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CHARLES D. WALCOTT, DIRECTOR

# GEOLOGY AND WATER RESOURCES

OF

## A PORTION OF EAST-CENTRAL WASHINGTON

BY

FRANK C. CALKINS



WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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# ILLUSTRATIONS.

# LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
*Washington, D. C., June 18, 1904.*

Sir: I have the honor to transmit herewith, for publication in the series of Water-Supply and Irrigation Papers, a report by Mr. Frank C. Calkins on the water resources of a portion of east-central Washington, made in connection with the investigation of the underground waters of the Western States, under charge of Mr. N. H. Darton.

The information contained in this paper is believed to be of value as a help to the understanding of the underground waters of that portion of the country.

Very respectfully,

F. H. Newell,
*Chief Engineer.*

Hon. Charles D. Walcott,
*Director United States Geological Survey.*

# GEOLOGY AND WATER RESOURCES OF A PORTION OF EAST-CENTRAL WASHINGTON.

By Frank C. Calkins.

## INTRODUCTION.

During the fall of 1902 the writer, acting under instructions from Mr. F. H. Newell, chief engineer, United States Geological Survey, made an examination of the water resources of a portion of east-central Washington. The location and extent of the district investigated are shown on the index map, fig. 1.

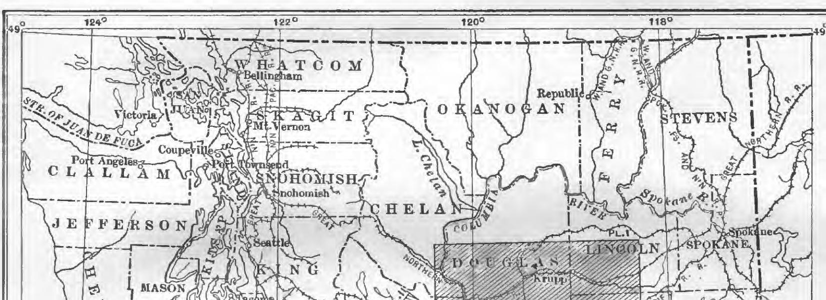


Fig. 1.—Index map, showing location and extent of district investigated.

The objects of the investigation were determined by the natural conditions of the region. The climate of central Washington is arid, and a large portion of the district here especially considered is almost without surface streams available for the uses of mankind. Surface wells capable of supplying perennially even the modest requirements of domestic use can be sunk only in places where conditions are locally favorable. Springs once formed the only source of water for a large area, but they are so widely scattered and often so difficult of access that great labor is sometimes involved in hauling a supply from them. Deep wells, now fairly numerous and rapidly increasing in number, are coming to be considered the most satisfactory sources of water. To determine to what extent the supply from these wells may be increased, and to find whether there is hope of obtaining artesian flows in any portion of the region, were the prime objects of the writer's expedition.

Geologic reconnaissance was carried on at the same time, as a knowledge of the character of the rocks and of their geologic structure is necessary to an intelligent opinion in regard to the possibility of obtaining underground water. A sketch of the geology of the region will, therefore, be incorporated in this report. It is limited on the one hand by the economic purposes which it is meant to serve and by the fact that it is intended primarily for nonscientific readers, and on the other by the hasty character of the work and the lack of a good topographic base, which made impossible a complete geologic survey of the region. The routes indicated on Pl. I show the ground covered and will enable the reader to judge to what extent the opinions expressed are based on actual observation.

Field work was carried on during the four weeks beginning October 6, 1902. The equipment consisted of a spring wagon and team, a saddle horse, used in occasional excursions from the main routes, and a light camp outfit. Mr. D. F. McDonald, a student at the University of Washington, was engaged as teamster, and his intelligent interest in the work enabled him to assist materially in the collection of data.

