.06	2.60	2.11
Total or mean	58.0	4.42	51.01	32.04
1928				
June	57.0	.78	9.90	7.37
July	68.8	.45	11.76	8.48
August	64.2	.10	11.00	7.91
September	58.0	.13	6.87	4.76
October 1-17	45.8	.47	2.40	1.58
Total or mean	58.8	1.93	41.93	30.10

[1] Newell, T. R., Segregation of water resources, American Falls Basin and American Falls Reservoir: Unpublished repts. to Committee of Nine, Water District 36, 1927-28.

AMERICAN FALLS AND MICHAUD

Records of evaporation were obtained at American Falls Michaud, in Power County. The pans at both places are stand United States Weather Bureau class A land pans, situated adjacen the American Falls Reservoir. The American Falls pan is in sec T. 7 S., R. 31 E., and the Michaud pan is in sec. 1, T. 6 S., R. 33 Both pans are surrounded by uncultivated ground and are ab 4,400 feet above sea level.

Evaporation at American Falls and Michaud [1]

[Altitude 4,400 feet]

Month	Mean temperature (° F.)	American Falls		Michaud	
		Precipitation (inches)	Evaporation (inches)	Precipitation (inches)	Evaporation (inches)
1928					
June	57.0	1.49	9.50	1.16	
July	68.8	.63	11.48	.30	
August	64.2	.25	11.04	.39	
September	58.0	.21	7.12	.23	
October 1-17	45.8	.50	2.60	.39	
Total or average	58.8	3.08	41.74	2.47	

[1] Newell, T. R., Segregation of water resources, American Falls Basin and American Falls Reser Unpublished repts. to Committee of Nine, Water District 36, 1927-23.

MUD LAKE REGION

Evaporation and transpiration records have been obtained at Mu Lake, in Jefferson County, and are included in the report on th region.[1]

SUMMARY OF EVAPORATION LOSSES

It is well known that evaporation as measured by land pans even by floating lake pans is greater than the evaporation from lar water surfaces.[2] In the following table the figures for the open-wat months are based on measured evaporation from the lake pans Milner and American Falls, multiplied by a coefficient of 90 percen to give reservoir evaporation losses, and those for the winter month on the Jerome records for evaporation from ice and snow surfaces.

Computed average evaporation and loss from large water surfaces in the Snake Riv plain

[+ indicates gain]

Month	Evaporation (inches)	Precipitation (inches)	Net gain or loss (inches)	Month	Evaporation (inches)	Precipitation (inches)	Net gain or loss (inches)
January	0.52	1.19	+0.67	August	6.91	.51	-6.
February	.56	1.05	+.49	September	4.73	.80	-3.
March	2.15	.91	-1.24	October	2.95	1.10	-1.
April	4.36	1.04	-3.32	November	1.25	1.04	-.
May	5.70	1.45	-4.25	December	.70	1.05	+.
June	6.67	.91	-5.76				
July	6.88	.60	-7.28	The year	44.38	11.65	-32.

[1] Stearns, H. T., Bryan, L. L., and Crandall, L., Geology and water resources of the Mud Lake region Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

[2] Am. Soc. Civil Eng. Trans., vol. 90, p. 266, 1927.

THE EFFECT OF EVAPORATION AND TRANSPIRATION ON PRECIPITATION AND STREAM FLOW

The large amount of water lost by evaporation from reservoirs and transpired and evaporated from the irrigated land is not necessarily a total loss of water to the region. It has long been recognized that areas remote from the ocean receive a considerable part of their precipitation from water lost by evaporation from the land.[3] On account of the topography of the Snake River drainage basin the prevailing west and southwest winds carry a part of the moisture that is evaporated on the Snake River Plain to the mountainous headwater region on the east side of the basin. There, on account of the greater altitude, the moisture of the ascending winds is in part precipitated and may reappear as stream flow.

TREE RINGS IN RELATION TO CLIMATE

The period for which records of precipitation, stream flow, and other conditions are available in the Snake River Plain is relatively so short that a study was made of tree rings in an endeavor to obtain an idea of climatic conditions prior to 1868, when records of precipitation were first started in Idaho.

The careful studies of tree rings in their relation to climate made by Douglass [4] have demonstrated that, although there are many factors which tend to affect the formation of these rings, precipitation has so predominant an influence that it is safe to assume that tree rings form an approximate measure of the rainfall. He finds a 70 percent correspondence between tree-ring growth and rainfall in a dry climate, and a much closer agreement if the degree of conservation of moisture can be taken into account. Although data from a considerable number of trees in a given region greatly increase the accuracy of the conclusions by permitting allowance for variable factors, Douglass' work demonstrates that study of even a single tree gives results of considerable reliability provided it grows fast enough.[5]

The only native tree that has a wide distribution over the Snake River Plain is the juniper, which occurs generally wherever the annual precipitation exceeds 13 to 14 inches. This is somewhat unfortunate in the present connection, as Douglass [6] found that in Arizona juniper was less satisfactory than some other kinds of trees, particularly yellow pine. The native junipers in Idaho usually do not live to be more than 150 to 200 years old, especially where rooted in soil; if rooted largely in lava rock they have a longer life, smaller annual ring width, more heartwood, and less tendency to decay. Several

[3] Huntington, E., Climatic laws, p. 82, 1924.

[4] Douglass, A. E., Climatic cycles and tree growth: Carnegie Inst. Washington Pub. 289, 1919.

[5] Douglass, A. E., A method of estimating rainfall by the growth of trees, in Huntington, Ellsworth, The climatic factor as illustrated in arid America: Carnegie Inst. Washington Pub. 192, p. 109, 1914.

[6] Douglass, A. E., Some aspects of the use of the annual rings of trees in climatic study: Smithsonian Inst. Ann. Rept., 1922, p. 236.

specimens were found that ranged from 350 to 600 years old, one, in the Fifield Basin, grew for 1,600 years before finally fallin victim to a farmer's need for fuel. Several pines from 300 to years old were found near the edge of the valley, where the pl merge into the adjacent foothills.

In all 20 specimens were cut from different trees scattered over Snake River Plain. (See pl. 8.) Pertinent data regarding th specimens follows:

1. Craters of the Moon. Limber pine. Taken from Craters of the M National Monument, Idaho. Cut by Harold T. Stearns in 1926. Tree d when specimen taken, having been killed by lightning about 2 years bef Needles still hung from the branches. Grew in a crack at the edge of a re lava flow where there would be a tendency for a little water to accumulate but snow to linger. The rock is so permeable that rain and melting snow would away rapidly.

2. Massacre Rocks. Juniper. Taken 10 miles west of American Falls, Ida on the north side of the Snake River, near the place commonly known as "M sacre Rocks." Cut by Harold T. Stearns and W. G. Steward in the fall of 1 from a living tree. Grew on a high lava bluff overlooking the river. The la is partly covered with blow sand, and many juniper trees are growing h Moisture is retained in the blow sand, which fills the lava cracks, for lon periods than it would remain, where not so much fine sand or soil is presen Center of tree decayed.

3. Black Lava. Western juniper. Taken from a point about 12 miles southwe of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from living tree and hauled to his ranch in the NE¼ NE¼ sec. 26, T. 2 N., R. 36 E., in the winter of 1927 or 1928. Specimen cut from tree by W. G. Steward in the spring of 1929. Conditions surrounding the place where this tree stood are not known except that it was cut on the bare lava beds.

4. Fifield. Western juniper. Taken from the bare lava beds about 15 mile southwest of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from a living tree and hauled to his ranch, in the winter of 1928. Specimen sawed from tree by Harold T. Stearns, W. G. Steward, and H. G. Haight in the spring of 1929. Grew in a crack at the margin of a lava ridge. By far the oldest and best specimen of juniper known to have been taken in Idaho.

5. Woodville. Western juniper. Taken about 12 miles southwest of Idaho Falls, Idaho, in the Fifield Basin area. Cut by Steve Krolik from a dead tree and hauled to his ranch in the winter of 1927 or 1928. Specimen taken from tree by W. G. Steward in the spring of 1929. Conditions surrounding the place where this tree stood are not known except that it was cut on the bare lava beds.

6. Wapi I. Western juniper. Taken 20 miles due west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. Grew at foot of lava ridge and approximately at central western edge of a grove of junipers estimated to cover 160 acres. Would receive benefit of drifted snow. Lava very broken and permeable. Seepage would carry any rain or melting snow away rapidly. Center of tree decayed.

7. Wapi II. Western juniper. Taken 20 miles west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. This tree grew about 150 feet west of Wapi I, farther from the foot of the ridge. Center of tree decayed.

8. Wapi II. Western juniper. Unpolished.

Wapi III. Western juniper. Taken 20 miles west of American Falls, Idaho. Cut by W. G. Steward and H. G. Haight in October 1931 from a living tree. This tree stood 200 feet southwest of Wapi I, farther from the foot of the high ridge that encircles this grove. Conditions same as described under Wapi I. Center of tree decayed. At the time these specimens were cut, a few posts had been cut from this grove by nearby dry-farmers. Late in the fall of 1932 most of the trees in this grove had been taken for fuel.

10, 11, 12. Graham Canyon. Mountain mahogany. Taken 4 miles west of Almo, at what is called locally "Graham Canyon." Cut by W. G. Steward and H. G. Haight in November 1931 from living trees. Grew on a steep hillside of decomposed rock with a slope to the southwest. Would retain little moisture. Rings of these specimens could not be counted or measured, except for short disconnected periods, because of an overlapping or blurred growth.

13. Minidoka. Western juniper. Taken 24 miles west of American Falls, Idaho. Cut by Viggo Christofferson and Lars Larsen in December 1931 from a living tree. Grew in the center of a small grove of juniper trees on silt-covered lava bed that was sheltered by a high lava ridge.

14. Almo. Piñon. Taken in Graham Canyon 4 miles west of Almo, Idaho. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Grew on the southwest slope of a steep hillside of decomposed rock. This slope is exposed to the hot summer sun, and little moisture would be retained. Rain and melting snows would no doubt run off rapidly.

15. Cedar Creek. Western juniper. Taken on the south rim of Cedar Creek, 2 miles below Cedar Creek dam and about 8 miles southwest of Roseworth, Idaho. Slightly decayed at center. Cut by H. G. Haight and Stella Perrine Haight in October 1932 from a living tree. Grew on a rock shelf 12 feet below the top of the rim of Cedar Creek Canyon, which is about 200 feet deep at this point. Partly protected and subject to some snowdrift. Otherwise in a decidedly dry location. The only tree for miles around except those in the bottom of the canyon.

16. San Jacinto I. Juniper. Taken 14 miles southeast of San Jacinto, Nev., on Trout Creek. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Decayed at center. Grew on the top of a high rocky ridge overlooking Trout Creek. A large number of junipers in this vicinity. Three selected from the decidedly unfavorable location. No place to collect or hold precipitation and at the mercy of the winds and temperature.

17. San Jacinto II. Juniper. Taken 14 miles southeast of San Jacinto, Nev., on Trout Creek. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932. This tree killed by fire and decayed at center. Grew on the steep side of a rocky gulch about 600 feet southeast of San Jacinto I.

18. San Jacinto III. Juniper. Taken 14 miles southeast of San Jacinto, Nev. Cut by H. G. Haight and H. G. Haight, Jr., in October 1932 from a living tree. Slightly decayed at the center. Grew in a pass between two higher ridges. Stood apart from the other trees. About three-quarters of a mile southwest of San Jacinto I and II.

19. Bliss. Sage brush. Taken about 8 miles northwest of Bliss, Idaho, near the Elmore County line. Cut by H. G. Haight in October 1932 from a living shrub. About 104 years old. This is one of several samples that have been gathered for study in the future.

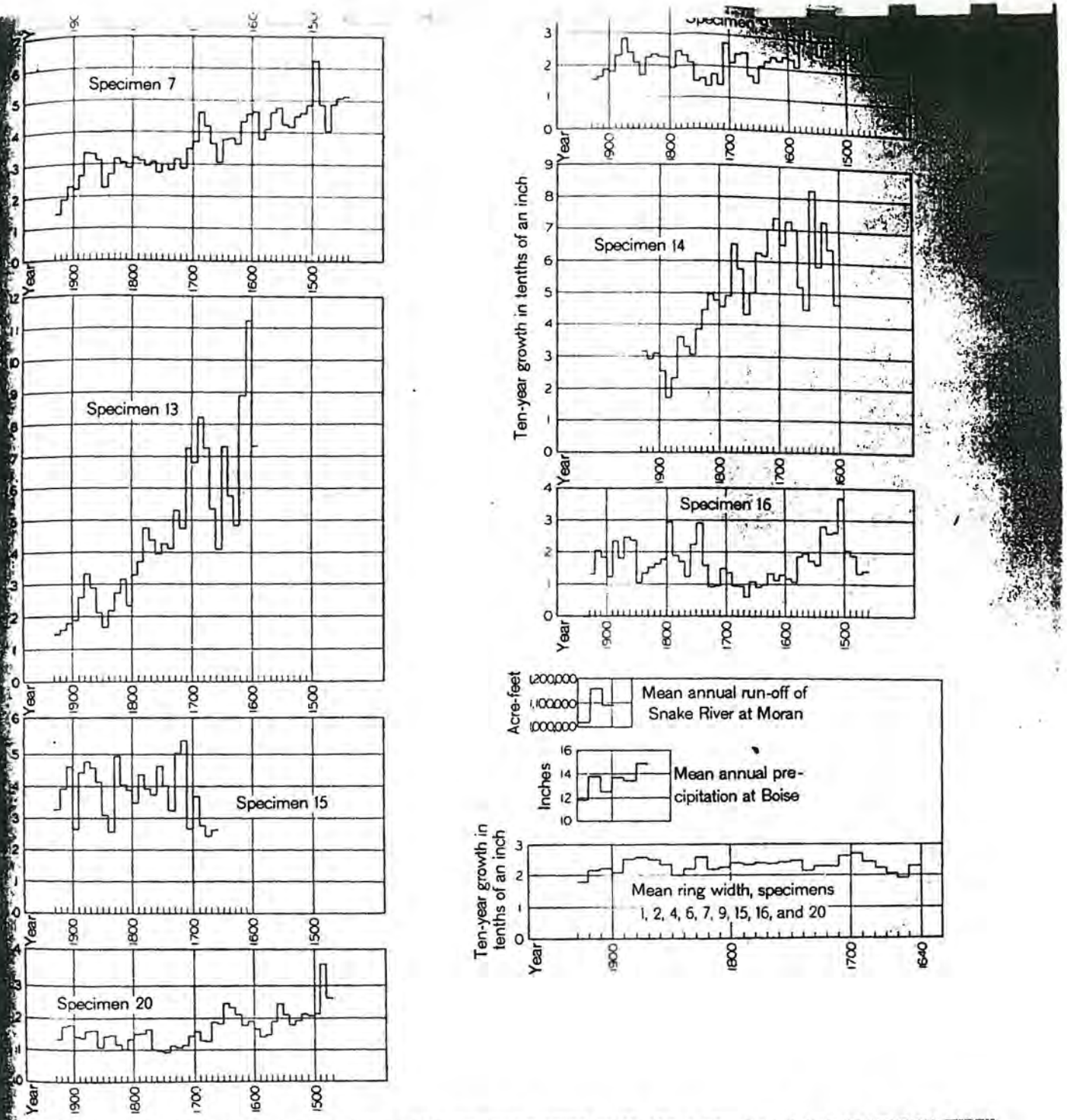
20. Blue Lakes alcove. Western juniper. Taken 5 miles north of Twin Falls, Idaho, on the north side of Snake River Canyon and the south side of the Blue Lakes Cove. Cut by H. G. Haight and Stella Perrine Haight in October 1932 from a living tree. Decayed at center. Grew on a large shelf 60 feet below the main rim of the Snake River Canyon and on a sharp nose of rim rock that projects

nyon proper and the Blue Lakes Cove. This was
this dry rocky shelf. Conditions are anything but
dy.

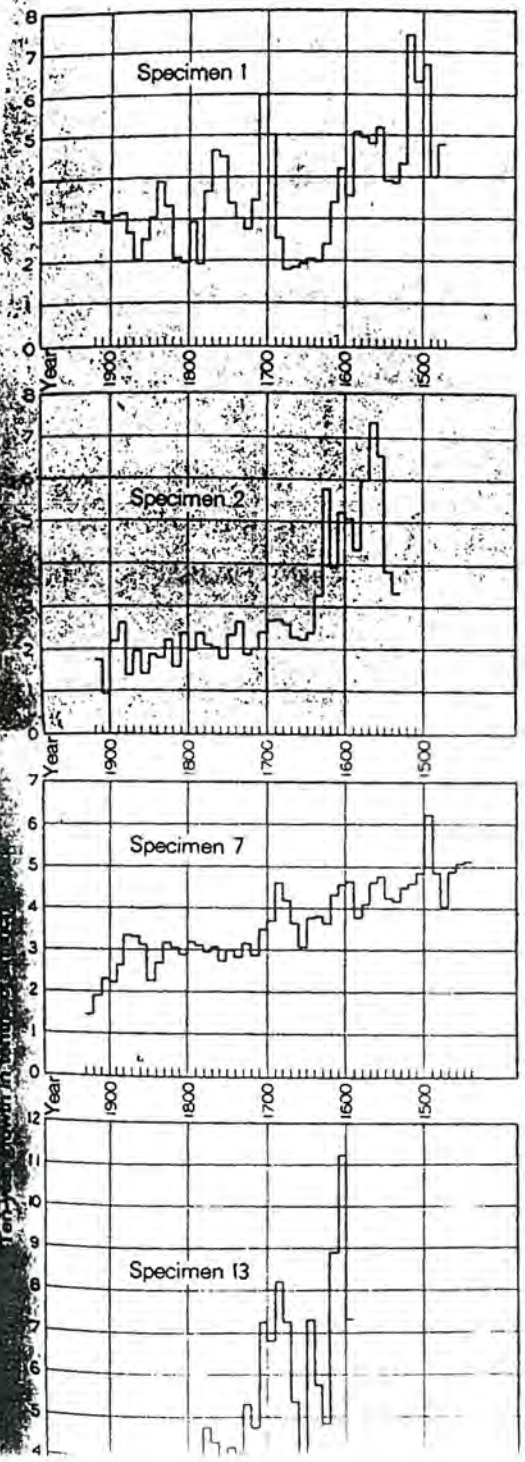
nstructed by W. G. Steward and H. G. H
the ring widths of all the specimens. The diff
rdwood piece grooved for runners; a steel ro
d with 20 threads to the inch; a 12-inch w
r-level recorder, divided into 10 equal parts, w
d into 10 equal parts; an indicator point; a m
hich is connected to the threaded rod and m
s, a specimen board to which the specimen
ntersunk screws driven in from the under
or holding magnifier; a three-legged low-p
g glass with eyepiece of heavy brown paper gl
of the upper lens and an auxiliary lens with g
he lower surface fitted into and held between
; a small light attached to the magnifier arm
ctor, which throws light onto the specimen a
l a counter attached to the outside center of
evolutions.