Mention should be made here of geologic and hydrographic work previously done in this region and in neighboring areas where conditions are similar. Among the earliest scientific explorations in the region whose results have been published were those of Thomas W. Symons, who, in the fall of 1881, explored the Columbia from Grand Rapids to the mouth of Snake River. His report [a] includes a description of the Great Plains of the Columbia and a sketch of the geologic history of the region. The most extensive and important work in the Columbia Plains has been done by Prof. Israel C. Russell, the results of whose investigations in central Washington,[b] southeastern Washington,[c] and northwestern Idaho [d] have appeared in publications of the United States Geological Survey.

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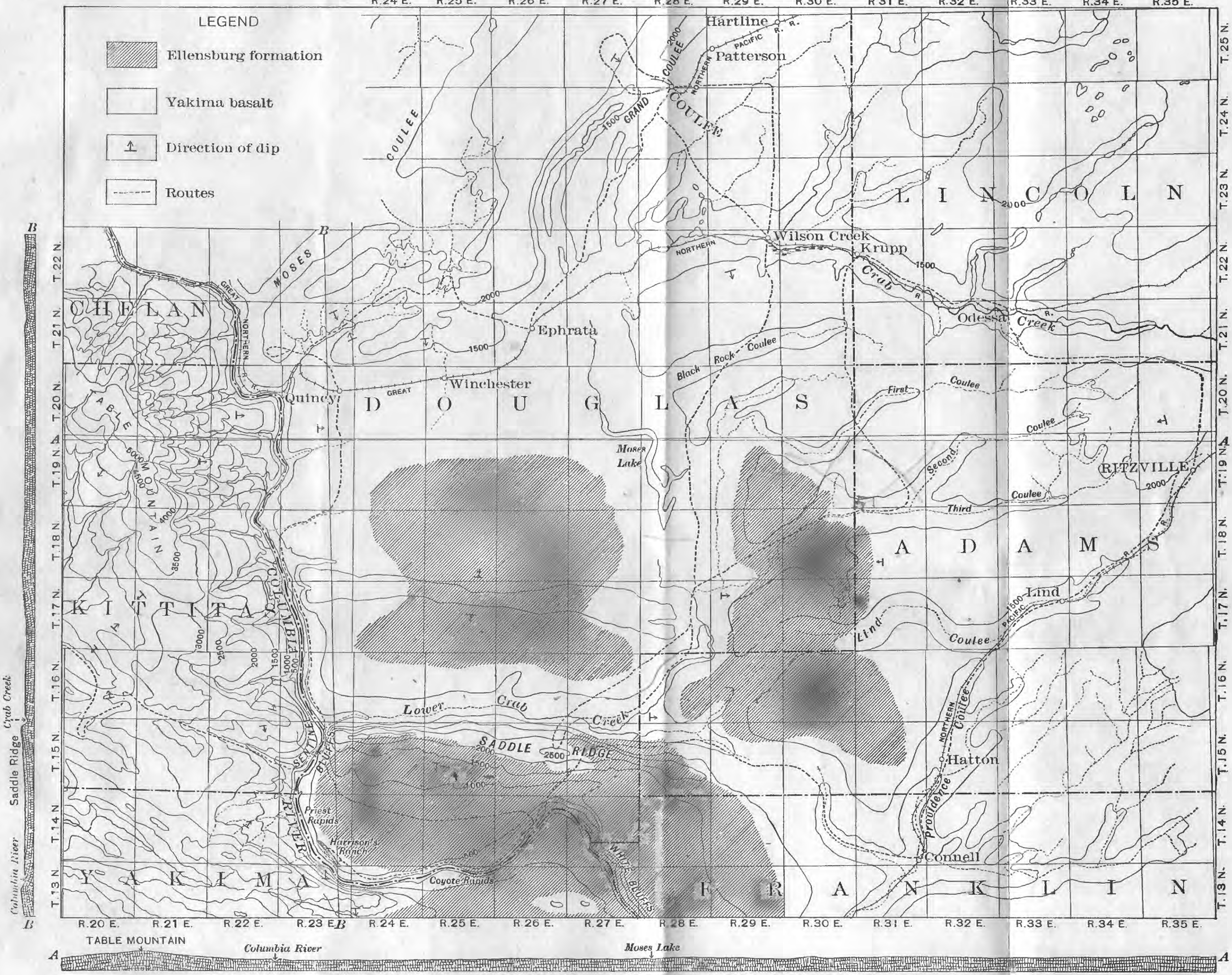
[a] Report of an examination of the upper Columbia River: Forty-seventh Cong., 1st sess., S. Doc. No. 186, 1882.