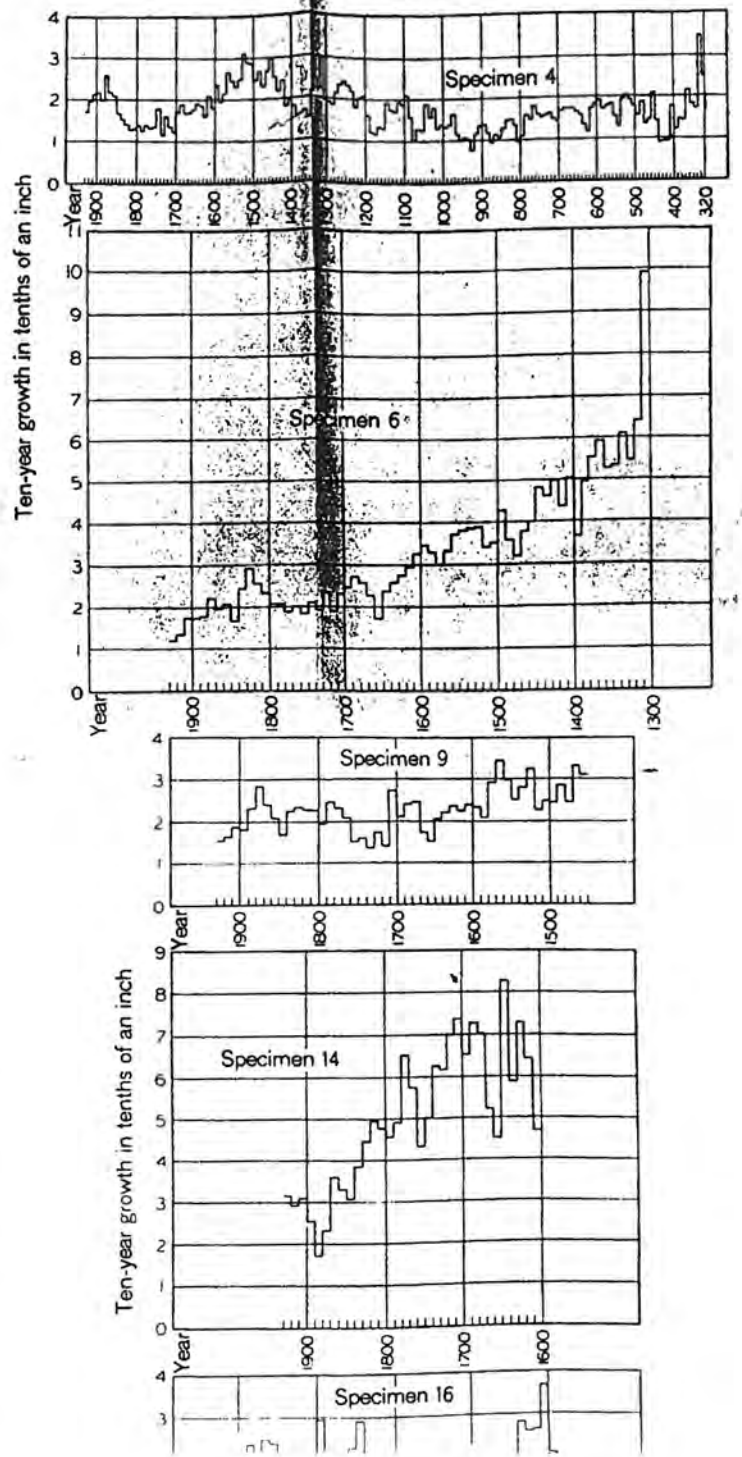
lvanometer, the total ring widths were measur
od for a selected number of specimens and
plate 8. The specimens were selected for clea
th, locality, and freedom from distorted grow
of the Fifield juniper (pl. 8, specimen 4),
ngth, affords a basis of comparison with oth
ll the other trees examined began their life d
th period, as indicated by the Fifield reco
a larger growth in 10-year periods during th
t 100 years. Several, particularly specimens
steadily decreasing growth with advancing a
in considerable part from other causes than l
n in growth of nearby trees is shown by sp
representing growth of trees within a few hu
er.

ect of erratic growth records of individual tre
growth during the early years of the life of t
gram showing mean ring width of the vario
300 years was prepared (pl. 8). In prepari
13 and 14 were excluded because their grow
ffected to a great extent by causes other th
wth records prior to 1640 A. D. were elimina
e to early age growth of some of the specimen
ipitation at Boise, the only station adjacent
ng-time precipitation record, and the run-off



GRAPH SHOWING WIDTH OF RINGS IN 11 TREES FROM THE SNAKE RIVER PLAIN AND A GRAPH OF THE AVERAGE RING WIDTH OF 9 TREES IN COMPARISON WITH PRECIPITATION AT BOISE AND THE FLOW OF SNAKE RIVER AT MORAN.





ATER OF SNAKE RIVER PLAIN, IDAHO

nyon proper and the Blue Lakes Cove. This was on
his dry rocky shelf. Conditions are anything but fa
dy.

nstructed by W. G. Steward and H. G. Ha
the ring widths of all the specimens. The differ
rdwood piece grooved for runners; a steel rod
ed with 20 threads to the inch; a 12-inch wh
-level recorder, divided into 10 equal parts, wh
d into 10 equal parts; an indicator point, a m
hich is connected to the threaded rod and mo
rs; a specimen board to which the specimen
untersunk screws driven in from the under s
for holding magnifier; a three-legged low-po
g glass with eyepiece of heavy brown paper glu
of the upper lens and an auxiliary lens with gr
the lower surface fitted into and held between
; a small light attached to the magnifier arm
ctor, which throws light onto the specimen at

ake River at Moran, above irrigation diversions, for years of ble records. The precipitation and run-off trends are in sub- al agreement. The precipitation record and the mean ring- record both show a general downward trend from 1870 to date, gh the two records do not always show the same relation between nt decades.

rding to the mean ring-width diagram (pl. 8), the decade 0 was less favorable than any similar period during the last ars, although many of the individual tree diagrams (pl. 8) show es less favorable than that of 1920–30.

SOIL

rly half a million acres of the Snake River Plain consists of bare, and fissured lava with practically no soil covering, and a still area consists of lava with a scant covering of wind-blown soil nges in depth from only a few inches to a foot. Considerable ns of the region, however, are underlain by soils of good depth, places 6 to 8 feet.

soil that covers the lava plain between the river and the ains on the north is a fine loess, consisting essentially of minute les of quartz with slight amounts of calcium carbonate as a nting material. The loess originated chiefly as dust blown by the ailing westerly winds from the lake beds to the west, but some of dust was derived from the alluvium of tributary streams and from anic ejecta. Its slow rate of accumulation is indicated by the fact the most recent lava flows in the region, probably not less than years old, are still free of soil. Only the cracks in their surface evidence of some desposits of wind-blown material.

rule the soils in the region are fertile and are very productive irrigated. Several studies of the soils in the region have been ished.[7]

ong the borders of the plain, near the mouths of tributary streams, along the Snake River, occur extensive gravel deposits which yield derable road-surfacing material and gravel for concrete. In this el, particularly in the section of the main river channel from Black- to the mouth of the Big Wood River, near Bliss, appreciable

[7] Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, pp. 136-137, 1902.
Blandon, W. E., Soil survey of the Blackfoot area, Idaho: U. S. Dept. Agr., Bur. Soils, Field Operations, 1904, pp. 1027-1041, 1904.
Lewis, H. G., and Peterson, P. P., Soil survey of the Portneuf area, Idaho: Idem, 1918, pp. 1-52, 1921.
Youngs, F. O., Baldwin, Mark, Kern, A. J., and McDole, G. R., Soil survey of Minidoka area, Idaho: Idem, 1922, pp. 859-902, 1928.
Baldwin, Mark, and Youngs, F. O., Soil survey of the Twin Falls area, Idaho: Idem, 1921, pp. 1367-1394, 1924.
Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, p. 118, 1920.
Poulson, E. N., and Thompson, J. A., Soil survey of the Jerome area, Idaho: U. S. Dept. Agr., Bur. Chemistry and Soils, ser. 1927, no. 16.

quantities of gold are found, and extensive placer-mining operations were carried on in former years. The gold is so fine, however, that its recovery proved difficult, and the placers were abandoned. In recent years, however, attempts to obtain gold from these placers have been renewed. Above American Falls the irrigated lands on both sides of the river have soils that are mainly of alluvial origin.

South of the Snake River, from a point near Pocatello to a point beyond King Hill, occur extensive lake beds, in places more than 1,000 feet thick. Except in a few favorable localities the benches underlain by these lake beds are not readily susceptible of irrigation because of their topography and height above the river.

Residual soils formed by the decay of the underlying rocks occur to some extent in the mountains bordering the Snake River Plain, but the basalt that underlies most of the plain is relatively so recent in origin that it has not disintegrated sufficiently to make any appreciable contribution to the soils of the region. The basalt eroded from the Snake River Canyon has contributed only in minor degree to the alluvial deposits along the river except at the downstream sides of former lava dams as in Hagerman Valley or near King Hill.

In a few areas shifting material consisting mostly of quartz sand forms the surface soil. Most prominent is the sand-dune area between the Birch Creek Sink and the Big Bend Ridge. In this area migrating sand hills attain heights of 100 feet or more and cover many square miles. From Wendell southward to the Snake River Canyon the soil is mainly silt or fine sand, on the whole well adapted to cultivation under irrigation. There are small areas of shifting "blow sand", not well adapted. Similar areas of blow sand occur locally in other areas. From King Hill eastward isolated sandy knolls rise 10 feet or more above the plain and support a sufficient cover of vegetation to prevent shifting of the sand.

CROPS AND VEGETATION

Irrigated lands on the Snake River Plain produce a wide range of diversified crops common to the intermountain region, among which the staples are alfalfa and other hay crops, wheat, oats, barley, potatoes, corn, beans, sugar beets, garden vegetables, and some tree and bush fruits. The largest acreage is in alfalfa. Of the principal crops potatoes have yielded the highest average acre value. Much of the hay and grain crop is used locally for stock feed. Crops entering into interstate commerce include potatoes, onions, beans, clover, small grains, alfalfa seed, peas, and head lettuce. Along the borders of the plain and in the tributary valleys up to the zone where frosts are likely to occur in any month of the year, irrigated areas are devoted largely to the growing of alfalfa, native grasses, small grains, and garden vegetables.

Much of the uncultivated area of the plain supports considerable native vegetation, some of which is valuable for grazing. Sagebrush (*Artemisia tridentata*) predominates and lends a dusty-green hue to the landscape. At the lower limits of rainfall the moisture naturally available for plant growth is so little that practically desert conditions prevail, and the natural growth includes transition desert shrubs, of which rabbitbrush is the most conspicuous. At the higher limits of rainfall a considerable undergrowth of grass is associated with the sage. Where the rainfall is from 15 to 25 inches a year the natural vegetation consists principally of the Idaho and wheat bunch grass and shrubs that furnish excellent spring, summer, and fall range. Grain crops, principally wheat, have been raised without irrigation on large areas of this type.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCKS

SUMMARY

The Snake River Plain is commonly regarded as a structural depression that has been filled mainly by Pliocene and later basalt and kindred volcanic rocks which are locally intermingled with sediments. Subsidence continued intermittently until Pleistocene time, so that the older rocks filling the depression are down-warped in varying degree and locally broken by faults. The basalts covering the surface of the plain are nearly all Pleistocene and Recent and they are practically undisturbed. This great mass of volcanic rock, about 95 percent of which is in the area described in this report, is termed the "Snake River basalt."[8] In numerous places on the borders of the plain rhyolitic flows and pyroclastic and related rocks emerge from beneath the basalt. Locally there is evidence that similar rocks extend well under the plain. Estimates as to the age of the rhyolitic rocks by different authors and in different localities range from early Pliocene to late Oligocene. This wide range in age assignment results in part from inadequate data. It may well be, however, that exposures in different parts of this large region, even though broadly similar in lithology and stratigraphic relations, may record eruptions at materially different times. Beneath the Tertiary strata in the nearby mountains lies a complex aggregate of sedimentary rocks of which the oldest is generally of pre-Cambrian age, and the youngest is either Carboniferous or Mesozoic. The youngest are extensively exposed in the mountains bordering the plain. These rocks are locally interbedded with and intruded by igneous rocks of several different kinds and ages.

[8] Russell, I. C., op. cit., p. 59.

Volcanism and deformation have thus played dominant parts in the development of the present Snake River Plain, although locally stream erosion by the Snake River and its tributaries, as in the Snake River Canyon, and wind action, as in the Mud Lake region, have had noticeable effects. These diverse processes, the results of which can as yet be evaluated in detail only in certain small areas, have, in a general way, produced a great basin floored with relatively impermeable rock and filled with a variety of materials, many of which are readily permeated by ground water. The many streams issuing from the mountains and the Snake River itself provide a large supply of water for the filling of the partly enclosed underground reservoir thus created. The volcanic processes are inherently catastrophic, intermittent, and irregular, their results in this region have introduced many complexities into the behavior of the ground water. Consequently, an especially thorough understanding of geologic details is required in connection with the study of problems of water supply. Over large areas of the Snake River Plain the lack of stream incisions renders it impossible to examine any but the most recently formed rocks, so that many local details are undecipherable. It so happens, however, that most such areas are of relatively small agricultural value, and large stretches of them are unsuited for cultivation of any kind, so that the incompleteness of knowledge in regard to them is of comparatively minor economic importance.

The salient features of the geology of the Snake River Plain are shown in plate 4. This map is based primarily on data gathered by H. T. Stearns during the present study and related investigations. For areas not covered in the course of these studies, mainly along the mountain border, other data, principally in published reports of the United States Geological Survey and the Idaho Bureau of Mines and Geology, have been utilized. The mapping of the northeastern portion of the area shown in plate 4 is based on a geologic map of the Mud Lake region, one of the parts of the plain studied in especial detail, to be published elsewhere.[9] The geology along the canyon of the Snake River from a point below Blackfoot to King Hill was mapped in detail, and those sections of the canyon along which the data obtained are too complex to be adequately portrayed in plate 4 are shown on a larger scale in plates 5 and 6.

The first of the two following tables is intended to aid in grasping the outstanding features of the stratigraphy of the Snake River Plain. The second table summarizes the stratigraphy along the part of the canyon of the Snake River that was studied in detail.

[9] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho

Geologic age	Geologic unit	General character	Water-bearing characteristics
	Dune sand and loess (not distinguished in mapping from the rock it covers).	Light-colored wind-blown sand, consisting chiefly of round quartz grains and some particles of ash. The loess is somewhat intermingled with soil. Dunes are rare except locally, as in the area east of Mud Lake, but loess covers most of the Snake River Plain to depths of about 10 feet or less. Still in process of formation.	Generally above the water table. Where the loess lies in the zone of saturation, it is so fine-grained as to be relatively impermeable. Extensive deposits in such situations commonly act as confining or perching beds. Dune sand in the zone of saturation carries water but generally causes trouble in drilling by running into the well.
	Landslides and talus.	The landslides form hummocky topography, mainly in canyons, and the talus forms aprons at the foot of cliffs. Both consist largely of jumbled blocks of rock. They are mapped only along the canyon of the Snake River.	Unimportant with relation to water because of the small size of individual masses.
	Younger alluvium (not separated from older alluvium on the maps).	Sand and gravel derived from the erosion of preexisting rock and alluvial deposits, confined to the small recent flood plains along present stream channels. Locally contains unfossilized bones of mammoths and extinct bison.	Commonly contains considerable water at shallow depths, but because it occupies small areas it is of little value as a source of water supply.
	Black basalt and associated fragmental deposits.	Fresh black basaltic flows and fragmental deposits associated with them. The flows consist of about equal amounts of aa and pahoehoe and are free from covering of soil or loess. The lava in the Craters of the Moon National Monument is the youngest of all.	All these recent lavas lie above the water table. They are very permeable and serve as intake areas for ground-water recharge. Locally they contain pools of water in caves and crevices, derived from melting ice, which are valuable as watering places in the desert.
	Local		
	Older alluvium (not differentiated from younger alluvium in mapping).	Floors most of the tributary valleys as well as the canyon of the Snake River. Consists of sand, gravel, and locally boulders. Differs from the younger alluvium chiefly in lying topographically higher on terraces. In numerous places contains bones of elephants, camels, sloths, and bison, as yet scarcely fossilized.	A good water-bearer wherever the topographic situation is suitable. Commonly contains water at shallow depths.
Pleistocene.	Lake beds.	Largely clay and silty clay. Locally sandy where stream deposits are included. In part at least as young as the older alluvium, but in part interfingers with Pleistocene basalt, mostly made up of flows high in the sequence. Locally interbedded with basalt and tuff. Distinguished only near Terreton, Market Lake, and American Falls.	Yield water to wells only in the local sandy parts, mostly nearly impermeable. Intercalated basalt flows are permeable and locally cause springs.

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho—Continued

Geologic age	Geologic unit	General character	Water-bearing characteristics
Pleistocene—Con.	Pre-Wisconsin glacial deposits.	The only deposits of glacial origin mapped within the region are those near Ashton. Outwash plains occur near Island Park and in Camas Meadows. These consist of bedded sand and gravel, commonly overlain by gumbo clay.	Except where clayey, yield water copiously to shallow wells.
Late Pleistocene and possibly locally early Recent. In part contemporaneous with Pleistocene sediments listed above.	Younger basalt flows and related cones, older than the black lava listed above (not everywhere distinguished from the older flows).	Mainly basaltic lava. Flows are locally mantled by and interbedded with loess and soil. Many of the buttes on the plain, some of which are composed of cinders, are the source of these flows. Along the canyon of Snake River several members have been distinguished.	Highly permeable because of the presence of numerous openings of diverse kinds.
	Local.		
	Tuff.	Tuff and unconsolidated lapilli interbedded with basalt. Mapped only in and near Menan Buttes, western Madison County.	Yields water satisfactorily to wells where suitably situated.
	Local.		
Earliest Pleistocene.	Basalt flows.	Blue and gray basalt, with and without feldspar and olivinephenocrysts. Dominantly pahoehoe; contains numerous caves. Thin and restricted loess and clay beds locally intercalated in the basalt. Most of the flows originate from definite cones north of the Snake River, and some fill old tributaries of the river.	Highly permeable and constitute valuable aquifers. Almost without exception water is present in them, the depth depending on the position of intercalated or underlying impermeable beds or other local conditions.
	Unconformity.		
Pliocene and Pliocene(?).	Lake beds and other sediments.	Sedimentary beds at several horizons, older than the Pleistocene basalts. Mainly clay, silt, and sand, with local gravel deposits. In part consist of reworked tuff. A little basalt and tuff intercalated locally. Some of the beds contain Pliocene vertebrate fossils. The age of others is less precisely fixed by their relations to other formations. Mapped near Medicine Lodge Creek, in Clark County, and at several places along the canyon of the Snake River, especially in Hagerman Valley.	The fine-grained beds, which predominate, are relatively impermeable, but the gravel and intercalated basalt constitute aquifers.
Pliocene.	Basalt and related volcanic rocks.	Mainly blue, black, brown, and greenish weathered basalt. Some tuff and other pyroclastic rocks and locally a little intercalated clay and gravel.	Much of the basalt and coarser pyroclastic rocks are permeable and constitute fair aquifers.
	Unconformity.		
Miocene(?).	Intrusive rocks.	Granite and related porphyrites, which cut the Challis volcanic rocks in Blaine and Butte Counties and may be the sources of some of the rhyolitic flows.	Not so situated as to have any appreciable effect on the ground water of the Snake River Plain.

Generalized stratigraphic section of the Snake River Plain east of King Hill, Idaho—Continued

Geologic age	Geologic unit	General character	Water-bearing characteristics
Miocene(?)—Con.	Flows and related rocks.	Include the so-called "rhyolitic rocks" and also the Challis volcanics (Oligocene?) where that formation has been traced into the regions here discussed. Mainly latitic, rhyolitic, and andesitic flows, with large amounts of pyroclastic material commonly welded and locally basalt. Within this region the age is not positively fixed, except that the beds are everywhere older than the contiguous basalt flows of the Snake River Plain.	Not very permeable, except where fractured.
	Great unconformity.		
Miocene rocks (Tertiary?, Mesozoic, Paleozoic and pre-Cambrian?).		The sedimentary and intrusive rocks that compose the mountains and doubtless underlie the Snake River Plain below the Tertiary volcanic rocks.	Relatively impermeable, except where fractured. Form the containing walls of the ground-water reservoirs of the Snake River Plain.

Generalized stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho [1]

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
	Wendell Grade basalt.	25±	A dense black olivine pahoehoe basalt with a soil cover too thin for farming. It covers many square miles near Wendell and is later than the Snake River Canyon, because three branches of this flow cascaded over the rim at Hagerman Valley.	Very permeable but lies above the zone of saturation.
	Local.			
	Minidoka basalt.	30±	A vesicular blue pahoehoe basalt containing tiny crystals of olivine and feldspar and thinly covered with loess. It overlies alluvium at Minidoka Dam and crops out for 5 miles along the north shore of Lake Walcott Reservoir. It displaced the Snake River to the south.	Very permeable and causes leakage from Lake Walcott Reservoir.
	Local.			
Pleistocene.	Sand Springs basalt.	500±	A prominent pahoehoe lava flow, which enters the Snake River Canyon near Sand Springs. From this place it flowed downstream for at least 14 miles and is now preserved as lava benches along the river. It fills a former deep canyon of the Snake River from Paul to Sand Springs. (See pl. 9.) On the upstream side of this lava dam were deposited the Burley Lake beds, which underlie the Minidoka project and are overlain by the Minidoka basalt.	Very permeable and serves as a channel for the movement of ground water under the North Side Twin Falls tract. Many of the large springs are fed by it. Below Thousand Springs water is found in the bottom of the basalt except where it forms isolated small benches along the Snake River. These benches do not contain water. The Burley Lake beds are in part permeable, but water does not move through them fast enough to prevent drainage problems on the Minidoka project.
	Local.			

[1] Each formation along Snake River is underlain by a local erosional unconformity but superposition in the table does not necessarily mean superposition in the field.

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pleistocene—Continued.	Bliss volcanics.	100±	Form dikes, a cone, and a flow. The dikes are dense, narrow, and short, and the cone is composed of comminuted basaltic glass and black cinders. Pillow structure and fragmental glassy porphyritic lava characterize the flow. Phenocrysts of olivine and feldspar occur in a glassy brown groundmass free from pyroxene. It crops out at numerous places for 7½ miles downstream in the Snake River Canyon below Malad River.	Sullivan, Bliss, and unnamed springs from this basalt. It permeable but is locally a water bearer cause it occurs as isol patches above the table in most places even these springs prob have their source in Madson basalt.
	Local.			
	McKinney basalt.	500±	A decidedly porphyritic grayish-black pahoehoe basalt containing phenocrysts of fresh green olivine and long laths of plagioclase. It covers an extensive area north of Bliss and displaced parts of the Big Wood and Snake Rivers between Bliss and King Hill.	Except where it fills an cient canyon of the S River it lies above the of saturation, and all cations point to a small amount of water, even in the occupying the buried ley. This is not due to of permeability but adequate intake area.
	Local.			
	Thousand Springs basalt.	100±	An olivine basalt occupying a buried canyon of the Snake River north of the present one and shallower. It is filled with tubes, and open contacts occur between successive layers.	This basalt is very perm and is the source of Springs, Thousand Spr and all other springs do stream to Riley Sprin
	Local.			
	Malad basalt.	400±	A black basalt containing feldspar, olivine, and pyroxene. It fills an ancient canyon of the Snake River north of the present one. Sufficient soil rests on its surface to make good farm land.	A very permeable bed The source of Ma Springs and of the spr that feed Billingsly Cr Water occurs in it ev where from 50 to 400 below the surface.
	Local.			
	Madson basalt.	200±	An extremely fine grained black basalt in places very evenly jointed. It fills a former canyon either of Snake River or Big Wood River carved in the Hagerman lake beds.	Too tightly jointed in places to be a prolific w bearer but at the base open and permeable. probably the source Steele, Madson, Sulli and Bliss Springs.
	Local.			
	American Falls lake beds.	150±	Buff even-bedded clay and sand, only partly consolidated. Near the top occur local pebbly lenses, and about 60 feet below the top there is a 6-foot bed of laminated basic tuff. The deposits change northeastward into coarser sediments. Between American Falls and Gibson Butte along the north side of the Snake River aphanitic gray pahoehoe about 10 feet thick is interstratified with the sediments.	The finer-grained beds relatively impermea but near Springfield a ing well yields a small ply of water from coarser beds. The calated basalt membe the source of nume large springs on the Sp field-Aberdeen tract.
	Local.			
	Cedar Butte basalt.	200±	An aphanitic blue pahoehoe basalt with fresh green olivine phenocrysts. It dammed and displaced the Snake River near Massacre Rocks and now forms imposing cliffs along the Snake River and Lake Channel. Its surface supports considerable vegetation.	Permeable but in most p lies above the zone of ration. However, a Lake Channel springs from it, indicating water occurs in its lo part, or in general abou feet below the surface.
	Local.			

Detailed stratigraphic section of the rocks along the Snake River between King Hill and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing characteristics
Pleistocene—Continued.	Early undifferentiated basalts.	500±	Blue and gray basalt flows, generally containing phenocrysts of olivine and feldspar and covering most of the Snake River Plain and forming a considerable part of the Snake River Canyon. Few individual beds exceed 50 feet in thickness. They contain numerous caves and are predominantly pahoehoe. A few thin and local loess beds are found intercalated in the series. The undifferentiated basalt shown in plates 5 and 6 originated chiefly from cones on the south side of the Snake River and in places fills ancient tributaries of the river.	These flows are valuable aquifers of southern Idaho. Almost without exception water is found in them at different depths, depending upon the depth to the intercalated or underlying impermeable beds.
	Erosional unconformity.			
Upper Pliocene.	Hagerman lake beds.	600±	Nearly level and partly consolidated buff to white clay and silt beds which in most places contain a gravel cap 20 feet thick and in some places pebbly lenses and sandy beds near the top. Along a considerable part of the Snake River Canyon between Salmon Falls Creek and King Hill there is a thin intercalated basalt flow 200 feet below the top, or a basaltic tuff bed at about the same altitude. Near the mouth of Salmon Falls Creek a bed of diatomite 20 feet thick occurs only a little above the tuff bed. The lake beds contain in places well-fossilized bones of mammals and numerous fresh-water shells.	The sedimentary parts of the series are impermeable and poor aquifers, but the intercalated basalt contains water and gives rise to landslides, segments of it sliding on the saturated clay beneath it during wet periods.
	Banbury volcanics.	300±	Extensive outcrops of this basalt occur along the canyon walls between Salmon Falls Creek and Blue Lakes. It is dark brown but commonly has a greenish hue. Its color is due largely to weathering, and even in a hand specimen it is easily distinguished by its iron stains from any younger basalts. The flows are massive and continuous. Closely associated with it is the tuff of the Riverside Ferry cone. At one place a bed of pebbly alluvium containing a fossil camel bone was found interstratified with it.	A relatively poor water bearer, but numerous seeps have issued from it since irrigation started on some of the land above it. In some places it forms the basement of the great underground reservoir of the Snake River Plain.
	Unconformity—			
Middle (?) Pliocene.	Raft lake beds.	200±	Partly consolidated buff-colored beds of clay, silt, and sand, generally in lenticular form and in places filled with concretions. Weather to a brown sandy loam and are eroded into rounded rolling hills except along the Snake River, where they form a terrace.	Contains water in small quantities except where it forms benches above the water table along the Snake River.
	Rockland Valley basalt.	250±	Series of even-bedded blue and black basalts that show considerable weathering. Intercalated with them is at least one bed of clay 15 feet thick. All are tilted about 4° NW.	Permeable but has not been studied sufficiently to determine its water-bearing value.
	Unconformity—			

Detailed stratigraphic section of the rocks along the Snake River between Kin and Blackfoot, Idaho—Continued

Geologic age	Formation	Thickness (feet)	General character	Water-bearing charac
Pliocene (?) (lower Pliocene?).	Massacre volcanics.		Massacre Rocks is a neck or feeder of a former large cone composed chiefly of pyroclastic debris and a few lava flows. The cindery tuff is exposed for a distance of 11 miles upstream from Massacre Rocks along the Snake River but for only 2 miles downstream. It is well consolidated and is red to brown. In places it contains angular fragments of the underlying older formations. Faulting has greatly disturbed this series. There is one persistent fine-grained blue basalt flow 23 feet thick at the base of the series underlain by 6 inches to 2 feet of partly baked loess soil.	The coarser tuff and th are permeable and less waterbearing. and Mary Fran Springs issue from basalt member.
	—Local.—			
	Eagle Rock tuff.	35±	Well-defined sequence of rhyolitic tuffs crops out at different places along the Snake River between American Falls and Massacre Rocks. The sequence from top to bottom consists of red felsitic welded pumice 6 inches thick, welded obsidian tuff 21 feet thick containing spherulites and lithophysae; black comminuted glass only partly consolidated at the bottom, grading upward into a hardened dull obsidian tuff 4½ feet thick; banded gray to white tuff of fine texture 9 feet thick, in places pisolitic. The whole was evidently laid down in rapid succession by a series of explosions from the same volcano.	Only slightly permeabl since the construction American Falls Res small amounts of wate found seeping th them.
	Neeley lake beds.	100±	Flesh-colored to brown lacustrine deposits consisting partly of reworked tuffs. Evenly bedded and commonly sandy in texture. Their base is not exposed.	Relatively impermeable
	Unconformity—			
Miocene (?) (upper Miocene?).	Pillar Falls mud flow.	40±	Red and black andesitic waterworn pebbles and boulders intermingled with compact ash and soil. The top few inches is baked by the overlying basalt. Fills the irregularities in the underlying andesite.	Only slightly permeable.
	Erosional unconformity			
	Shoshone Falls andesite.	200±	Black and purple glassy porphyritic columnar jointed or platy andesite; weathers pinkish brown. On it is a dark soil about 1 foot thick.	Impermeable.
	Unconformity—			
Paleozoic.	Carboniferous.	Not measured.	Isolated outcrops of blue and buff compact limestone.	Contains water in joints crevices but has no defined water table.

ROCK FORMATIONS AND THEIR WATER-BEARING PROPERTI

PRE-MIOCENE ROCKS

The pre-Miocene rocks in the mountains bordering the Snake Rive Plain include a great variety of sedimentary and igneous rocks. The are alike in being thoroughly consolidated and, in comparison wi

of the younger rocks of the plain, poorly permeable. Except ng faults and other fractures, they appear everywhere to be unable transmit water with sufficient readiness to have any material aring on problems of water supply in the Snake River Plain.

MIOCENE (?) ROCKS

GENERAL CHARACTER

In the mountains on both sides of the Snake River Plain there are rge quantities of lava and associated pyroclastic rocks, for the most rt materially older and more silicic than the basaltic flows that nderlie most of the plain. Part of the rocks of this character north the plain belong to the Challis volcanics.[10] In most places the hallis volcanics are dominantly latitic and andesitic, with basalt cally abundant and considerable rhyolite high in the formation. In veral places clastic beds composed dominantly of tuff are associated th the flows and locally make up a large part of the formation. The ly rocks of this character distinguished on plate 4 are those near head of Pass Creek, in the Lost River Range. The small mass re may have been brought to its present relatively low altitude by ulting. Most similar beds are beyond the area mapped. The total ickness of the formation is commonly several thousand feet and cally over a mile. Fossils from beds high in the sequence in Custer and Lemhi Counties, according to unpublished studies by R. W. Brown, indicate that the Challis volcanics here are of late Oligocene or early Miocene age. This tentative assignment accords with the ratigraphy and structure of the formation in Custer, Blaine, and Lemhi Counties and adjacent areas.[11]

Along the borders of the Snake River Plain and in scattered exposures within its area, there are large quantities of dominantly silicic volcanic rocks, in part belonging to and in part probably younger than the Challis volcanics, which may for convenience be grouped as Miocene (?) rhyolitic rocks and are thus shown on plate 4. Most geologists who have described portions of the region have loosely referred to these rocks as "rhyolite." Some have applied such local designations as "Mount Bennett rhyolite",[12] "Owyhee rhyolite",[13] and "Tertiary late lava" [14] to portions of the group. Although a considerable part of this lava is correctly termed rhyolite much of it

[10] Ross, C. P., Geology and ore deposits of the Seafoam, Alder Creek, Little Smoky, and Willow Creek mining districts, Custer and Camas Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 33, p. 2, Mar. 1930.

[11] Ross, C. P., The geology and ore deposits of south-central Idaho: U. S. Geol. Survey Prof. Paper — (in preparation).

[12] Russell, I. C., op. cit., p. 42. Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, p. 8, [1926].

[13] Kirkham, V. R. D., Igneous geology of southwestern Idaho: Jour. Geology, vol. 39, no. 6, pp. 564-591, 1931.

[14] Kirkham, V. R. D., A geologic reconnaissance of Clark and Jefferson and parts of Butte, Custer, French, Lemhi, and Madison Counties, Idaho: Idaho Bur. Mines and Geology, Pamph. 19, pp. 33-38, 1927.

is actually quartz latite [15] or has even more calcic composition and differs little from that of many flows in the Challis volcanics where that formation was originally described. Few of the many isolated exposures of the rhyolitic rocks in and bordering the Snake River Plain exhibit direct evidence as to their age other than the fact that they are all probably older than the Snake River basalt, the main bulk of which is regarded as Pliocene or later. In the few places in which the Challis volcanics have been traced to the vicinity of the plain it has been found that the rhyolitic and associated beds belong to the upper part of that formation.[16] On the other hand it is probable that some of the rhyolitic flows are as young as Pliocene, although for the region mapped on plate 4 evidence in support of this suggestion is at present scanty.[17] There is reason to believe that some, at least of the rhyolite southeast of the Snake River may be as young as Pliocene. It appears from Mansfield's descriptions [18] that this rhyolite has different relations and is probably much younger than the Challis volcanics. It may be that some of the rhyolitic rocks farther north are similar in relations and age. In southern and southwestern Idaho the rhyolitic rocks are tentatively regarded in the most recent reports [19] as Miocene or Pliocene.

In relation to ground-water problems the different rhyolitic and related rocks are mainly of interest in elucidating structure. Their presence at any locality is evidence that the base of the basalt flows of the Snake River Plain has been reached. The rocks themselves, except where much fractured, are not readily permeable and in few places are so situated that water for irrigation has been sought in them. In the region south of the canyon of the Snake River, where the rocks dip northward and contain intercalated tuffaceous beds, they locally also contain water under artesian pressure.

In areas studied during the present investigation nearly all the nonbasaltic volcanic rocks are included in the Miocene (?) rhyolitic rocks, as the term is here used. The basalt of Big Southern and West Twin Buttes has geologic relations akin to those of the Miocene (?) rhyolitic rocks and consequently may be grouped with them. On the other hand, the rhyolitic Eagle Rock tuff is regarded as younger than most of the Miocene (?) rocks. Available data regarding each

[15] Kirkham, V. R. D., op. cit. (Pamph. 19). Anderson, A. L., Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 14, pp. 60-66, 1931. Stearns, H. T., Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press). Also unpublished data by C. P. Ross.

[16] Ross, C. P., op. cit. (Pamph. 33), p. 23. Also unpublished data.

[17] Stearns, H. T., Volcanism in the Mud Lake area, Idaho: Am. Jour. Sci., 5th ser., vol. 11, p. 361, 1926.

[18] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 119, 1927; Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, p. 42, 1929.

[19] Kirkham, V. R. D., Igneous geology of southwestern Idaho: Jour. Geology, vol. 39, no. 6, pp. 564-[illegible], 1931. Anderson, A. L., op. cit., p. 66.

of the areas of Miocene (?) rhyolitic rocks studied in connection with this and related investigations are summarized below.

RHYOLITIC ROCKS IN AND NEAR THE MUD LAKE REGION

Rhyolitic rocks, chiefly welded tuffs, but containing subordinate amounts of agglomerate, andesite, latite and basalt are extensively exposed in the Centennial Mountains, the southern part of the Beaverhead Mountains, Big Bend Ridge, Juniper Buttes, and smaller neighboring hills. These rocks have been described elsewhere.[20] As these flows may in part interfinger with overlying sediments tentatively supposed to be Pliocene, the flows may also be of this age. Whatever their exact age they have the same general relation to the basalt of the plain as the rest of the Miocene (?) rhyolitic rocks. Kirkham [21] has described similar flows on both sides of the valley of the Little Lost River.

RHYOLITE OF BIG SOUTHERN BUTTE

Three great buttes in the lava fields between Arco and Blackfoot form prominent landmarks. Big Southern Butte, about 5 miles in diameter, the largest of these masses, reaches an altitude of 7,658 feet and rises nearly 2,500 feet above the Snake River Plain, 21 miles southeast of Arco.

The butte is composed of basaltic and rhyolitic flows of different textures. The main mass is a light-colored porphyritic rock containing large quartz crystals, which was identified megascopically as a rhyolite. The bulk of the material is glassy or pumiceous and obviously accumulated as explosive debris on the summit of a volcano. If a crater formerly existed, it has been completely dissected by erosion. The summit is made up largely of huge blocks of white pumice among which are a few obsidian bombs. Some of the obsidian is spherulitic. In places beneath the coarse ejectamenta beds of white ash and agglomerate crop out.

Near the mouth of the largest gulch that drains the north side of the butte there is a playa that formerly contained water throughout much of the year. Prior to the drilling of wells this playa was the only water hole between the Fort Hill Bottoms and the Big Lost River, and for many years all stage roads led to it. More recently a stock ranch has replaced the old stage station, and the owner has developed about a third of a second-foot of water by tunneling into the alluvium at the mouth of the gulch. When visited in 1921, the tunnel was 532 feet long and reached bedrock. Water from the coarse alluvium seeps into the tunnel through most of its length. The water is piped about a mile to a small reservoir. After stock and domestic

[20] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press); Volcanism in the Mud Lake area: Am. Jour. Sci., 5th ser., vol. 11, pp. 360-362, 1926.

[21] Kirkham, V. R. D., op. cit. (Pamph. 19), pp. 33-38, 1927.

requirements are met, the surplus is used to irrigate a small patch of alfalfa. The tunnel simply recovers the underflow of the gulch. The fact that most of the water was encountered near the contact of the alluvium and bedrock indicates that the water recovered is following the old bedrock surface. The success attained in this gulch suggests that similar developments might be made at the mouths of other gulches around the butte, but is is doubtful if the drainage areas of the others are large enough.

In ascending the gulch above the tunnel a porphyritic basalt containing phenocrysts of feldspar and olivine was found. It is deeply weathered and appears to be of the same age as the rhyolite and intruded from the same crater, although this could not be definitely established. Farther up, the narrow gulch opens into an amphitheater that may have been originally a crater. In this amphitheater occurs a remnant of an asymmetric basaltic red cinder cone. The feeding dike of aphanitic basalt can be traced down the side of the gulch from beneath the cinders. The fresh character of this basalt and the associated pyroclastic material, together with its topographic position, shows that it is much younger than the weathered porphyritic basalt described above. A bed of aphanitic vesicular basalt flowed northward over the rhyolite from this cinder cone. It is now detached from the cone by erosion. This eruption is definitely younger than the rhyolite and seems to be associated with some of the older basaltic eruptions of the plain. However, as the flow has been removed by erosion from the side of the butte it must be older than the late basalts encompassing it. The topographic relation of the flow and cone to the gulch suggests that the amphitheater is a crater and that the basic eruption took place prior to the breaching of the crater by erosion.