[b] Russell, I. C., Geologic reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893.

[c] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897.

[d] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Papers Nos. 53 and 54, U. S. Geol. Survey, 1901.




GEOLOGIC SKETCH MAP AND SECTIONS OF A PORTION OF THE COLUMBIA PLAINS, WASHINGTON

TOPOGRAPHY COMPILED FROM U. S. LAND OFFICE PLATS, NORTHERN TRANSCONTINENTAL SURVEY, AND FIELD OBSERVATIONS BY F. C. CALKINS

GEOLOGY BY F. C. CALKINS

1904

Scale

5 0 5 10 15 20 25 miles

Contour interval 500 feet

Datum is mean sea level

Professor Russell's first work in the region was a reconnaissance in 1893, which embraced a large area in central Washington, including the greater part of the district considered in the present report. The conclusions in regard to certain geologic problems reached by the writer after a more thorough examination of the ground differ in some particulars from those of Professor Russell, but they can not claim the authority of final solutions, which must depend on more detailed studies. It is a pleasure, however, to acknowledge indebtedness to Professor Russell for many helpful suggestions contained in his reports.

The water resources of a portion of Yakima County were studied in 1900 by Mr. George Otis Smith.[a] His report is of especial interest because it describes the most successful artesian basin in the State and because his data were based largely on detailed areal work in the Ellensburg quadrangle. The Ellensburg folio,[b] which has recently been published, affords a detailed description of a region where the geologic conditions are similar to those of a part of the area described in the following pages.

The writer's acknowledgments are due to Mr. F. H. Newell and to Mr. George Otis Smith for suggestions and criticisms in regard to the preparation of this report. For assistance in the collection of well data he is indebted to a great number of drillers, ranchers, and others, to mention all of whom by name would require too much space, but to whom he expresses thanks collectively. He would, however, express especial obligations to Mr. Ralph Kauffman, of Ellensburg, who furnished a large part of the information concerning the water resources of Kittitas Valley.

## GEOGRAPHY.

### TOPOGRAPHY.

#### MAIN TOPOGRAPHIC DIVISIONS OF EASTERN WASHINGTON.

The most important topographic feature of Washington is the Cascade Range. This noble chain of mountains, beginning in northern California, extends north through Oregon and Washington, but in the neighborhood of the forty-ninth parallel it loses its mountainous elevation and ruggedness and merges into a deeply dissected but distinctly lower plateau. The average elevation of the Cascade summits is between 6,000 and 7,000 feet, and though comparatively few peaks rise above the latter height, a large number are more than 6,000 feet high. A few great extinct volcanoes, such as the well-known cones of Rainier, Adams, and St. Helens, covered with eternal snows, tower to double the height of the rest.

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901.

[b] Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

The region east of the Cascade Mountains, in which the area considered in this report is embraced, lies for the most part in that broad topographic province known as the Great Plains of the Columbia. This province may be roughly defined as follows: On the south and southeast its boundary is somewhat irregularly marked by the Blue Mountains of Oregon and Idaho, on the east by the Bitterroot and Cœur d'Alène ranges, on the north by a mountainous though not extremely rugged region comprising the Okanogan highlands and the Colville Mountains, and on the west by the Cascade Mountains, which merge into these highlands.