TRACHYTE OF EAST TWIN BUTTE

The Twin Buttes rise above the lava plain 15 miles northeast of Big Southern Butte. They are about 4 miles apart. The East Twin Butte, locally known as East Butte, rises about 1,100 feet above the plain, and its light color forms a strong contrast to the surrounding dark lava fields.

The beds of trachyte, pumice, and obsidian of which the butte is composed dip about 30° S. and strike east. The trachyte, which is the most abundant, has phenocrysts of glassy feldspar (mainly orthoclase) and a few of quartz, in a fine-grained white groundmass composed mainly of orthoclase. The butte is deeply eroded, like Big Southern Butte, and on the south side an alluvial fan stretches southward for nearly a mile. No vestige of any crater remains on the summit, but the character of the rocks indicates that they accumulated near the top of a volcano. Inclusions of porphyritic basalt in the trachyte show that all the lavas of this cycle were not highly

AIRPLANE VIEW OF ROCK BENCH BORDERING BOTH SIDES OF SNAKE RIVER AND FORMING

Note the gaping parallel cracks of incipient landslides in the basalt along the rim of the canyon

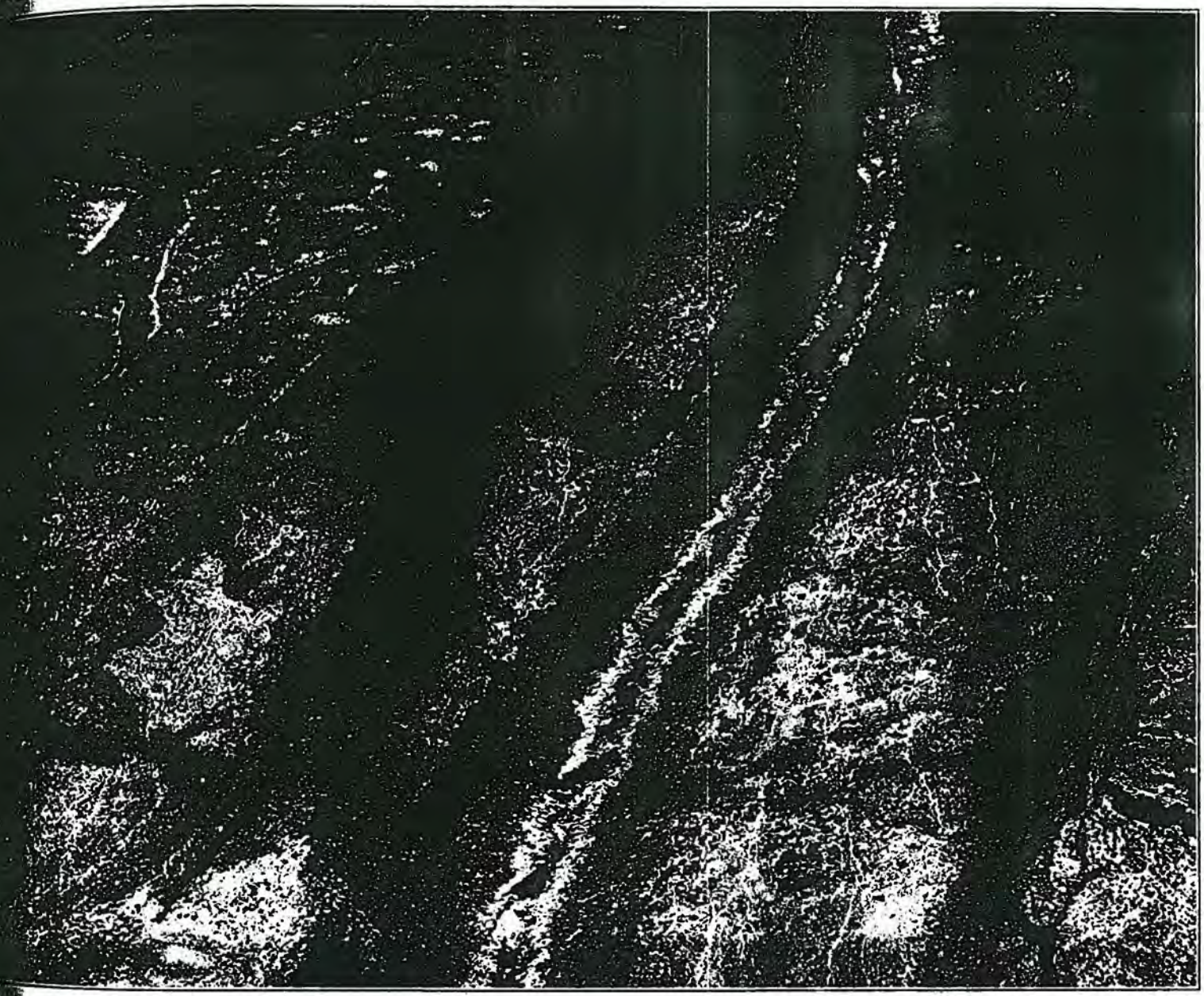
is used to irrigate a small pa
vers the underflow of the
was encountered near the c
cates that the water recove
e. The success attained i
lopments might be made
he butte, but is is doubtful
ge enough.

e tunnel a porphyritic basal
d olivine was found. It is
e same age as the rhyolite a
ough this could not be defi
row gulch opens into an
ginally a crater. In this
ymmetric basaltic red cinde
t can be traced down the side
The fresh character of this
erial, together with its topo
unger than the weathered p
bed of aphanitic vesicular
from this cinder cone. It
ion. This eruption is defi
ms to be associated with so
plain. However, as the flo
side of the butte it must be
g it. The topographic relati
iggests that the amphitheat
took place prior to the bre

ST TWIN BUTTE

lava plain 15 miles northe
about 4 miles apart. The
Butte, rises about 1,100 feet
a strong contrast to the surr

nd obsidian of which the bu
rike east. The trachyte, wh
of glassy feldspar (mainly o
e-grained white groundmass
butte is deeply eroded, lik
th side an alluvial fan stre
vestige of any crater remain
he rocks indicates that they
Inclusions of porphyritic b
avas of this cycle were not hi



AIRPLANE VIEW OF ROCK BENCH BORDERING BOTH SIDES OF SNAKE RIVER AND FORMING A CONSPICUOUS FEATURE NEAR KIMBERLY.

Note the gaping parallel cracks of incipient landslides in the basalt along the rim of the canyon. Photo by U. S. Army Air Corps.

The butte is much older than the encompassing basalt ewed from a distance appears to surmount an elevated plat-

Twin Butte may be an eroded fault block of silicic lava, but ive of its structure its lava flows appear to belong to the same cycle as those in Big Southern Butte.

BASALT OF WEST TWIN BUTTE

Twin Butte or Middle Butte rises nearly as high above the East Twin Butte and lies about 4 miles west of it. The butte sed entirely of basalt that dips 10° S. and has well-defined jointing. A thin section examined by Mr. M. N. Short abundant feldspar, olivine, and pyroxene, with a little al, partly recrystallized brown glass. Abundant calcite has icles and replaced the glass. The minerals are all very Although the texture of this basalt, like that of most of the ones described below, is ophitic, the coarser, more abundant and nearly colorless pyroxene give it a distinctly different nce. The abundance of calcite is another distinctive char-

ost plausible theory to account for this single block of tilted ising above the surrounding basalt fields is that of differential of a range made up of acidic and basic lavas. The southerly he beds in both East Twin Butte and this one suggests that a lock several miles long was uplifted and tilted to the south n eastward trending fault, but faulting is not essential to ory. Subsequent erosion of this block, followed by the erup- later basalt, left the two buttes as "kipukas."[22] The presence inclusions in the trachyte of East Twin Butte and the ancient low on Big Southern Butte show that here as elsewhere basalt companied the silicic eruptive rocks.

SHOSHONE FALLS ANDESITE

Shoshone Falls andesite is a massive porphyritic vitreous mass nknown thickness. It has an exposed thickness of about 200 d a typical outcrop of it is shown in plate 7. Both Shoshone d Pillar Falls owe their origin to the resistance of this rock ion as compared with that of the weaker ancient basalts stream from the falls. A specimen from the foot of the Perrine was examined under the microscope by Mr. Short, who has bed it as follows:

> rock consists of large tabular crystals of oligoclase and andesine in a mass that is composed of a mat of tiny feldspar laths in a brown glass. dspar phenocrysts reach 5.0 millimeters in length and are proportionately han in other specimens. Magnetite grains ranging from 0.1 to 1.0 milli- in diameter are fairly common.

[22] Kipuka is defined as an island of older rock in a lava flow.

Most of the andesite is massive, with numerous large irr shaped vesicles, whose size is increased by weathering. Locall platy and exhibits flow structure. Along its upper contact th is black and glassy.

The andesite is exposed along the Snake River only from th of Twin Falls downstream as far as the Perrine ranch, a distan 6 miles by river. (See pl. 5.) It terminates so abruptly downst as to suggest the possibility of faulting, but a thick flow of this position might well come to rest with a similarly steep front. abundance of glass, especially near the top, and the vesicles flow structure suggest that this rock is a flow, although the evid at hand does not preclude an intrusive origin. The base of andesite is not exposed. The rock is separated from the over rocks by an erosional unconformity. A lateritic soil at least a thick was formed on its irregular surface before being covered by next succeeding formation, the Pillar Falls mud flow. The and is megascopically similar to the rock in Mount Bennett,[23] 30 mile the northwest.

In the Twin Falls Cemetery well in the SE¼SW¼ sec. 14, T. 10 R. 17 E., the basalts of the plain were passed through at 270 fe below which was 23 feet of boulders, probably the Pillar Falls mu flow. From 293 to 750 feet the well is in hard rock except for th streaks of clay 2 to 3 feet thick. A fragment of rock recovered fro the well is typical Shoshone Falls andesite, and a specimen of th so-called clay at 600 feet is a brown greasy material resembling chemical deposit of some sort rather than clay. This 8-inch hole reported to have yielded only about 45 gallons a minute at 270 fe This well indicates that the andesite extends southeast at lea 3 miles farther than mapped and if all the rock below 293 is Shoshon Falls andesite then it is more than 450 feet thick.

PILLAR FALLS MUD FLOW

From Shoshone Falls downstream the Pillar Falls mud flow rest on the eroded surface of the Shoshone Falls andesite. Upstream from these falls basalt rests directly on the andesite, indicating tha the mud flow was either local in occurrence or else was removed b erosion prior to the eruption of the basalt. The latter hypothesis i favored, because the mud flow is also absent from some of the high points of the andesite downstream. The mud flow was not differ entiated from the andesite in plate 5 because its outcrops are found only in the vertical walls of the canyon, and hence in the horizontal plan of the map their area is negligible. Furthermore, this material

[23] Russell, I. C., Geology and water resources of the Snake River Plain of Idaho: U. S. Geol. Survey Bul 199, p. 44, 1902. Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, p. 8 [1926].

to have no important bearing on the occurrence of ground

mud flow consists of well-rounded gravel and huge boulders feet in diameter composed of silicic extrusive material in a matrix of sand, ash, and soil. The lack of sorting indicates he material was deposited by a stream overloaded with ash from a volcanic explosion. In the exposure examined angular ion blocks were absent, indicating that the source of the ash not nearby. Some of the soil on the underlying andesite is mingled with the mud flow. The upper several inches of the low is dull gray to red as a result of baking by the overlying In a few places the mud flow is sufficiently consolidated to ang, but in other places it is easily removed with a pick. Rus- was apparently the first to note it, although the underlying ite was described earlier by King.[25]

obably at some time subsequent to the eruption of the Shoshone andesite a deposit of ash was spread widely over the surrounding ry. Torrential rain concurrent with or following shortly after sh shower swept the incoherent material off the slopes in amounts great as to form a pasty flow of mud, which shoved or floated rything movable in its path. The soil on the andesite shows at considerable time intervened between the eruption of this lava and its covering by the mud flow. On the other hand, the absence fragments of basalt in the mud flow indicates that it was probably deposited before the episode of basaltic eruptions, which began in late Pliocene time. As the break at the top seems greater than that at the base the mud flow is tentatively assumed to be of Miocene rather than Pliocene age.

RHYOLITIC ROCKS SOUTH OF SNAKE RIVER

In the area between the canyon of the Snake River and the southern boundary of Idaho and extending as far east as the Malta Range there are large areas of rhyolitic rocks, most of which have been studied only in reconnaissance fashion. In the course of the present work these rocks were seen in many places but not mapped.

The valley of Salmon Falls Creek above the dam that forms the reservoir is carved in silicic lava and associated pyroclastic material. Farther north these Miocene (?) rocks are largely covered by later beds. Near Castleford a silicic layer 25 feet thick, possibly a welded tuff, is exposed beneath the Pleistocene basalt. Under this layer is 6 to 8 feet of reddish soil, which in turn rests on massive rock, probably an andesite flow, with an exposed thickness of 100 feet.

[24] Russell, I. C., op. cit., p. 43.
[25] King, Clarence, U. S. Geol. Expl 40th Par. Rept., vol. 1, pp. 592–593, 1878.

Still farther downstream at a point a third of a mile south Salmon Falls Hot Spring in sec. 31, T. 8 S., R. 14 E., an ex bearing on the relation of an andesite flow to the Hagerman lak and the Banbury volcanics occurs. Although this flow is dou not the same one as at Shoshone Falls, probably it has essentiall same age. At this point on the east bank of Salmon Falls C 60 feet of platy andesite occurs with its bottom going below level. Above it is 30 feet of bedded sand and clay with the top of clay baked red by an overlying weathered basalt flow 50 feet vesicular at the top and typical of the Banbury volcanics. this basalt is 30 feet of lake beds. The basalt dies out on th side of the canyon and in that side the andesite is overlain by 20 of lake beds which are capped with a later basalt. The basalt east bank appears to have flowed from the north and east an andesite from the south. The andesite terminates about 80 south of the hot spring. Its contact with the overlying sedim not exposed but one gets the impression it ends either in a n margin or by erosion, rather than by faulting. However, it is o here as it was not at Shoshone Falls, that the andesite underli Hagerman lake beds and Banbury volcanics.

Near the heads of Deep, Cottonwood, McMullen, Rock, and Creeks, successively farther east, occur thin widespread even-b fluidal pink rhyolitic rocks with glassy tops, apparently largely w tuffs, and intercalated ash beds. This series of rocks dips north along the border of the Snake River Plain is apparently much dis by faulting, with the downthrow generally to the north.

Similar rhyolitic rocks continue eastward into the valley of Creek. Here Piper [26] distinguished early Miocene (?) rhyolit late Miocene (?) lacustrine beds with "intercalated and capping of rhyolitic lava."

Rhyolitic tuff and lava flank Marsh Creek, the next stream east, on both sides. On the west these beds rest on Paleozo quartzite. Near the mouth of the valley the tuff is quarried fo locally as building stone. The ridge on the east, which sepa this valley from that of the Raft River, is composed chiefly of rhyo and obsidian with here and there a white tuff bed capped by a p ent glassy rhyolite. The mountains east of the Raft River Valle least on their east side, contain volcanic rocks of several kinds res on Paleozoic sedimentary beds. Presumably the volcanic rocks to be correlated in part with those farther west. From this vic east and northeast rhyolitic, andesitic, and related flows and clastic rocks continue to be exposed at intervals. Most of them

[26] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Ida Mines and Geology Bull. 6, pp. 26-35, 1931.

described by Mansfield [27] and were not closely examined during ent work. The information available indicates that the thick ce of rhyolitic rocks, and associated beds west of the Malta either originally thinned out rapidly immediately to the east range or else has been largely obliterated as a result of subsevents. The silicic volcanic rocks in the area between the iver and the vicinity of Pocatello differ somewhat in appearance ickness from those to the west.

SOURCES OF RHYOLITIC AND RELATED ROCKS

amount of rhyolite and associated volcanic rocks in and on the of the Snake River Plain is much greater than can be accounted known vents in this region. Within the region examined there all cone near Fort Hall [28] and several near the Blackfoot Reserbut no other cones that appear to be suitable sources for the lava are known. Indian Creek Butte [30] in Clark County of being a cone, as formerly thought, may consist of a hill of ock blanketed with welded tuff.

of the vents from which these silicic volcanics issued may be beneath the copious Pliocene and later basalt flows. The hesis that one of the major sources of the silicic flows was a of volcanoes extending from the Yellowstone National Park Boise along the axis of the Snake River Plain accords with the facts within this region, although it is supported by little direct ce. It is clear from the descriptions which follow that the ne and Pleistocene basalts locally attain an aggregate thickness least 1,000 feet, and the maximum thickness is probably much r. Even this minimum figure is sufficient, especially if some nce is made for erosion and possible down-warp prior to the c eruptions, to account for the burial of rhyolitic cones of conble size. Kirkham [31] has presented evidence tending to show ear the west end of the Snake River Plain the bottom of the sion that was filled with Tertiary beds may perhaps now be as as 20,000 feet below sea level. However, his evidence of downin the area studied is chiefly based on the dip of the silicic volwhich he considered as flows. Because many of them are welded

[27] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, U. S. Geol. Survey Bull. 713, pp. 57-61, 1920; Geography, geology, and mineral resources of part of ern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 116-130, 1927; Geography, geology, and mineral of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, pp. 40-45, 1929. Mansfield, and Ross, C. S., Welded rhyolitic tuffs in southeastern Idaho: Am. Geophys. Union Trans., 308-321, 1935.

[28] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, U. S. Geol. Survey Bull. 713, p. 72, 1920.

[29] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Prof. Paper 152, p. 362, 1926.

[30] Ross, H. T., Volcanism in the Mud Lake area, Idaho: Am. Jour. Sci., 5th ser., vol. 11, p. 362, 1926.

[31] Kirkham, V. R. D., Snake River downwarp: Jour. Geology, vol. 39, no. 5, pp. 473-479, 1931.

tuffs their dip may have resulted from the topography on which they fell and not on subsequent tilting.

The differences in the character of the rhyolitic rocks in different parts of the region accord with the concept that they came from separate vents arranged more or less parallel to the axis of the plain rather than that they flowed widely from a single area, such as the Yellowstone National Park, where rhyolitic flows are abundant.

Whether or not the buried volcanoes suggested above furnished some of the flows, evidence is rapidly accumulating [32] that there are many intrusions in the mountains of south-central Idaho which are of suitable age and petrographic character to have been the source of a large part of the lavas older than the basaltic flows of which the Snake River Plain is built up. Some of these intrusions in the Lava Creek [33] and Alder Creek [34] districts are shown in plate 4. Numerous others, some of which are much larger, are exposed in the mountains farther north and west.[35] Erosion has been so active in this high region since most of the intrusive rock now exposed became solid at depth that any original connection with surface flows has been eroded away or otherwise obscured. Recently Udell [36] has found that there are in the Muldoon mining district, Blaine County, not far from the border of the Snake River Plain, two lines of vents or craters which he regards as the sources of much of the Challis volcanics of this locality. He further finds that there are in the Muldoon district granitic and other intrusions comparable in age and character to those above referred to, and that some of the rhyolitic dikes here are materially younger than the granitic masses. This accords with the concept, expressed above, that the rhyolitic flows of the region may be of more than one age.

PLIOCENE ROCKS

OCCURRENCE AND CHARACTER

Over most of the region mapped on plate 4 rocks as old as Pliocene, if present, are deeply buried. Locally, at the base of the Centennial Mountains, along the canyon of the Snake River and in and near Hagerman Valley, rocks are exposed which may, with different degrees of certainty, be referred to the Pliocene. Some of these are lacustrine and fluviatile deposits, most of which contain fossils,

[32] Ross, C. P., Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 36, no. 8, pp. 682-684, 692-693, 1928. Anderson, A. L., Geology and ore deposits of the Lava Creek district, Idaho: Idaho Bur. Mines and Geology, Pamph. 32, pp. 21-25, 1929.