The extensive area thus outlined is by no means a plain in the strict sense of the word; between its lowest and highest points there is a difference in altitude of 4,000 feet. It includes great plateau-like areas in its eastern and northern portions and broad stretches of low-lying sandy waste along the Columbia in southern Washington and northern Oregon. The level expanses are broken, moreover, by hills and ridges, usually of rather gently rounded profile, and the high plateau-like portions are trenched by streams that have formed magnificent steep-walled canyons. But to the traveler upon the broad stretches between the streams the canyons are not visible until he reaches the brink, and the hills and ridges, not rising in general to great heights, are of little importance in comparison with the vast intermediate areas, level or but gently sloping. Thus the inequalities of the surface, while relieving the monotony of the landscape, do not determine its character, nor make its designation as a great plain seem inappropriate to one familiar with the region.

As the western border of the Columbia Plains crosses the area with which this report is especially concerned it will be necessary to make some further statement in regard to its character and its relations to the Cascade Mountains.

The boundary between the Cascade Mountains and the plains varies in sharpness of definition. North of Wenatchee the division is very accurately marked by Columbia River. West of the profound canyon of this river the country is rugged and thoroughly dissected by streams that are generally separated by sharp, or at least narrow, divides. On the east the rim of the canyon is the edge of a plateau standing about 2,000 feet above the river, and although Badger Mountain rises rather prominently above its general level, and its border is notched by canyons tributary to the Columbia, it has the general topographic character of the Columbia Plains.

South from Wenatchee to Sentinel Bluffs the plains are overlooked on the west by Table Mountain, which rises with a somewhat gentle slope from the brink of the river gorge to a broad summit over 5,000 feet above the level of the sea. South of Table Mountain, however, the boundary between the mountains and the plains becomes less


GEOLOGIC SKETCH MAP AND SECTION OF KITTITAS VALLEY, WASHINGTON

TOPOGRAPHY BY U. S. GEOLOGICAL SURVEY AND NORTHERN TRANSCONTINENTAL SURVEY
GEOLOGY COMPILED FROM U. S. GEOLOGICAL SURVEY SHEETS AND FIELD OBSERVATIONS
BY F. C. CALKINS
1904

Scale
2 0 2 4 6 8 10 miles
Contour interval 500 feet

definite, and there intervenes a region intermediate, not only in position but in topographic character, between the two great provinces in their typical aspects.

This border region is characterized by the presence of many well-defined ridges, whose trend varies from east-west to northwest-southwest, and whose even crests rise gently toward the west and merge with the Cascade Mountains proper, while to the east they gradually sink and are lost on the surface of the plains. Between these foothill ridges there are broad valleys which, by the aid of irrigation, have become the richest farming lands of eastern Washington; the aggregate area of these valleys, however, is barely equal to that of the distinctly hilly lands. To a traveler in the valleys the landscape presents an aspect very similar to that of the Columbia Plains, the resemblance being heightened by the fact that the character of the natural vegetation is similar in the two regions. The hills in the landscape, however, give it a certain degree of contrast with the more monotonous scenery of the plains. This borderland between the plains and the mountains, therefore, while not very distinctly marked off from either, is sufficiently well characterized to deserve recognition as a topographic province. It might appropriately be called the foothill region.

## TOPOGRAPHIC DETAILS.

### KITTITAS VALLEY.

The region considered in this report includes a portion of the foothill region, but lies mainly in the Columbia Plains.

Kittitas Valley (see Pl. II), which forms the westernmost portion of the area, is the northernmost of the large foothill valleys. The broad floor of this basin-like depression contains an immense area of fertile farm land. Its configuration is favorable to irrigation from Yakima River and from its numerous small tributaries that flow from the mountains west and north, for there is everywhere a gentle slope toward the principal stream. Yakima River, however, does not flow through the valley from end to end, but only traverses its western portion diagonally and makes an abrupt exit through a profound gorge. The southeastern continuation of the basin is without perennial streams, and since it has a somewhat steeper gradient than the western portion, a large part of it can not be irrigated from the highest ditch now taking water from the river.