[33] Anderson, A. L., op. cit. (Pamph. 32), pp. 21-25.

[34] Ross, C. P., Geology and ore deposits of the Seafoam, Alder Creek, Little Smoky, and Willow Creek mining districts, Custer and Camas Counties, Idaho: Idaho Bur. Mines and Geology: Pamph. 33, pp. 13-14, 1930.

[35] Ross, C. P., Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 36, no. 8, pp. 682-684, 1928.

[36] Udell, Stewart, The geology of the Muldoon mining district, Blaine County, Idaho: Idaho Bur. Mines and Geology Pamph. — (in preparation).

though thoroughly diagnostic collections have been made only in Hagerman Valley. More or less closely associated with the different sedimentary units are beds of basalt and other volcanic rocks whose stratigraphic position (so far as determinable) and degree of weathering indicate that they are of approximately Pliocene age. It appears from the data summarized below that in the region here considered Pliocene rocks make up a relatively small part of the great mass of beds accumulated subsequent to Miocene time.

Four units have been mapped for whose age positive evidence is lacking but whose relations suggest that they are mainly older than the definitely recognizable upper Pliocene rocks and younger than the Miocene (?) rocks above described. These rocks are here grouped as lower Pliocene (?) and are described below. All but those in Clark County lie along the Snake River from American Falls to the east side of the Raft River, and they are considerably disturbed by faulting and in general dip northward, away from the foothills. The Rockland Valley basalt and Raft lake beds appear younger than these rocks but older than the upper Pliocene. They are therefore grouped as middle (?) Pliocene. The Banbury volcanics and Hagerman lake beds may on stratigraphic and paleontologic grounds be confidently assigned to the upper Pliocene.

LOWER PLIOCENE (?) ROCKS

TERTIARY SEDIMENTS IN CLARK COUNTY

A considerable area in the vicinity of Medicine Lodge Creek in northwestern Clark County is covered by fanglomerate and kindred material which overlies and may in part interfinger with the rhyolitic flows so abundant in this area.[37] Most or all of these deposits are stream-laid, and they are evidently but little younger than the rhyolitic flows of the vicinity. Pieces of thoroughly fossilized camel bone from a well in the gravel were regarded by J. W. Gidley as suggestive of Pliocene age. The sediments have therefore been tentatively referred to the Pliocene, although if the rhyolitic flows should prove to be as old as some of the similar flows in other parts of Idaho these sediments may likewise be pre-Pliocene.

NEELEY LAKE BEDS

In the bluffs of the Snake River near Neeley, 5 miles southwest of American Falls, a series of lake beds has an exposed thickness of 100 feet, but its base is concealed, hence it must be thicker. (See pl. 6.[38]) These beds consist of flesh-colored to brown sandy lacustrine deposits

[37] Stearns, H. T., Bryan, L. L., and Crandall, Lynn, Geology and water resources of the Mud Lake region, Idaho: U. S. Geol. Survey Water-Supply Paper 818 (in press).

[38] The geology on this map was originally plotted on a U. S. Bureau of Reclamation map. In replotting on the new U. S. Geological Survey base the geology was adjusted to fit the new base, and this may have given rise to errors.

composed partly of reworked and subaqueously deposited basic presumably accumulated behind a lava dam. The deposits even-bedded and dip 3°–5° N. except where disturbed by faults They are sufficiently indurated to form steep bluffs wherever th have been eroded.

Although this formation is coarser than some of the other beds it is not sufficiently coarse to yield much water. No wells known to derive their supply from this formation, and no perenn springs issue from it.

EAGLE ROCK TUFF

The Eagle Rock tuff, named from Eagle Rock, near American Fal is exposed at the base of the American Falls. The following secti was measured at this place, the type locality:

Section of Eagle Rock tuff on north bank of Snake River at American Falls

	Feet
Red felsitic tuff containing feldspar crystals 2 to 4 millimeters in length	0.6
Welded rhyolitic obsidian tuff containing spherulites and lithophysae. Some of the lithophysae are 3 inches in diameter	20.8
Even-bedded coarse black ash, composed of shards of rhyolitic glass. The top layer is compact and breaks into dull obsidian fragments and grades downward into ash that can be readily removed with a knife	4.5
Even-bedded gray to white rhyolitic ash, in places pisolitic	9.3
	35.2

The following descriptions are based partly on microscopic studies by M. N. Short:

The top bed is a fused rhyolitic tuff which contains large crystals of albite and owes its red color to the numerous minute hematitic inclusions. The 20-foot bed of obsidian tuff next below is less thoroughly fused. It contains a few rounded crystal fragments of microcline and oligoclase but with these exceptions is entirely glassy. The rock lacks joint planes and shrinkage cracks and presents an unusual appearance because of the honeycomb structure produced by the lithophysae and the weathering out of the spherulites from the matrix. In places where hollow spherulites or lithophysae predominate over the tiny symmetrical spherulites the matrix is pink. Small subangular obsidian pellets also weather out between the spherulites, and in these localities the matrix is easily removed with a pick. The next lower bed at the type locality is a compact dark-gray vitreous tuff, which consists of light-brown rhyolitic glass (refractive index 1.497) whose structure indicates welding and flowage. At another exposure along the Oregon Trail this bed is even more compact and megascopically gives no indication of its fragmental structure. The white ash in the lowest bed differs from the ash in the top bed only in its unconsolidated character. It consists of fragments of glass with only a few scattered grains of feldspar.

This formation has a uniform thickness except where eroded. Its component beds are so similar in composition and so closely comparable as to indicate that they followed one another in rapid succes-

sion and came from the same volcano. The presence of pisolites in the ash suggests subaerial deposition. The absence of cross-bedding or lamination indicates that the beds were formed from ash showers without appreciable sorting by wind or streams. Wind-blown soil at the top of the formation if deposited soon after the tuff accumulated would indicate that these rocks were laid down on dry land.

This formation has been recognized only in the canyon walls along Snake River. Beyond it is buried by younger formations. It extends for several miles along the river southwest of American Falls. On the west side of Rockland Valley, about 12 miles south of American Falls, there is an exposure of white consolidated pumice and ash 100 feet thick which may correspond to the white ash of the Eagle Rock,

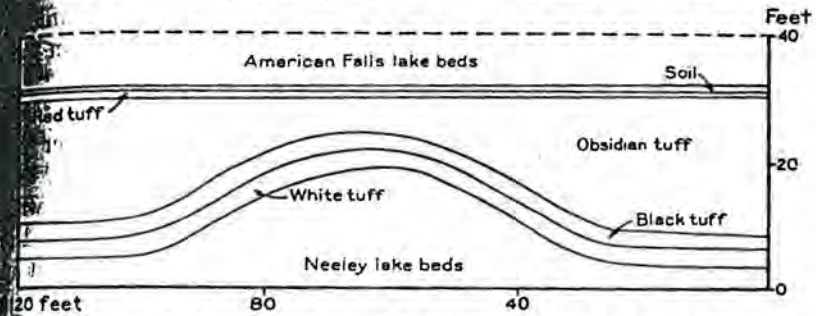


FIGURE 4.—Local unconformity between the Neeley lake beds and the Eagle Rock tuff.

and its greater coarseness and thickness here may be due to its being nearer the source. The pumice at this particular exposure weathers easily and is filled with cavities.

On the west bank of the Snake River in the NW¼ sec. 22, T. 8 S., R. 30 E., a slight variation occurs in the thickness of the beds. At this place a small mound a few feet high in the Neeley lake beds is overlain by the white and black ash beds retaining their usual thickness and conforming to the surface of the mound. The obsidian tuff above the ash thins sufficiently in passing over the mound to make its upper surface level. Consequently on top of the mound there is only about 4 feet of obsidian tuff, as compared with about 18 feet on each side. Above the obsidian tuff is the usual thin bed of red tuff and a few inches of soil containing scattered red basaltic cinders. On top of the soil rest the American Falls lake beds, which are much younger and which are described below. Figure 4 shows the relation of the obsidian to the underlying tuff and lake beds. These relations, coupled with the texture of the obsidian tuff, indicate that the fragments composing the tuff were molten when they fell and consequently coalesced into a mass sufficiently fluid to adjust itself to minor topographic irregularities. This suggests distribution as a hot avalanche or nuée ardente, as at Mont Pelée in the West Indies in

1902, or like the hot sand flow of the Valley of Ten Thousand Sm
in 1912.

MASSACRE VOLCANICS

In the center of sec. 6, T. 9 S., R. 30 E., is a group of kn
dense basalt. They are named "Massacre Rocks" because in
the Indians massacred an emigrant train at this point. The
represent the denuded feeder of an ancient volcano. The
distribution and coarseness of the pyroclastic rocks from thi
suggest that in comparison with similar less dissected cones in
regions, the original cone here may have been a thousand feet o
high and perhaps several miles in diameter. Its explosive pr
and flows were spread over more than 20 square miles. The pr
of this volcano, which are here named the "Massacre volca
are much older than the other basalts that now form the canyo
on the north side of the Snake River opposite the historic spot.

The volcano was mainly explosive during its history, for the b
ash, cinders, and bombs greatly predominate in quantity ov
lava flows. A few blocks of basalt, spherulitic obsidian, clay
limestone torn from the underlying basement are intermingled
these fire-fountain deposits. The beds are brown, red, or black
color depending upon the state of oxidation of the iron presen
them. They are all consolidated and readily distinguished from
underlying Eagle Rock tuff. In general they dip away from Mass
Rocks, but many of the beds have been tilted considerably by
sequent faulting. In the SW¼ sec. 21, T. 8 S., R. 30 E., a pe
bed of cinders crops out about 20 feet above the northwest bank o
Snake River. It contains numerous red concretionary balls of
tically pure calcite as much as 4 inches in diameter.

Beds belonging to the Massacre volcanics are exposed at inte
on both banks of the Snake River upstream from Massacre R
as far as Eagle Rock, a distance of about 11 miles. (See pl. 6.)
this place they are cut off by a fault. Downstream they are exp
to a point only 1½ miles from Massacre Rocks, where they are faul
down out of sight.

In the SW¼ sec. 22, T. 8 S., R. 30 E., on the south bank of
river, which there makes a right-angle turn to the northwest,
fire-fountain deposits are in contact with the underlying Eagle R
tuff. A similar contact can be seen on a neighboring island in
river. Here the deposits rest on 4 feet of loess soil containing ang
rock chips derived chiefly from the red felsitic tuff, which her
only 1 foot thick and lies on the spherulitic obsidian. This con
shows that sufficient time elapsed between the obsidian flow and
eruption of the Massacre volcanics to form deep soil and also that

[19] Fenner, C. N., The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Th
sand Smokes: Nat. Geog. Soc., Contributed Tech. Papers, Katmai ser., no. 1, pp. 70-74, 1923.

took place on dry land. In places thin layers of basalt,
was erupted from the Massacre Rocks volcano, cap the fire-
deposits and are interbedded with them. The prominent
rises about 500 feet above the Snake River in sec. 5, T. 9 S.,
., is capped with weathered porphyritic basalt that may have
rom this vent.

ther flow from the Massacre Rocks vent makes a prominent
long the highway just northeast of the mouth of Rock Creek,
12, T. 9 S., R. 29 E. A few thin flows interspersed with the
have not been differentiated on plate 6. Although these
are thin where exposed, they are close to the source, where
va was extremely liquid and was flowing down the cone slope.
fore they may represent the upper ends of originally extensive

he north bank of the Snake River near the foot of American
he soil above the obsidian is overlain by a fine-grained blue
flow 25 feet thick. This flow caps the rhyolitic tuffs for 5 miles
ream, except where it has been removed by erosion. As it
the same stratigraphic position as the Massacre volcanics,
have been erupted from the Massacre Rocks vent.

MIDDLE (?) PLIOCENE ROCKS

ROCKLAND VALLEY BASALT

On the west side of Rockland Valley even-bedded basalt flows
exposed in the deep, narrow canyon of Rock Creek. In sec. 8,
S., R. 30 E., about 250 feet of these lava flows is exposed. The
exhibit the usual columnar jointing and are all of the pahoehoe
They are considerably weathered, and their state of decom-
on readily distinguishes them from the adjacent later basalts
cover the Snake River Plain. The uppermost flow near the
th of Rock Creek is 40 feet thick and rests with apparent con-
ity on light-colored clay beds 15 feet thick, which in turn overlie
lt. Although the lavas do not exhibit subaqueous phases,
were evidently laid down at about the same time as the lake-bed
ays. These clays appear to be playa deposits, hence they may
been dry when the lava covered them. This suggestion receives
support from the fact that the clay beneath the 40-foot lava
is not baked red near the top by the basalt.

In the north end of Rockland Valley most of the lavas are buried
later deposits. The lavas extend toward Table Mountain, a high
te to the south, and it is possible that the vents lie in that direction.
ese lavas appear to have been tilted gently to the northwest.
Apparently the Massacre Rocks cone was too high to be covered by
em, for no remnants of them overlie the tuff; hence the cone was
obably a kipuka during the lava floods.

The total thickness of the Rockland Valley basalt may be exp somewhere in the Rockland Valley. The driller of the Burley well 5, about 40 miles west of the mouth of Rock Creek, reported the bottom of the well 647 feet of basalt, which occupies the str graphic position of the Rockland Valley basalt. (See p. 50.) Becau basalts are poured out over the land as semifluids, a flow may 1,000 feet thick at an outcrop, where it fills an old canyon, but mile away the same flow may be absent or be only a few feet thi The notable variation in thickness of basalts from place to place, contrasted with the relatively uniform thickness of sedimenta deposits, may involve considerable errors in correlation and doubtl causes some of the great difference in the logs of wells drilled with a small area.

In spite of its extensive weathering, this basalt is fairly permeabl and several domestic wells probably derive their supply from it.

RAFT LAKE BEDS

Lake beds, here named the "Raft lake beds" (pl. 6), extend westwa from the mouth of Rock Creek along the south shore of Lake Walco as far as the mouth of the Raft River. The beds in this formation appear to have uniform thickness when seen in any one exposure but individual layers are traceable for only short distances. The beds are buff to pale yellow and consist of partly consolidated silt sand, caliche, and gravel. At the mouth of Fall Creek lens-shaped beds of coarse gravel and hardpan are plentifully intercalated in them. Nodular concretions, as much as 10 inches in length, are characteristic of the beds, but tuffaceous beds are uncommon.

Near the mouth of Rock Creek the lake beds rest on the Rockland Valley basalt. A small outlier of them is seen in a depression in the Massacre volcanics a mile northeast of this creek, on the south side of the highway, and possibly another occurs beneath the Cedar Butte basalt on the north bank of the Snake River near Bonanza Bar, at the mouth of Lake Channel. In the Rockland Valley these beds form rounded hills covered with rich brown soil that is extensively dry-farmed. At the head of Fall Creek, in secs. 27 and 28, T. 9 S., R. 29 E., a basal conglomerate of the formation crops out and includes talus blocks from the adjacent Paleozoic limestone. The beds rest unconformably on ancient limestone in sec. 9, T. 10 S., R. 28 E.

The Raft lake beds are about 200 feet thick near Fall Creek, and there they also rise about 200 feet above the Lake Walcott Reservoir. At the Raft River, 8 miles to the west, they rise only about 50 feet above the reservoir. Their surface also rises gently toward the southeast and forms a plateau cut only by a few ephemeral streams. The plateau is capped here and there by gravel deposits, which probably are the alluvial fans deposited by similar ephemeral streams

tary to the ancient lake. The whole formation has been tilted the northwest, so that the beds dip in this direction about 5°. ey form a precipitous bluff along the Lake Walcott Reservoir, at one time they evidently extended much farther north into Snake River Plain. Although these lake beds were possibly moved by the Snake River, they may be terminated on the north an eastward-trending fault or series of faults.

The presence of several warm springs in sec. 19, T. 9 S., R. 28 E., ing at the base of the bluff, suggests faulting as the cause of the carpment, but similar bluffs have been carved by the Snake River in Hagerman lake beds in many places. Furthermore, the underlying Massacre volcanics and possibly even the Raft lake beds crop out on the north bank of the Snake River, and if a fault terminated the lake beds the tuffs should have been carried down out of sight. The Raft lake beds end abruptly on the east side of the Raft River, beyond which they have been removed by erosion and replaced by recent basalts.

From exposures near the mouth and from well records farther south, much of the Raft River Valley, under a cover of alluvium, seems to be filled with Raft lake beds. Warneke's well, in the NE¼SE¼ sec. 32, T. 13 S., R. 27 E., is reported to have penetrated 48 feet of gravel and then remained in fine-grained stream and lake deposits to its bottom, at a depth of 800 feet. A composite sample from the cutting dump shows that the last material drilled was arkosic sand.

In T. 15 S., R. 24 E., 6 miles due south of Almo and 5 rods from the Raft River, the Oasis Oil Co., of Burley, started a well for oil. According to the log furnished by A. T. Wilcox, of Almo, this well is 375 feet deep and below 5 feet of soil penetrated gravel and sand, with some clay.

The Raft lake beds are younger than those in the adjacent valley of Goose Creek, described by Piper [40], because they overlie instead of underlie the rhyolite, and they are quite different lithologically. According to Anderson [41], however, there are on both sides of the Raft River Valley sedimentary beds which are capped by and locally intercalated with rhyolitic flows. He maps these rocks only in the range east of the valley and in a small area south of Almo but notes their presence in small exposures in numerous other localities, particularly beneath the rhyolitic flows of the Malta Range.

City well 5 at Burley is 1,115 feet deep and between 255 and 468 feet below the surface penetrated 213 feet of lake beds with some basalt above them. The driller's description indicates that these beds are probably the Raft lake beds, because they occupy the proper strati-

[40] Piper, A. M., Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, pp. 27-31, 1923.

[41] Anderson, A. L., Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 14, pp. 35-44, 1931.

graphic position. Beneath the lake beds is 647 feet of basalt, v tions in which indicate that it may comprise nearly 50 separate fl The surface of the lake beds slopes about 18 feet to the mile west from the mouth of Fall Creek to the mouth of the Raft River. Bu is about 30 miles due west of the Raft River. If this same gradien maintained these beds should lie about 550 feet below the surfac Burley instead of 255 feet. A fault on the west side of the Raft R is postulated on page 106. If this fault moved again subsequent to deposition of the lake beds it would account for this difference of feet.

The lithology of the Raft lake beds points rather conclusively shallow-water conditions during most of the lake's existence. I highly probable that these sediments were laid down behind a dam in a depression that was fed by mountain streams, which fl certain parts of it at different times during the year, and that the w escaped through the dam or was evaporated. That is, the beds w formed in a playa rather than a lake, although in exceptionally years a temporary lake may have existed. Many of the fine-grai sedimentary beds that have accumulated in different places in south Idaho were formed under similar conditions.

The Raft lake beds are, as a whole, poor water bearers. perennial springs except the warm springs mentioned above are kno to issue from them. However, wells drilled about 200 feet into th have obtained domestic supplies. The beds in the Burley well supposed to belong to this formation did not yield appreciable amoun of water.

UPPER PLIOCENE ROCKS

BANBURY VOLCANICS

Flows.—The Banbury volcanics, named from the thick expos near Banbury Hot Springs, in sec. 33, T. 8 S., R. 14 E. (see pl. extend from the Perrine ranch, in sec. 28, T. 9 S., R. 17 E., at an alt tude of 3,250 feet above sea level, down the Snake River 63 miles the vicinity of King Hill, at an altitude of 2,500 feet. They crop o fairly continuously as a series of even-bedded massive basalt flows ov 300 feet thick. Basalt belonging to this formation extends up Salm Falls Creek also.