The flat lands of Kittitas Valley are separated by a considerable stretch of hills from the Columbia Plains.

### THE DESERT.

That portion of the plains lying just east of the Columbia has a desolate, almost desert-like aspect, and will for the sake of brevity be referred to as "the desert." The greater portion of it is nearly level, but its monotony is relieved by two east-west ridges, the most prominent of which is known as Saddle Mountain. This straight and simple ridge extends to a point about 40 miles east of the river, where it sinks gradually to the level of the plain. It is, in fact, an offshoot from the larger Table Mountain uplift, from which it has been cut away by the Columbia. The basalt cliffs known as Sentinel Bluffs, forming the portals of the gate which the river has made through the ridge, are among the grandest scenic features of the region. Saddle Mountain has a fairly gentle southern slope, but its northern face is strikingly abrupt, being for some miles east of the river a precipitous cliff more than a thousand feet high. Farther to the east this cliff gives way to a rather steep slope.

The surface of the desert is covered with a dry sandy soil, which is constantly shifted by the winds, although its motion is somewhat retarded by a scanty growth of shrubs and grass. The character of the soil and climate and the absence of surface water are conditions that have prevented attempts at cultivation, except along Columbia River and Crab Creek, though the northern border of the district is dotted with the cabins of a few homesteaders. The greater portion of the desert is given over to grazing and is without human habitation.

THE WHEAT LANDS.

Embracing the desert-like area on the north and east is the more elevated portion of the Great Plains of the Columbia, which extend northward into the so-called Big Bend of the Columbia and eastward into Idaho. The topographic character of the part south of upper Crab Creek is that of a plateau dissected by canyons. North of Crab Creek there is a ridge, whose cross profile is that of a broad, flat arch forming the south side of a valley with gently sloping sides. The two last-mentioned features are terminated to the west by the Grand Coulee, beyond which rises an elevation, plateau-like in character, but considerably ravined and with no very broad level areas.

These plateau-like portions of the Columbia Plains are fitted by natural conditions to wheat growing, and have a considerable and an increasing farming population. They will be referred to generally in the following pages as the "wheat lands."

DRAINAGE.

*Columbia River.*—The master stream of the region is the Columbia. Despite its great volume, this river contributes little to the economic resources of east-central Washington. It has several rapids in its course through the region, among them being Priest Rapids, which can not be ascended by steamers except with great danger and difficulty. These rapids extend for about 7 miles and consist of 7 "ripples;" at the foot of the last one the river is deflected by a ridge having a bold cliff for its northern face, along which it flows for several miles. The fatal obstacle to the use of the Columbia waters for irrigation lies in the fact that the stream flows in a canyon with fairly abrupt walls, sunk from 300 to 1,000 feet below the broad, flat stretches to the east, and that its gradient, though fairly high considering the volume of its flow, is much lower than that of the rivers in the foothill region, so extensively used for irrigation.

*Crab Creek.*—The large area of the Columbia Plains embraced in the great sweep of the river, bounded on the north and west by the Columbia, on the south by Snake River, and on the east by the one hundred and eighteenth meridian, has only very insignificant surface streams, the only one that maintains a perennial flow along the greater portion of its channel being Crab Creek, which rises in the vicinity of Davenport, Wash., at an elevation of about 2,500 feet. Its total length, neglecting minor curves and including the lakes in its course and the stretches where it flows beneath the alluvium in the bottom of its canyon, is about 250 miles, about the same as that of Yakima River. Its course through this region is readily divisible into three parts. The first and longest of these, in which the general direction of the stream is nearly from east to west, may be designated upper Crab Creek. The surface flow is perennial along the greater part of this stretch, though at the time of the writer's visit the channel was dry from an unknown distance above Odessa to a point about 3 miles below, where the stream emerges from the gravels in considerable volume. It sinks again below Wilson Creek, to rise near the head of Moses Lake, which probably owes its existence to the formation of a range of sand dunes across the ancient channel of the creek. The dam thus formed, however, is a leaky one, and the waters seep through, to gather below, forming a stream perhaps slightly diminished from its former volume by evaporation in the lake. This southward-flowing portion of the stream may be designated middle Crab Creek. About 15 miles below the lake the stream again takes a westerly direction, flowing in a broad-bottomed, steep-walled canyon. At some point near the middle of this lower course Crab Creek sinks finally, and delivers no surface water to the Columbia at the mouth of its canyon. This west-flowing section of the stream may be designated lower Crab Creek.