The basalt of this formation, wherever it is exposed, weathers to dark brown, often with a greenish cast. By this color and its relativ softness it is readily distinguished from the younger hard blue basalts that locally lie in juxtaposition with it. A fossil bone (specimen E-15) collected from a bed of gravel and sand 30 feet thick and of fluviatile origin, halfway below the rim of the south canyon wall of the Snake River in the SW¼NE¼ sec. 9, T. 9 S., R. 15 E., and interstratified with the Banbury volcanics, was identified by J. W. Gidley as the tibia of a large camel of either Pleistocene or Pliocene age. Because these

lavas are intimately associated with the overlying lake beds, which contain late Pliocene fossils, their age is fixed with considerable certainty. The bottom of the basalt series was not observed. The fact that the basalts crop out at a higher altitude to the east than to the west may be due to their being gently downwarped toward the west or to their having accumulated in a greater thickness in one end of the basin than in the other. That these lavas were not spread uniformly over the entire basin is attested by the local variations in them.

Near the crossing of Salmon Falls Creek known as "Castleford" the Banbury volcanics rest on and are back-filled against an abrupt face of Miocene (?) lava, probably andesite. The Banbury volcanics are again exposed about three-quarters of a mile south of a hot spring in sec. 31, T. 8 S., R. 14 E., and continue to a point a few yards north of the spring, where they are abruptly terminated apparently by a fault and brought into contact with the upper part of the Hagerman lake beds.

The flows of this formation are massive, and such openings as exist are largely filled with soil as a result of weathering. Consequently they are less permeable than most other basalts, and only small supplies of water have been obtained from the formation. One exception occurs on the Twin Falls project, where a drainage tunnel about 100 yards long in this formation developed about 1 second-foot of water.

Riverside Ferry cone.—On both sides of Snake River at the old Riverside Ferry in secs. 20 and 29, T. 8 S., R. 14 E., are cliffs 125 feet high exposing steeply dipping bedded dark-gray and reddish-black cinders and thin layers of weathered brown basalt typical of a dissected cone. It is cut through by the Snake River, but erosion has not yet bared the feeder, as at Massacre Rocks. The gravel, older basalt blocks, and porcelain-like fragments of baked clay hurled out during the eruption and deposited with the cinders indicate that these rocks underlie the cone. The tuff exposed at Thousand Springs, 1¼ miles downstream, is probably from this cone. Some of the flows in the adjacent Banbury basalt appear to have originated at this vent. The cone deposits are cut off by a steep erosional unconformity on the north side of the river and overlain by the Sand Springs basalt. On the south side of the river the cinders are in juxtaposition with lake sediments possibly as a result of faulting. They are not exposed on the east bank of Snake River south of Box Canyon.

Because the deposits from Riverside vent form an integral part of the Banbury volcanics there can be little doubt that individual cones were the source of part, if not all, of the Banbury basalt. The character of the deposits from this cone suggests that it formed beneath the waters of a lake. The tuffs from this cone are not differentiated on plate 5 from the Banbury basalt, but the cone is shown by a separate

HAGERMAN LAKE BEDS

The Hagerman lake beds rest on the Banbury volcani
prominent bluffs along the Snake River in Hagerman Vall
in plate 10, *A*. They comprise a series of white to buff
solidated clays and silts, and are named from the fine expo
valley. Intercalated with the fine sediments are a few gra
and basic tuffs and flows. Some of the clay beds are gypa
near the mouth of Salmon Falls Creek a 20-foot bed o
occurs in the series. A gravel bed 20 feet thick, laid down
was drained, forms the capping member. The beds are
zontal, and dips of only 2° to 3° were recorded except in a
the beds had been disturbed by landslides. They are ex
Melon Valley, north of Buhl, for many miles to the west
and only a small part of them is included in the area mapp

The top of the Hagerman lake beds reach an altitude of a
feet, and because of the practically undisturbed condition o
it is judged that this altitude represents approximately th
shore line of the lake. The types of sediments indicate tha
was more persistent than the playa lake in which the Raft
were deposited. Nevertheless, the character of the vertebra
and of the beds containing them, described below, shows that
was not submerged by a lake throughout the time during wh
Hagerman beds were accumulating. Some of the beds are
laid, and others appear to have been formed in a swamp, but the
almost exclusively in the upper part of the section. Only
four lava flows were intercalated in these sediments in this are
the long time in which they were being laid down.

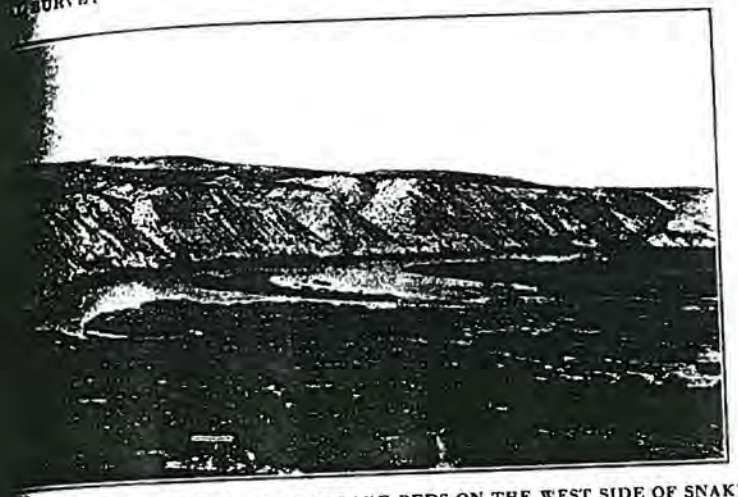
A flowing well that was drilled to obtain hot water for a nat
on the north side of the highway near the center of sec. 7, T.
11 E., about half a mile east of King Hill, penetrated 970 feet in
beds, and the log is given below.

Driller's log of well at King Hill

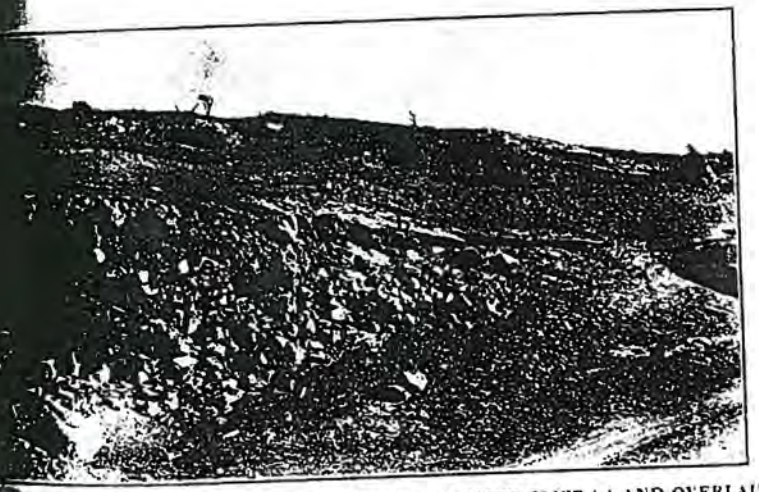
[E. B. Hughes, driller. Altitude 2,550 feet]

	Thickness (feet)
Boulders and sand (first surface water at 70 feet)	70
Clay	80
Hard rock	130
Clay	70
Clay and sandrock (small flow of about 15 gallons a minute[1] over casing at 350–360 feet; temperature 72° F.)	100
Sandrock (large flow of about 100 gallons a minute[1] at 450–480 feet; temperature 78° F.)	140
Hard rock	40
Soft sandrock (flow of about 200 gallons a minute[1] at 680–690 feet; temperature 83° F.)	60
Boulders and shale	110
Clay and boulders (last water at 820–840 feet; flow of about 300 gallons a minute;[1] temperature 92° F.)	170

[1] Driller's estimates of flow all believed to be too great.



EXPOSURE IN THE HAGERMAN LAKE BEDS ON THE WEST SIDE OF SNAKE RIVER IN HAGERMAN VALLEY.



BASALT CONTAINING TALUS BLOCKS OF A FORMER CLIFF (a) AND OVERLAIN BY VITREOUS VOLCANIC SAND (b) AND OLDER ALLUVIUM (c).

well started in alluvium, and the hard rock struck at 150 feet bably intercalated basalt. The basalt at the mouth of Clover shown in plate 5 is evidently croded completely away at the ite. The bed of hard rock 40 feet thick that is reported at 590 presumably basalt, is the only other interstratified lava to a of 970 feet. The mouth of the well is about 2,550 feet above vel; hence the drill penetrated to an altitude of 1,580 feet. It is nt from the log that sediments similar to the Hagerman lake beds encountered to a depth of 690 feet, but the boulders and clay for emaining 280 feet are difficult to interpret. The log of this well ates a greater thickness of lake beds at King Hill than is exposed agerman Valley.

upper Pliocene age for the Hagerman lake beds is indicated by ossil vertebrates that have been found in the bluffs along the side of the Snake River near the town of Hagerman. Stearns hunting for fossils heard that Elmer Cook, a farmer living in rman, had some fossils in his yard and was shown the source by Cook. Recognizing the importance of this rich fossil deposit, rns excavated several hundred pounds and sent a representative ection to the National Museum in 1928. He suggested that some- be sent to make further excavations. Parties from the Smith- ian Institution under Dr. Gidley in the next two summers and under H. Boss in 1931 obtained a large quantity of fossil material from locality. The great bulk of the collection consisted of horse ains and was uncovered in a quarry located on a hill in the NW¼ c. 16, T. 7 S., R. 13 E., about 30 feet below the top of the lake series. The equid material has been described by Dr. Gidley as *Plesippus shoshonensis* [42] and includes a large number of skulls, lower jaws, and er skeletal parts. Much of the material was disarticulated, but eral nearly complete articulated skeletons are included in the ection, and also some articulated limb and vertebral portions. *shoshonensis* represents a stage between that of the typical Pliocene *Pliohippus* and Pleistocene *Equus*. The Idaho form was noted by Dr. Gidley to be more advanced than the *P. simplicidens of* the Blanco ation of Tesas and *P. proversus* of the upper part of the Etche- in of California, suggesting a closer relationship to *Equus*.

The environmental conditions indicated by the fauna from the *Plesippus* quarry are described in the following quotations from Gidley's second report [43] on his explorations in Idaho:

> It [the quarry deposit] is evidently the remnant of a stream-channel deposit made up of cross-bedded layers of coarse and fine sand with occasional pebbles and here and there patches and lenses of almost pure clay, forming a part of the horizontally laminated beds of the Idaho formation [Hagerman lake beds of this

[42] Gidley, J. W., A new Pliocene horse from Idaho: Jour. Mammalogy, vol. 11, no. 3, pp. 300-303, 1930.
[43] Gidley, J. W., Continuation of the fossil horse round-up on the Old Oregon Trail: Explorations and Field Work Smithsonian Inst. in 1930, pp. 33-40, 1931.

report]. The bone deposit was evidently at the time of its formation a boggy springy terrane, perhaps a drinking place for wild animals in a semiarid country where water holes were not abundant. * * * Springs and swampy conditions are indicated from the fact that there are in the deposits the remains of frogs, fish, swamp turtles, beavers, and other water-loving animals, and an abundant evidence of vegetation, as shown by remnants of coarse grass stems, leaves, and even small pieces of wood. * * * In the lower stratum of the deposit the sand is heavily stained, and many of the fossil bones are encrusted and stained with light accumulations of bog iron.

The bed that yielded the fossils is a light-yellow partly consolidated cross-bedded sandstone, capped with a layer of clean gravel. Locally the sand is tightly cemented in large irregular lumps by either calcareous or limonitic cement. The limonite points to boggy conditions, suggestive of swampy water holes and shallow ground water. The conglomerate contains mostly water-worn gravel of red and other dark colors derived chiefly from the silicic extrusive rocks that crop out in the mountains to the south. Most of the pebbles in the gravel are less than 3 inches in diameter.

The hill in which the fossils occur has been subjected to erosion, but 30 feet of light-yellow loess, which has accumulated since the lake was drained, caps the gravel on the adjacent plateau.

In addition to the forms mentioned above as obtained from the quarry, this and other localities in the vicinity of Hagerman have yielded remains of mastodon, camel, peccary, sloth, cat, otter, hares,[44] aquatic birds,[45] and a rodent of the muskrat group. The presence of the otter, the muskratlike rodent, and aquatic birds adds materially to the evidence indicating the environment suggested by Gidley.

Considerable silicified wood has been found along Clover Creek near King Hill in these same lake beds. The following invertebrate fossils, identified by W. C. Mansfield, of the United States Geological Survey, were collected by Stearns from a highly fossiliferous sandstone member of the Hagerman lake beds along the King Hill canal at a large siphon about 5 miles upstream from King Hill:

Goniobasis taylori (Gabb)	Latia dalii White
Lithasia antiqua Gabb	Sphaerium sp.

Besides these fossil shells, large fresh-water clam shells that evidently belong to the *Unio* family were noted along the canal road farther upstream. All these fossils indicate that these beds were laid down in fresh water.

The interstratified basalt members of the Hagerman sediments are shown in plate 5. They occur as relatively thin basalt flows of remarkable continuity, indicating extreme fluidity at the time of extrusion. The lower contact zone is commonly stained yellow to

[44] Gazin, C. L., Fossil hares from the late Pliocene of southern Idaho: U. S. Nat. Mus. Proc., vol. 83, no. 2976, pp. 112-121, 1934.

[45] Wetmore, Alexander, Pliocene bird remains from Idaho: Smithsonian Misc. Coll., vol. 87, no. 20 (Pub. 3228), pp. 1-12, 1933.

dish brown and usually consists of comminuted and fragmental lava. The flows are considerably jointed and in a few places change into "pillow" lava, or balls of lava surrounded by a vitreous rind, a common feature of subaqueous basic flows. In places these intercalated volcanic beds are tuffaceous, especially near the mouth of Salmon Falls Creek and near Bliss. Both lava and tuff occur sparingly in the Hagerman lake beds, indicating that the tranquil waters of this lake were not often disturbed by volcanic eruptions.

The upper basalt layer in the Hagerman lake beds in the NW¼ sec. 18, T. 6 S., R. 13 E. (pl. 5), consists of 30 feet of columnar-jointed deeply weathered pahoehoe with the upper part showing the usual horizontal parting planes and vesicles. Nothing is present to indicate a subaqueous origin. About half a mile to the southeast the basalt is only 10 feet thick and rests on 12 feet of horizontal thin bedded basaltic tuff. Some layers of the tuff contain lapilli and others sand-sized particles, but foreign ejecta are scarce. This tuff is similar to that in the tuff craters of Oahu, Hawaii, and may have resulted from phreato-magmatic blasts.[46] The basalt pinches out a short distance southeast of this point and the tuff gets thicker. This tuff and lava indicates a vent not far away.

A deposit perhaps indicating a vent is exposed in the SE¼ sec. 20, T. 6 S., R. 13 E., but it is certainly unlike any volcanic deposit either at a vent or elsewhere known to Stearns. It crops out along the ditch road in the south side of the river in an exposure about 200 feet high. It is a decomposed dark-brown crumbly mass containing streaks and small balls of dense hard basalt intermixed with chunks of clay and streaks of agglomerate. The latter consists chiefly of weathered older basalts, and no andesite or quartzite fragments were noted. The whole deposit is overlain by 6 feet of laminated buff clay, which is distorted and so badly jumbled that its significance could not be determined. The whole mass dips to the northwest. To the southeast is another great mixture of rocks mapped as a landslide (pl. 5). Perhaps both have the same origin.

The Hagerman lake beds are in general so impermeable, because of their fine texture, that water occurs only sparingly in them. Most of this formation is traversed by canyons, hence precipitation falling on its outcrop appears as surface run-off. Perennial springs discharging over a few gallons a day do not occur, and small perennial seeps are few and far between. At the west end of the Twin Falls South Side tract these beds are saturated with irrigation water and yield water rather high in mineral content. The Banbury hot well, described on page 167, obtains its water from tuff and basaltic flows, intercalated with the lake beds. Wells penetrating the Hagerman

[46] Stearns, H. T., and Vaksvik, K. N., Geology and ground-water resources of the island of Oahu, Hawaii: Hawaii Dept. Public Lands, Div. Hydrography, Bull. 1, pp. 16-17, 1935.

lake beds will be unsuccessful for the most part, but if drilled d enough they will probably find sufficient supplies from the sa members or the interstratified basic tuffs and lavas. One of the w of the Oregon Short Line Railroad at Bliss, after penetrating 56 f of Pleistocene lava and clay, entered the Hagerman lake beds obtained a good supply of water at 517 feet. At 235 feet eno water was struck in the clay for drilling, but the main supply obtained from sandy layers between 456 and 470 feet. The wa rose to a level 350 feet below the top of the well. The well is ca to 422 feet and on October 17 and 18, 1917, was tested with a ste pump and yielded 80 to 100 gallons a minute. The draw-do during this test is not known.

PLEISTOCENE ROCKS

OCCURRENCE AND CHARACTER

All the volcanic and sedimentary materials that were laid dow the Snake River Plain from the end of the Hagerman epoch to end of the deposition of the older alluvium are assigned to the Pleis cene epoch. (See table, pp. 27–32, and pl. 4.) The lava flows, wh make up by far the greater part of the Pleistocene rocks, might further subdivided roughly into early and later groups, each gro comprising the products of numerous eruptions. Available data do not permit differentiation of the flows in the greater part of the plain partly because, in the absence of dissection, the youngest flows in each locality tend to conceal those previously erupted. The com paratively excellent exposures along the canyon of the Snake Riv between Blackfoot and King Hill have permitted the distinction 11 local Pleistocene formations which for the most part correspo in age with the younger group of basalts. These are, named in ord of decreasing age, Cedar Butte basalt, American Falls lake beds an intercalated basalt, Madson basalt, Malad basalt, Thousand Spring basalt, McKinney basalt, Bliss basalt, Sand Springs basalt, Buri lake beds, Minidoka basalt, and Wendell Grade basalt. Their di tribution is shown in plates 5 and 6. Similar local subdivisions of th Pleistocene sequence have been made in the Mud Lake region an elsewhere.

SOURCES OF THE ERUPTIONS

The principal vents from which the Pleistocene and later basalts issued are shown on plate 4. Altogether about 300 vents are mapped and probably about 400 occur in the entire plain. Most of the vent not shown lie in the desert between Idaho Falls and Kimama, and reconnaissance through this area on the few existing roads indicat that only about a third were mapped. Except for the cluster in th Craters of the Moon and the group north of St. Anthony, the vent are rather evenly distributed. No definite rift pattern is discernible,

though here and there short cone chains occur. The vents that plied the recent black lavas have not been differentiated by a rate symbol on plate 4 because generally their close relation to lavas is evident from their position. However, a few of the cones older and stand like islands in the areas of black lavas. About the Recent cones are shown on plate 4.

Near the foothills along the north side of the Snake River Plain, der cones 50 to 200 feet high predominate. Over most of the plain greater number of the vents are broad lava domes, each usually it 100 feet high and with the related flows covering an area of ut 30 square miles. The broad dome is capped by a smaller dome ch has slightly steeper slopes and is generally about 50 feet high. p craters in the domes are usually absent, and in many places a suggestion of a crater rim was left when activity ceased. ll spatter cones 10 to 50 feet high occur in some places, but beds saltic tuff indicative of explosive eruptions are rare. The lava to the surface through fissures or tubular vents and welled out tly and profusely. Unlike most volcanic cones of the central-vent , nearly all these cones had only one period of activity. When nic activity was resumed in the neighborhood of one of these s a new opening poured out lava, usually only a short dis- ce away.