*Coulees.*—Crab Creek has only a few branches that contribute to its surface flow throughout the year and a few more that flow during the rainy season, but it has a great number of tributary canyons which are perfectly dry except at periods of unusually heavy rainfall. Many of these are scores of miles in length and of corresponding width and depth. These canyons, dry or containing only small streams disproportionate to their size, are known as coulees. They have all the topographic characters of stream-carved valleys, but it is evident that they could not have been formed by stream erosion under present conditions. Their origin must be referred to a prehistoric period in which the region had an abundant rainfall and was well watered by surface streams. These branching systems of dry canyons represent ancient river systems.

The most important of the branches of the ancient Crab Creek system, except Grand Coulee, whose peculiar history separates it from the others, is Lind Coulee, in which the Northern Pacific Railway runs from Providence to Ritzville.

Providence Coulee, in which Hatton, Scott, and Connell are situated, is now devoid of flowing water, though it once formed the trunk of a river system almost as considerable as that for which Crab Creek is the master stream.

Of all the abandoned canyons of the Columbia Plains, however, the greatest and most remarkable is Grand Coulee. Not only does it possess many features of scenic grandeur, but its geologic history is of the highest interest. This great chasm was carved by Columbia River at a time when its profound gorge was dammed by a great ice lobe that came down the valley of the Okanogan and pushed southward some 30 miles across the plateau south of the master stream. The waters of the Columbia, deflected by the great glacier, flowed along its eastern face, and, continuing southward in what is now the bed of Crab Creek, regained their proper channel just above Sentinel Bluffs.

Opening from the canyon of the Columbia near the northwest corner of Lincoln County, the Grand Coulee extends in a southwesterly direction for over 30 miles. Throughout the greater portion of this distance it is a wide, flat-bottomed canyon, walled by cliffs, but a little south of its middle point its western wall subsides and it is joined by a broad valley with gently sloping sides. Opposite the mouth of this valley a plateau rises nearly a thousand feet above the bottom of the coulee, but the ascent to this upland is made on a moderate slope unbroken by cliffs. This break in the walls of the chasm, constituting the only point where the Grand Coulee proper can be crossed by a wagon, has determined the location of the small town known as Coulee City. Above this middle pass the coulee bottom, partly covered by alkaline lakes and playas, is about 1½ miles wide, with basalt cliffs which rise on either side to a height of about 400 feet. Two miles below the town the bottom of the canyon abruptly drops, and two amphitheaters, separated by a narrow point and walled by vertical cliffs 400 feet in height, mark the place where the Columbia once poured in a mighty cataract.

The gorge extends southward 15 miles farther. The eastern wall of this lower section does not rise much higher than the level of Coulee City, but its western side maintains a commanding elevation and forms a frowning escarpment visible for many leagues to the south and east. The coulee finally opens out in the northeastern portion of the desert upon a gravel plain, the surface being higher than that of Soap Lake, the southernmost of the chain that lies in the deep chasm. Beneath the mantle of surface material, however, the rocky channel probably persists, and is continued in the depression occupied by Moses Lake and Crab Creek.