It is obvious that the copious flows in the region must have inter- ed with drainage greatly and intermittently through a long period time. Several examples of such interference are described in sequent parts of this paper. The present channel of the Snake er through most of the region here considered lies close to the theastern and southern margin of the plain, a position which leads he inference that many of the Pleistocene vents were so situated t eruptions from them forced the river to shift in this direction tead of remaining more nearly in the median portion of the plain, re presumably it originally flowed. The fact that many of the y Pleistocene flows now recognizable lie in the southern part of the n supports the concept that later lava came largely from vents her north and thus covered the older flows there. The early lava g the Snake River west of the Minidoka Dam issued in large t from cones on the south side of the river and from buttes near en, a short distance north of the canyon. The fact that the streams ich reach the plain from the north now have no channelways con- ting them with Snake River also constitutes evidence in favor his concept. It would seem that when the major drainage pattern he region was originally established these streams must have been ctly tributary to the Snake River.

There is direct evidence that flows from cones to the south tended ally to shift the channel northward also. Examples are known near

Yale, in the Raft River Valley, and also in the South Side Twin Falls tract.

WATER IN THE PLEISTOCENE BASALT

The basalts of the Snake River Plain are in general very permeable and their usefulness as aquifers is indicated by the large amount of water discharged from them in the form of springs between King Hill and Milner. In 1902 these springs discharged about 3,900 second-feet, and in 1918, as a result of irrigation, they had increased to about 5,100 second-feet. Wells that have penetrated the water table in these basaltic areas, almost without exception, yield abundant supplies of water for domestic and municipal use, with but slight draw-down. Yields of more than 50 gallons a minute for each foot of draw-down are not uncommon, and yields of more than 500 gallons a minute for each foot of draw-down are recorded. The Ralph Raumaker well, near Hamer, is about 50 feet deep, and the draw-down is only a few inches when the well is pumped with a 5-inch centrifugal pump that discharges about 450 gallons a minute. The Pleistocene basalts are fresh, and the cavities in them are as a rule open. The openings that allow ground water to move through the lavas are the clinkery contacts of one flow with another and the vertical joints or shrinkage cracks that characterize these flows. The open spaces in extrusive basalt through which water can move, exclusive of those due to later disturbances of the rocks, are listed in approximate order of usefulness as follows:

1 —— Large open spaces at the contact of one lava flow with another or of a lava flow with the underlying formation.
2 —— Interstitial openings in cinders, aa, and subaqueous lava formed during deposition.
3 —— Open spaces in joints formed by shrinkage of the basalt in cooling.
4 —— Tunnels and caves produced by liquid lava flowing out from under a hardened crust.
5 —— Vesicles and cavities due to the expansion of gases during the cooling of the lava.
6 —— Tree molds, resulting from lava surrounding a tree and solidifying before the tree has burned away.

The upper crust of a lava is generally rough and broken because of movement within the flow after the crust has formed. Inundation by another lava flow never completely fills these irregularities. Consequently many openings, some of which are extensive and capable of holding or transmitting large quantities of water, occur between successive beds. Beds of cinders are not extensive in the Snake River Plain and occur chiefly as buried cones. Drillers often report red cinders in drilling, but generally they refer to beds of red doughy masses that lie at the bottom of a lava flow or to the fragmental part of aa lava. Aa lava flows are the most permeable of the lava beds. This brecciated rock produced by granulation of the lava stream while

in motion is, prior to weathering, probably the most permeable rock formation on the face of the earth. The blocks are rough and angular and resemble talus. They cover an appreciable area of the Snake River Plain, and drillers report the aa clinkery lava in wells.

Subaqueous lava, of which the Bliss basalt is typical, differs considerably from aa but is also brecciated and permeable. In many places where lava flows rest on older sediments they exhibit a subaqueous phase at the contact. Thousand Springs and most of the other large springs in the Snake River Canyon issue from basalt of this type. Cinders, aa, and subaqueous basalts, because of their fragmental character, yield readily to weathering and hence are commonly the first to become watertight with age.

Lava tubes are common in the Snake River Plain, and it is through a system of ramifying tubes that the pahoehoe type of lava was distributed from the vents. On relatively steep slopes these tubes are left open after the flow stops, and the lava drains out of them. Some of these tubes are as much as 50 feet in diameter and several thousand feet long. The Sand Springs basalt, which is about 300 feet thick near Thousand Springs, contains many open tubes. Lava tubes are sometimes encountered in drilling. Stearns was lowered on the drilling cable into the new Idaho Falls city well, near the mouth of Willow Creek to examine a cavity about 8 feet in diameter that was struck about 100 feet below the surface. In the J. A. Melton well, west of Mud Lake, a lava tube full of water was encountered. Large tubes full of water were also encountered in the Wilkinson and Cox drainage tunnels on the South Side Twin Falls tract.

Joint cracks due to shrinkage of the basalt at the time of cooling range from a fraction of an inch to several feet in width and in general are nearly vertical. They are useful in the transmission of water from one lava flow to another one below and doubtless are the means by which irrigation water in many places percolates readily downward to great depths. The Goyne sump, in sec. 10, T. 9 S., R. 23 E., serves as an outlet for drainage water on the North Side Minidoka project. It is about 100 feet deep and 8 feet in diameter, and all except the upper few feet is in basalt. About 22 second-feet of water will sink continuously in this pit, but when 25 second-feet is allowed to enter, the pit fills up, because its transmission capacity has been reached. Wells drilled into the lava on this project and near Roberts have been used successfully for drainage. The fact that many of the wells drilled in basalt blow and suck air with changes in barometric pressure is further evidence of the connected systems of cracks and caverns that occur in these lavas.

Vesicles and cavities caused by the expansion of gases during the cooling of the lava are usually disconnected, and hence water cannot move readily through them. Near the top of a lava flow these vesicles

are commonly so numerous as to give the crust a spongy appe
and this part is generally more permeable than the main mass
flow. Drillers frequently state that this spongy lava yields
volumes of water. The spongy or vesicular lava is in fact com
not the source of these large yields, however, but its presence in
that the drill has passed from one flow to the top of another
water is obtained largely from the open spaces at the contact
lava beds or from the numerous joint cracks which occur at
of the flow rather than from the vesicles.

In places where lava flows have entered forests tree molds are
mon and form an appreciable amount of the voids in the lava.
Craters of the Moon National Monument there are certain
areas where tree molds are plentiful, and molds full of water hav
encountered in drainage tunnels on the Twin Falls tract. Ho
if the Snake River Plain was nearly treeless during the accum
of the lava flows, as it is at present, it is not likely that tree mo
sufficiently numerous to be very useful in the movement of
water.

In small areas in the valley water in the basalts is confi
impermeable beds of clay and loess, of sufficient extent to
slight artesian heads. This condition occurs in the vicinity
Lake, where there are flowing wells with large discharge and
specific capacity.

A somewhat similar artesian condition has been developed in
areas in the Aberdeen-Springfield and Twin Falls South Side
as a result of irrigation. In the Twin Falls South Side tract the
wells have proved effective in the drainage of swampy land.
wells, like those at Hamer, have low head but yield abundantly.

Dike systems and sills have not been recognized in any of the
developments except at Bliss Spring, although they must exist
parts of the Snake River Plain. From the wide distribution
vents and the absence of dikes in the walls of the Snake River
they are probably too scattered to affect the circulation of water
locally.

The rate of flow of the water through the basalt is depende
the geologic structure. Thus in the Twin Falls South Side
which lies from 50 to 300 feet above the Snake River, on
bordering the Snake River Canyon, swampy tracts have
through irrigation, whereas on the opposite side of the canyon
also irrigation water is applied in large amounts, there are
no seeped areas and the water table lies far below the surface
condition is interpreted as being caused by loess beds on the
side, which are intercalated with the lava flows and which
artesian wedges, whereas on the north side these loess beds have
cut through by former channels of the Snake River. These

were later filled with permeable basalt and now form
wedges in which no loess occurs. The Sand Springs basalt
fills such a canyon, and from it issue many of the largest springs.
the north side is favored with natural drainage channels, but
ake River has never cut a channel farther south than the present
the vicinity of Twin Falls. This means that the South Side
none of these lava-filled canyons through which ground water
rapidly away from the project. Furthermore, a study of
logy and water table indicated that the greater part of the
River Plain from Big Bend Ridge, near Ashton, to King Hill
these ancient canyons through which the ground water
freely.

ate at which the water moves through the basalt is difficult
mine because it varies from place to place according to the
ility of the lava, the geologic structure, and the hydraulic
The daily records of the flow of Blue Lakes Spring in sec. 28,
17 E., from 1917 to 1920 afford a basis for estimating the
movement of the ground water tributary to it. The contour
the water table (pl. 19) shows that the water that supplies
rings passes under Wilson Lake and the First Segregation of
Side tract at Hazelton. There is no irrigated area between
Segregation and Blue Lakes, and therefore a time interval
derground travel between the two points can be determined by
ing the observed flow of Blue Lakes Spring with fluctuations
se and hence the seepage loss of water on the North Side
and the amounts of water in Wilson Lake, which loses at a
ate when containing much storage water.[47] The records of
iversions and of storage in Wilson Lake are plotted by 15-day
in plate 11. During the early part of each irrigation season
ake drops rapidly, with corresponding decreases in percola-
On the other hand, there is an increase in losses during
period from increased irrigation diversions. Records are
ilable for Wilson Lake during the winter.

udden increase in diversions and lake storage during the
of May 1917 is clearly reflected by the increased discharge
Lakes Spring during the first part of August, 3 months later,
in plate 11. The time between the average of the summer
diversions in that year and the corresponding peak in the
Blue Lakes Spring in 1917 was about 3½ months. A similar
occurred in 1918. In 1919 the time between the seasonal
only 2 months. That year, however, was one of deficient
ply, causing deliveries to the First Segregation to be less
the average in normal years, hence contributions to the

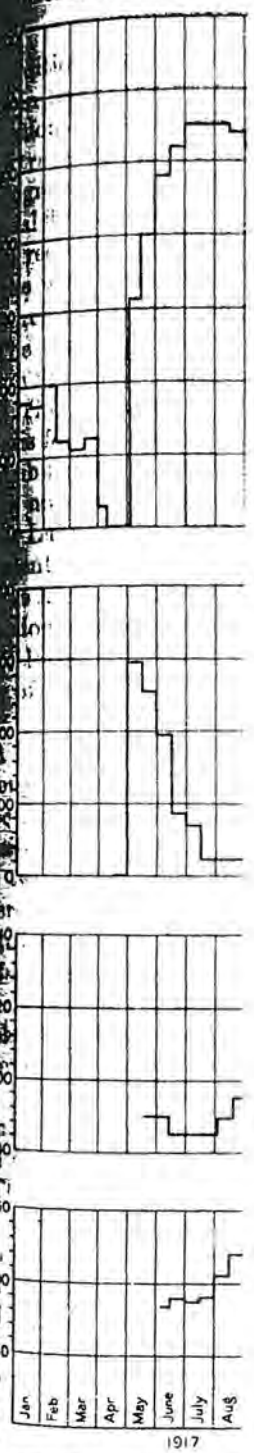
T., Success and failure of reservoirs in basalt: Am. Inst. Min. Met. Eng. Tech. Pub. 215,

water table from irrigated lands were very small. The seasonal flow of Blue Lakes Spring in 1919 was about 3 to 3½ months than the peak at Wilson Lake, and probably the fluctuations in year reflected the ground-water contributions from Wilson Lake much greater extent than the contributions from irrigated lands.

The large amount of water diverted through the canal la October 1919, after the canal had been dry for a month, clearly c the increased flow at Blue Lakes Spring 3 months later. (See pl The time between the peak diversions in 1920 and the maximum of the spring was about 3½ months, although the period when canal was dry in the later part of September 1920 could be det only 3 months later at Blue Lakes Spring.

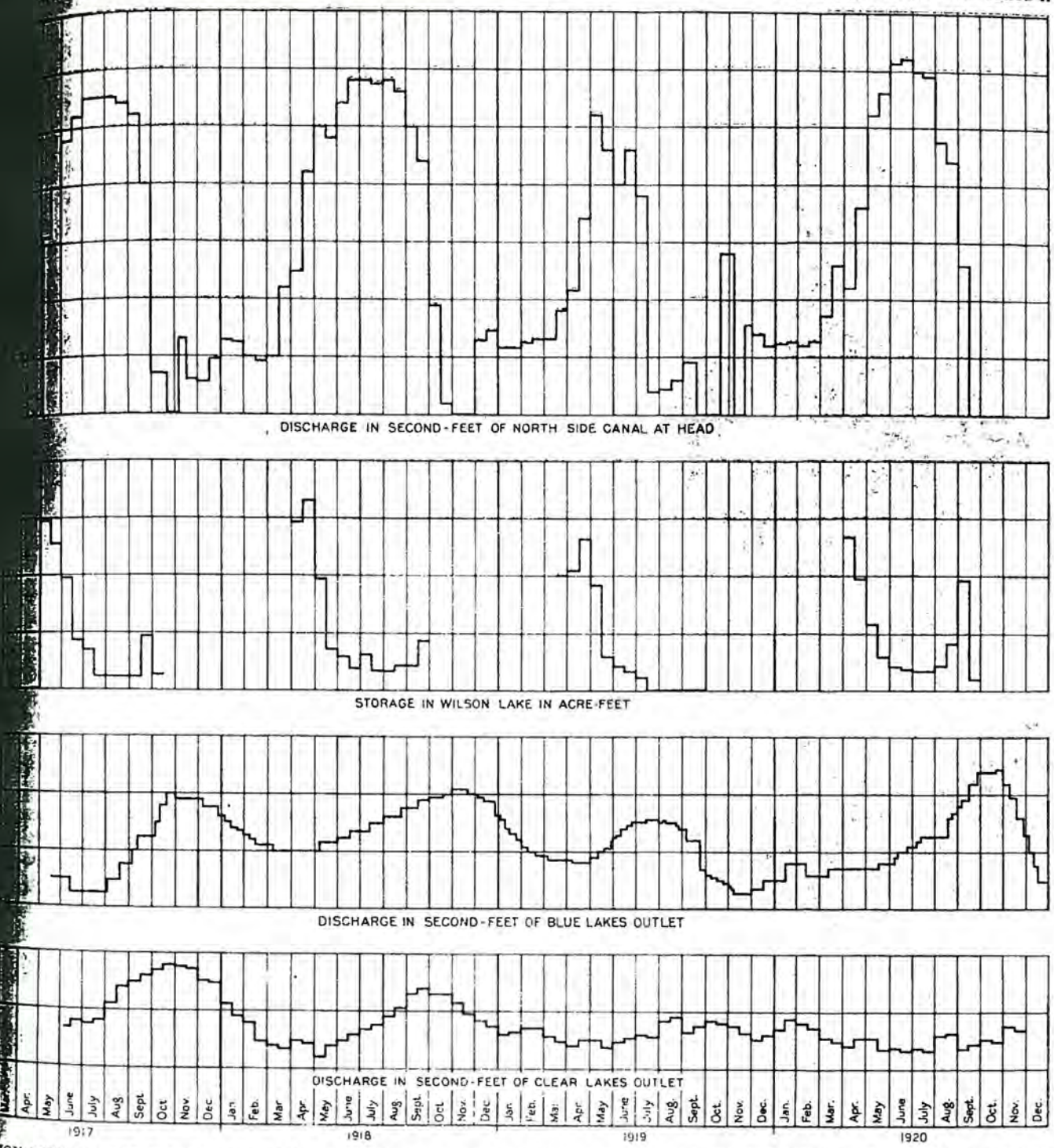
It thus appears that the time interval between seasonal peak about 3½ months but that sudden large increases in the contribu to the water supply require only about 3 months to travel Wilson Lake and the First Segregation to Blue Lakes Spring point half a mile south and 1½ miles west from Hazelton is abou center of ground-water contributions from the First Segregation the Wilson Lake region. This point is 15 miles east of Blue L Spring. Thus about 3½ months is required for the ground water move 15 miles. The average seasonal rate of movement of gro water between the two points is therefore about 750 feet a d whereas under certain conditions it apparently travels about 850 f a day through the same permeable basalts underlying this area.

The altitude of the water surface in the town well at Hazelton 3,836.2 feet on July 2, 1917, whereas that of the outlet of the spri that supplies Blue Lakes is about 3,300 feet. The difference in water surface between the two points, 16½ miles apart, is therefo 536 feet, and the average slope is 32.5 feet to the mile. It appe from the ground-water contours of this section on plate 19, howev that the water table from Hazelton toward Blue Lakes has an aver fall of only about 20 feet to the mile, which in 16½ miles would amou to 330 feet, or about 206 feet less than the total difference in altitu between the water table at Hazelton and that at Blue Lakes. Th drop in the water table of 206 feet is probably concentrated in a sh distance above the springs. The springs are about 160 feet high than the Snake River and about three-quarters of a mile from making an average fall from the spring outlet to the river of 214 f to the mile. If the ground-water cascade of which Blue Lakes Spri is the outlet continues on this gradient it would thus extend for abo a mile in an easterly or northeasterly direction before reaching main underground flow, which is moving westward under the pla north of the Snake River.



RELATION BETWEEN TI

om irrigated lands were very small. The
Lakes Spring in 1919 was about 3 to 3½
at Wilson Lake, and probably the fluctu
the ground-water contributions from Wil
xtent than the contributions from irrigat
mount of water diverted through the
after the canal had been dry for a month,
ow at Blue Lakes Spring 3 months later.
en the peak diversions in 1920 and the m
was about 3½ months, although the peri
n the later part of September 1920 could
ater at Blue Lakes Spring.
ars that the time interval between seas
s but that sudden large increases in the
upply require only about 3 months to
d the First Segregation to Blue Lakes
south and 1½ miles west from Hazelton
l-water contributions from the First Seg
region. This point is 15 miles east of
bout 3½ months is required for the grou
The average seasonal rate of movement
he two points is therefore about 750 f
rtain conditions it apparently travels abou
same permeable basalts underlying this
the water surface in the town well at Ha
ly 2, 1917, whereas that of the outlet of
e Lakes is about 3,300 feet. The differe
ween the two points, 16½ miles apart,
average slope is 32.5 feet to the mile.
vater contours of this section on plate 19
le from Hazelton toward Blue Lakes has
20 feet to the mile, which in 16½ miles wou
ut 206 feet less than the total difference
table at Hazelton and that at Blue Lak
table of 206 feet is probably concentrated
springs. The springs are about 160 f
iver and about three-quarters of a mile
fall from the spring outlet to the river of
ground-water cascade of which Blue Lak
ues on this gradient it would thus extend
ly or northeasterly direction before rea
flow, which is moving westward under
River.



TION BETWEEN THE USE OF IRRIGATION WATER ON THE TWIN FALLS NORTH SIDE TRACT AND THE FLOW OF BLUE LAKES AND CLEAR

vidence of the relatively rapid rate of ground-water ion is afforded by the fact that the ground-water con- more than 600,000 acre-feet annually from the North pear each year as underground run-off without causing se in the water table under the project. The average ion in the water table amounts to about 6 feet, resulting from irrigation water, but each year the water surface turns to practically its former level, which is several below the ground surface.

ge of Clear Lake outlet, the only spring beside Blue for which daily records are available, is shown by plate uations recorded at the Clear Lake gage do not afford ulating the rate of flow, because the irrigated area that the water that emerges at this point extends for many st and is not localized enough to indicate the source of ter. The low flow of this spring in 1919 was caused by a r supply for irrigation, but the failure of the spring to 1920 as it was in 1917 and 1918 is probably due to the of the Jerome Reservoir in the fall of 1919, part of the from that reservoir evidently having contributed to the r Lake.