*Lakes.*—Lakes, generally shallow and of small extent, are very numerous in the northern portion of the region. They are invariably situated in coulees, their basins having been formed by the erosion of former streams or dammed by wind-blown materials. They are, therefore, usually elongated in form and separated by stretches of dry or meadowy land; often they are disposed in chains. The most important series in this region is that which lies in the bottom of the Grand Coulee. In this chain we may include Moses Lake, the largest sheet of water in the Columbia Plains.

The majority of the lakes in this arid region have no outlets, while others overflow only in the rainy season. As a consequence, the small amounts of salts contained in all surface waters are concentrated in the lake basins by evaporation, and a majority of the lakes are more or less alkaline, Moses Lake containing about 0.32 gram of total solids per liter of water.[a]

The lakes in the lower section of the Grand Coulee are successively higher from south to north, and the northern lakes occasionally overflow to the south at seasons of high water. It follows that, while the water of the northernmost of these lakes is comparatively fresh and palatable, the waters of the others become successively more alkaline to the south. Soap Lake, the most southerly, is extremely alkaline; its waters when they lap against the shores on windy days are beaten into great masses of white foam like soap suds. The alkalinity of the lake is further shown by the soapy feeling observed on rubbing the hands in its water and by its bitter taste, so strong and disagreeable that it is refused by a thirsty horse accustomed to more palatable water. The cattle of the neighborhood, however, constrained by necessity, have overcome this natural repugnance and the lake is a drinking place for a large number of them.

Soap Lake contains 28 parts in 1,000 of matter in solution, consisting essentially of carbonates, sulphates, chlorides, and bicarbonate of soda.[b]

[a] Ann. Rept. Geol. Survey of Washington, vol. 1, 1901, p. 294.

[b] Ibid., p. 295.

Sulphur Lake, in Washtucna Coulee, is another pond in which the water is an extremely concentrated alkaline solution.

In this connection should be mentioned the numerous "alkali flats" or playas, which are ponds during a portion of the year, but become dry every summer, and which have their supply of salts annually increased by the amount held in solution by the waters that flow into them during the rainy season.

A typical coulee, containing small lakes, is shown on Pl. III, *A*.

## CLIMATE.

The most characteristic climatic features of eastern Washington are due to the fact that the region is separated from the ocean by a broad belt of fairly high mountains. The great influence of the Cascade Range is rendered manifest by the sharp contrast that obtains between the climates of eastern and western Washington. The region on the seaward side of these mountains has a climate that is remarkably mild, considering the rather high northern latitude, and that is without extremes of heat or cold. The most characteristic feature, however, is its extreme humidity. The eastern part of the State, on the contrary, being removed from the tempering influence of the ocean and the warm Japan Current, which flows along the north Pacific coast, has the wide range of temperature that is characteristic of the climate of interior regions. The winds of the Pacific, which supply the abundant rainfall of the Sound country, can not cross the broad Cascade Range without losing the greater portion of their moisture by condensation in the form of rain or snow, and the climate of eastern Washington is therefore as decidedly arid as that of western Washington is humid.

The average yearly rainfall in Kittitas Valley, as deduced from Weather Bureau statistics covering many years, is approximately 8 inches. For other localities in the area with which we are directly concerned there are only the most fragmentary records. At Lind, in the wheat lands, the observations for 1898 and 1899 show a total for each year of about 12 inches. Incomplete records at Ritzville during the same years apparently indicate an annual average about equal to or slightly less than that of Ellensburg. At Coulee City the scanty data indicate an annual rainfall not far different from that of Ritzville. At Connell, in the southeast quarter of the area considered, the precipitation in 1900 was 2.29 inches for all of the year except April and November; in 1899, 2.24 for all except January, February, and March. These figures indicate that the mean precipitation at that locality is extremely low, probably not above 5 inches per annum. Although figures are lacking for what has been termed the desert, its general aspect indicates that its annual rainfall probably does not average more than that of the vicinity of Connell.

*A.* TYPICAL COULEE SOUTH OF COULEE CITY.

*B.* COLUMNAR PARTING IN BASALT, UMPTANUM VALLEY.