UNDIFFERENTIATED BASALT

proportion of the flows throughout the Snake River Plain the early Pleistocene group, but in many areas these are concealed beneath later deposits, and in others it is im- th the available data, to distinguish definitely between oups. In the Mud Lake region, and to some extent else- relations to glacial and other deposits and the degree of show that most of the flows in the vicinity of the present (exclusive of those grouped as Recent black lava) are as ate Pleistocene, and some are possibly Recent. Along the er between the Minidoka Dam and King Hill the flows "undifferentiated basalt" on plates 4 and 5 are older than ocene flows described individually. Upstream from the Dam the basalt thus grouped includes flows both younger than those downstream.

leistocene flows in general are readily distinguished from the alts by their comparative freshness. In most outcrops of ne basalt weathering has penetrated less than an inch. alt is commonly gray to black, fine-grained, and vesicular, many exposures has small feldspar and olivine phenocrysts o the unaided eye. Most of the flows are pahoehoe, whereas of the Recent black lavas are aa. One of the few aa flows in es overlies the American Falls lake beds north of American and thus belongs to the later Pleistocene flows. Samples of

drill cuttings taken at intervals of 1 to 5 feet in the Y
dry hole north of Minidoka, were examined by H. T.
the results given below. Drillers' logs of other wells
the region show broadly similar variations in the charact

Log of Yarnell well, north of Minidoka

Soil consisting of loess and wind-blown quartz sand
Blue basalt, red at base, containing olivine crystals 1 to 3 millimeters in diameter. Vesicular at top and base of flow
Loess soil
Blue basalt flow with phenocrysts of olivine and feldspar. The uppermost and lowermost 3 feet are composed of red vesicular lava
Loess soil, baked red
Reddish-brown basalt, changing downward into extremely dense basalt except at 68 and 72 feet and at the base of the flow, which is vesicular
Blue-black basalt flow, with vesicular rock at 88 to 94 feet. Number of olivine grains greatly increases in densest part of flow, which is at 98 feet
Wind-blown soil
Blue basalt containing small amount of olivine and extremely dense at 110 feet
Wind-blown soil
Olivine basalt
Wind-blown soil
Brownish-blue basalt, with abundant olivine discolored by weathering
Wind-blown soil
Reddish vesicular olivine basalt except for dense rock at 173 feet
Wind-blown soil
Gray-blue basalt, with olivine and clear feldspar crystals in abundance and a dense streak at 182 to 194 feet. At 197 feet the cuttings change to red vesicular rock, indicative of base of flow
Olivine basalt with only a thin vesicular band at top and bottom
Wind-blown sand
Blue basalt, extremely dense in lower 15 feet; evidently bottom of hole is near the bottom of the flow but not quite through it

This well, if continued deeper, will encounter water,
drilled to discover gold ore, which, of course, does not
bedded with the basalts as the driller believed.

Individual flows are commonly 10 to 75 feet thick, b
flow piles up in a preexisting drainage channel its thick
abruptly increase. In the early lavas exposed in the w
canyon beyond the Minidoka Dam local thickenings resul
such fills are relatively small. The aggregate thickness o
flows exposed in this vicinity is 600 feet. Northwest of St
a well 1,050 feet deep failed to reach rock recognizable as p
cene. In Laidlow Park, a short distance south of the Crat
Moon National Monument, a well penetrated 918 feet
before reaching the older silicic lava. It is probable that o
of the central part of the Snake River Plain the Pleistoc
aggregate fully 1,000 feet in thickness.

SEDIMENTARY BEDS IN THE LAVA

Loess and clay are intercalated in the Pleistocene flows.
places, as near Trail Springs, there is also some gravel.
canyon of the Snake River these materials are especially
near the new Twin Falls bridge. The sedimentary beds ar
where thin as compared to the basalt. Some are thick eno

intervals of quiescence of considerable length between
The products of any single eruption covered only a small
plain, and meanwhile soil accumulation continued undis-
where. The thickness of an individual loess bed depends
nearness to a source of supply than on the time interval
uptions. For example, only a short distance west of the
area extensive outcrops of incoherent lake beds have long
sed to the wind. During the time required to accumulate
oess on lava in this vicinity only an inch or two will prob-
eposited on the basalt 50 miles to the northeast. In spite
factors of this sort it appears to be broadly true that the
uniformity of cover of loess soil on a given area of basalt
of the age of the flows. On this basis it is postulated, for
that the basalt south of the river near Twin Falls, which is
ywhere covered by deep soil, is materially older than that
he river in the same locality, where numerous areas of
posed and most of the soil is comparatively thin.

places masses of sedimentary material, so thick or exten-
they can be separately mapped, are associated with the
flows. Each of these masses that has so far been recog-
described on succeeding pages.

PLEISTOCENE FORMATIONS ABOVE THE CANYON OF SNAKE RIVER

LAVA FILLS

umerous displacements of the Snake River and its tributaries
lows have caused it to aggrade behind the dams thus caused,
own through these dams, and to build accumulations of
short distances beyond them. The local formations dis-
d along the present canyon of the river and described
(pp. 65–84) have all resulted more or less directly from such

Snake River before displacement by the Sand Springs basalt,
mple, was flowing in a basaltic canyon 500 feet deep with
vertical walls. The inflowing lava was pahoehoe basalt that
great volume from a cone on the north side of the river.
va had first spread laterally on the plain above, but when
it reached the north rim and cascaded into the canyon it
orarily built up a lava delta. The sudden change in grade of
ace on which the lava flowed accelerated the draining of the
tube leading from the vent and tended to make this the
drain. Thus, from the time the lava began cascading into
yon the flow tended to cease spreading laterally, and most
va flowed toward the canyon.

ough canyon lava fills in this area are impressive because of
length and thickness they do not ordinarily represent greater

outpourings than occurred elsewhere on the plain. Instead of sheets, V-shaped lava fills were formed.

As some of these lava fills are 50 miles long and 300 to 500 feet thick, it is obvious that they must have retained much heat. Here as elsewhere [48] this was doubtless accomplished by movement of the lavas through tubes of its own construction beneath an insulating crust. In all localities where the Snake River was displaced the flow filled the canyon at the original point of entry and then because of topographic control spread along it, chiefly but not exclusively downstream. The lava rarely extends more than a fraction of a mile on the south side of the canyon, except where it fills tributary valleys owing to the easier escape down the canyon.

In all places studied in detail the lava had completely obliterated the preexisting canyon for several miles. Then it had become confined between the walls of the canyon for a few miles and stopped. The Sand Springs flow, for example, obliterated the Snake River Canyon for 50 miles downstream beyond its point of entry and stopped 10 miles farther down. The ends of the flows are not now exposed except where they are cut through by the Snake River. They are generally about 20 feet high, or the same height as if the flow had spread out on the plains, even though the lava fill upstream may be 500 feet thick.

During such an accumulation of lava in the canyon, especially in the early phases of an eruption, the margin of a flow advancing upstream was continually entering ponded waters and producing local steam explosions. One such explosion is definitely known to have formed a cinder and ash cone more than 200 feet high. Most of the products of these explosions were later buried by the sediments deposited behind the lava dam; hence they are seldom found.

It is not unusual to find lava several miles upstream from the point where the flow entered the canyon. The downstream advance of such a flow was accompanied by many activities and changes. The following hypothesis is offered to account for the pillow lava and glassy brecciated pahoehoe at the base of the lava fills.[49] Where the stream bed was underlain by saturated gravel or other permeable materials the lava that flowed over such wet ground was comminuted or brecciated by steam explosions. This extremely permeable phase of the pahoehoe made the dam start leaking at the outset. The leakage was continually available for minor explosions and for the formation of pillow lava at the downstream margin. To a less extent the same permeable material is found at the contact of the lava with the canyon wall, apparently because steam rising in most places along

[48] Stearns, H. T., Geology and water resources of the middle Deschutes River basin, Oreg.: U. S. Geol. Survey Water-Supply Paper 637, pp. 145–146, 1931.

[49] Stearns, H. T., Origin of the large springs and their alcoves along the Snake River in southern Idaho:

the contact was available for the disruption of the lava. As the hydraulic gradient of the water moving through the lava dam was probably somewhat steepened by the damming effect of the debris caused by the steam explosions at the downstream margin and by the progressive widening of the dam, the water table in the lava dam may have risen simultaneously with the accumulation and cooling of the lava, so that it may have been fairly close to the hot lava at all times.

Because of the narrowness of the canyon, the newly created lake had small storage capacity, hence it may have overflowed even while the eruption was in progress, unless leakage through the dam with the added effect of steam explosion was sufficient to dissipate the inflow. These agencies, however, could not have sufficed to dispose of the inflow of so large a river as the Snake during prolonged eruptions. In fact, a dam 50 miles wide and only a mile across would be entirely different from any known engineering structure. As the dam was permeable, the seepage, instead of following a few well-defined devices, must have built up a water table with a fairly uniform slope from the surface of the impounded lake to the toe of the dam.

At the moment of overflow the great volume of water in the Snake River was sufficient to establish a course along the southern margin of the new lava flow until it reached the point where the lava no longer filled the canyon. At this point the water tumbled back into its former course and formed a cascade on the surface of the lava fill until the end of the flow was reached, where it again returned to normal grade in its prelava channel. The river was influenced by topographic irregularities near the margin of the lava and at some places did not follow that margin very closely. For example, it established a course half a mile to 5 miles south of the Sand Springs lava fill from the lake it created near Burley to Shoshone Falls. Here it again returned to the edge of the lava, which it followed to Salmon Falls Creek and then reentered its former canyon.

On the irregular surface of the lava fill the river took a meandering course that soon became established. As the downcutting proceeded remnants of the fill were left first on one side of the river channel and then on the other as detached benches. While the new channel was being established there was doubtless considerable leakage into the lava. In at least one place this leakage was sufficient to give rise to large springs at the toe of the dam.

When the Snake River was displaced by lava flows and had taken its new course it faced the great task of draining the lakes so formed and of resuming its former grade. While the outlets of the lakes were being cut down the debris carried by the river was settling in the quiet waters behind the lava dams. In some of the lakes this process of sedimentation was more rapid than the cutting, so that the

lakes filled with silt before the outlets were appreciably reduced. In others, where the new course was in relatively weak lake beds and one abutment of the newly formed lava dam was in lake beds also, the outlet was reduced so rapidly that there was time for only a thin veneer of gravel to form in the lake bottom. Thus, the texture of the lake sediments would be dependent in some measure upon the size of the lake and the weakness of the dam.

While a lava-dammed lake was being filled with sediment and its outlet lowered, the Snake River actively aggraded its bed at the toe of the dam. The river cascading down the dam with a gradient in some places as much as 150 feet to the mile, loosened huge blocks of lava and rolled them to the toe, where the sudden flattening of the grade made them drop. The jointing in basalt permitted ready plucking, so that water-worn boulders 5 to 12 feet in diameter are common. During the early stages the debris accumulated rapidly enough to form a steep fan overlapping the toe of the dam and extending a mile or more downstream. With the flattening of its gradient and the subsequent reduction in quantity of debris supplied, the river ceased to build its fan and began to destroy it. The decreased velocity of the river at this stage permitted only the smaller material to be removed, and the large boulders are left as a residual concentrate much like that seen at hydraulic placer mines. Spectacular groups of boulders formed in this way can be seen in Hagerman Valley and near King Hill. They resemble the coarsest of morainal deposits. The alluvial fan near King Hill was only partly reworked by the river and now forms steeply sloping alluvial terraces that border the river. Boulder deposits of this type served as valuable field criteria in determining the location and number of the places where the Snake River had been ousted from its channel by lava. Such groups of boulders occur at the mouth of Rock Creek in connection with the lava dam at American Falls, and there are several similar occurrences in Hagerman Valley (pl. 12, *A*) and near King Hill.

Where a lava fill, such as those described above, has been largely removed through reexcavation of the canyon, its former presence is commonly recorded by benches composed of residual masses of the fill clinging to the canyon walls. Similar topographic forms, however, can be produced in other ways. Where a series of essentially flat beds of different degrees of resistance to erosion is cut into by a stream, a bench of somewhat similar appearance commonly results. Where the canyon of the Snake River is cut in basalt alone, the flows are of so nearly equal resistance that only a single conspicuous example of this type of bench was noted. This bench commences near Milner Dam, where it is so small as to be hardly noticeable. It increases in size in a short distance downstream, and between Murtaugh and Shoshone Falls is a conspicuous topographic feature on both sides of the river.

(See pl. 9.) The part of this bench above Shoshone Falls lacks the hillowy surface commonly characteristic of a youthful intracanyon flow. Good exposures near Twin Falls seem to show that the bench was formed because of the resistance of a massive layer of basalt at a time when a temporary base level was established by the resistant andesite now exposed at Shoshone Falls. Benches of this kind can be distinguished from remnants of intracanyon fills by the absence of any unconformity at the junction of bench and canyon wall.

CEDAR BUTTE BASALT

In secs. 22, 23, 26, and 27, T. 8 S., R. 29 E., there are two buttes, one of them known as "Cedar Butte" (pl. 6), which are former vents of a large basaltic dome. Like most of the great lava producers of the Snake River Plain both of them lack well-formed craters. The basalt spread southward from the cones as massive pahoehoe, with lesser amounts of aa. The lava is an aphanitic blue basalt containing phenocrysts of fresh green olivine as much as 3 millimeters in diameter. On the eastern knob of the northern butte there are a few cinders.

Prior to the eruption of the Cedar Butte basalt, the Snake River occupied a course roughly parallel to the present one but a few miles north of it, between a point near Blackfoot and the mouth of the Raft River. The Cedar Butte eruption filled at least 20 miles of this channel, damming the river and forming a lake about 40 miles long and 12 miles wide, which extended from Massacre Rocks nearly to Blackfoot (pl. 4).

AMERICAN FALLS LAKE BEDS

Sedimentary beds.—Along the Snake River from Springfield nearly to Massacre Rocks stretches a series of yellowish-white to buff lake beds, which are regarded as produced by sedimentation back of the dam described above. (See pls. 4, 6.) They form steep bluffs about 150 feet high along the north bank of the river from the American Falls Dam to the Narrows, a distance of about 5 miles. They consist of even-bedded, partly consolidated silt, clay, and sand, with local pebbly lenses near the top and a 6-foot bed of laminated basic tuff 50 feet below the top of the series southwest of American Falls. Large parts of them have been removed by erosion from the south bank of the Snake River below the dam. Along the north side of American Falls Reservoir just at the shore line, or about 100 feet below the highest deposits of the lake, basalt is interstratified with the sedimentary beds.

Although the precise stratigraphic relations between the tuff and basalt were not established because of the lack of adequate topographic maps and the distance between their outcrops, it seems likely that the tuff resulted from explosions caused by the basalt entering water.

The absence of tuff cones in the adjacent area supports the idea of local origin.

Near the junction of the Low Line and High Line canals on the Aberdeen-Springfield project large basalt blocks lie scattered over the surface of the lake beds 100 feet or more from their parent outcrop. These blocks were presumably plucked from the basalt along the shore of the ancient American Falls lake and rafted away on ice cakes. The altitude of this place of plucking is 4,450 feet, which tends to establish the altitude of the shore line of the ancient lake. In some places a definite shore line exists near the High Line canal of the Springfield-Aberdeen project, but in others the lake beds grade imperceptibly into the loess covering the basalt of the plains. A well 178 feet deep in sec. 7, T. 4 S., R. 31 E., did not penetrate any sedimentary beds, hence the lake did not extend this far to the northwest. The exposure of the sedimentary rocks farthest downstream is in sec. 9, T. 8 S., R. 30 E., about 2½ miles above the point where the Cedar Butte basalt crosses the present canyon of the Snake River in Massacre Rocks. Remnants of the basalt crop out about 170 feet above the river on both sides a quarter of a mile below this point.

The completion of the American Falls Reservoir has caused the submergence of the lower part of the lake beds upstream from American Falls, but wave action has undermined the banks, exposing the upper beds. From American Falls to the mouth of the Portneuf River, along the southeast side of the reservoir, the top layer becomes progressively coarser and grades from fine shot-sized gravel through all sizes to huge boulders near the mouth of the Portneuf River. Red and white quartzite gravel predominates, suggesting that most of the gravel was derived from the Portneuf and adjacent tributary streams rather than from the Snake River. From the Portneuf River around the head of the reservoir to a point south of Springfield younger gravel at or slightly above the reservoir level obscures the lake beds, if they are present. The upper surface of the lake beds on the south side of the Snake River, with its veneer of later gravel, corresponds to the Gibson terrace described by Mansfield.[50]

A flowing well in the center of sec. 15, T. 4 S., R. 32 E., is reported by the driller to have encountered 265 feet of clay and silt with some beds of colored gravel. A 36-inch log of redwood was drilled through at 190 feet. One piece of bone, too small to be identified, was found in the lake beds. It was not fossilized like those from the Hagerman lake beds. Leo Lee, of Aberdeen, obtained several bones and teeth which he states were removed from these beds during the excavation of the west abutment of the American Falls Dam. They have been identified by J. W. Gidley, of the Smithsonian Institution, as being

[50] Mansfield, G. R., Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. 713, pp. 16-17, 1920.

bones of *Elephas* sp., of Pleistocene age, probably late Pleistocene. These beds rest on the eroded and deformed Eagle Rock tuff and Massacre volcanics and are unconformable on some of the basalt of the plains. In a general way they resemble the Hagerman lake beds in their lithology and undisturbed condition, but their shore line is 4,500 feet above sea level, or about 1,050 feet higher than that of the Hagerman beds.

The American Falls lake beds are generally so fine grained as to be poor water bearers, but in the vicinity of the reservoir the more sandy members carry sufficient water for domestic use.

Basalt member.—Gibson Butte rises several hundred feet above the Snake River in sec. 32, T. 3 S., R. 32 E., and is among the largest and most prominent basalt domes on the Snake River Plain. Its surface is heavily veneered with loess, but the character of the butte is shown by a few small outcrops of scoriaceous aphanitic gray basalt and a broad, shallow crater on its summit.

Young alluvium mantles the south and west sides of the butte, but on the southeast and east it abuts against the ancient alluvium of the Gibson terrace, which corresponds to the upper part of the American Falls lake beds. Across the Snake River and practically at the foot of the butte occurs a basalt flow whose sparse soil cover indicates youth. This condition and the fact that it seems to have come from the north indicates that it had no connection with the eruptions from Gibson Butte. Farther downstream much basalt is definitely intercalated with the American Falls lake beds. Other patches of basalt similar in character and stratigraphic position extend as far downstream as American Falls. The most southwesterly of these outcrops differs from the rest in that it contains tiny phenocrysts of olivine. Although this difference by itself does not prove that this basalt had a different origin from the rest, such an assumption is strengthened by the fact that there is some evidence that the basalt fills a depression cut in the lake beds instead of being merely intercalated in them.

So far as can be judged, the basaltic member lies at an average depth of 100 feet below the top of the lake beds. The basalt thickens northeastward toward Gibson Butte, with corresponding thinning of the overlying sediments suggesting that Gibson Butte is the source of this lava. Near the old shore line the basalt is only 1 to 10 feet thick and locally has the characteristics of lava that flowed under water. As much of the basalt does not have these characteristics, the lake may have been shallow at the time of eruption.

The basalt was, at least in part, buried under lake beds and alluvium at the time the lake was tapped by the Snake River, and therefore it had no effect on the original position of the channel cut by the river. The river started to cut down along the north shore of the former lake,