The seasonal distribution of the precipitation is very characteristic; as in all the far West, there is a wet season and a dry season. By far the greater portion of the annual supply of rain and snow falls between October 1 and May 31. The precipitation is for the most part in the form of gentle rain, which is generally almost entirely absorbed without considerable loss by run-off. The amount of snowfall in winter is often fairly large, however, and the drifts are often sufficiently deep on the hills to obstruct travel from Kittitas Valley to the Columbia.

The mean annual temperature at Ellensburg is approximately 48°. For localities in that portion of the area considered which lies in the Columbia Plains very scanty records are available. In 1899, when the annual average for Ellensburg was 46.5°, that for Lind was 50.2°. It may be safely asserted that the average temperature for the eastern part of the area is slightly above that for Kittitas Valley, and probably not far from 50°. The range of temperature, as mentioned before, is high, the greatest variation noted being in the Weather Bureau record for Lind during 1899, when the maximum was 112° and the minimum —33°. The temperature at Ellensburg, however, generally keeps within the limits +96° and —15°, while in the lower portions of the Columbia Plains both limits are somewhat higher. The figures giving the dates between the last killing frost in spring and the first in autumn are of considerable interest to students of agricultural conditions. The last spring frost usually occurs in the latter part of May, but has been known to be deferred until early in June. The first severe frost of autumn usually falls near October 1, but occurred at Ellensburg on September 9 in the unusually severe year of 1895. The lateness of spring frosts is inimical to the culture of such fruits as peaches, cherries, and apricots.

## VEGETATION.

The natural vegetation of central Washington is chiefly influenced in its broad variations by climatic conditions. The only great forested area in the region here considered is on Table Mountain, whose height gives it a much moister and cooler climate than that of most of the region. The Columbia Plains and the comparatively low foothills are almost treeless, though Yakima River and certain small streams are bordered with a more or less considerable growth of trees and shrubbery. The treeless regions are clothed with a scanty vegetation composed of hardy grasses and shrubs, whose general aspect would be familiar to anyone acquainted with the arid regions of the West. In addition to the important influences of climate and water supply, soil conditions cause more local and less conspicuous variations in the flora.

The forest that clothes the top of Table Mountain comprises many species of fir, spruce, pine, and tamarack. In the sparse growth of its lower slopes the prevailing species is the yellow pine. The woody growth that borders the Yakima includes many large trees, mainly cottonwood and alder, with a sprinkling of yellow pine and a dense undergrowth of willows and other shrubbery. East of Kittitas Valley there are few plants worthy to be called trees. The small streams and springs are fringed with a more or less scattered growth of willow, birch, and wild cherry. The Columbia's banks are destitute of trees except for a few small junipers growing on its flood plain.

On the Columbia Plains and the southeastern foothills, almost desert-like in their aspect, the characteristic species are sagebrush and bunch grass, occurring in variable proportions. Sagebrush is moderately plentiful in all the western part of the region exclusive of the forested areas, attaining perhaps its greatest size and abundance in the central portion, near the boundary between the desert and the wheat lands. Eastward it diminishes, growing rather sparsely about Connell, Ritzville, and the other towns along the Northern Pacific Railroad. Bunch grass was seen in greatest luxuriance where the sagebrush is least abundant, but as it had there been protected for some years by fencing, it is difficult to say where it grew thickest before the land was swept by grazing herds.

The local variations of flora, determined by the character of the soils, are of considerable interest. In the sandy western portions of the plains, for example, while the general aspect is similar to that of the typical sagebrush land, the shrubs are mainly of species other than the true sage, and the true bunch grass is replaced by species more adapted to survive in this very dry soil. In the coulee bottoms other peculiar conditions have an equally decided influence on vegetation. The borders of the fresh-water ponds support a growth of tules. The meadow lands are covered with wild grasses, the short stiff-bladed salt grass being characteristic of the more alkaline soil. In soil that is alkaline but dry rye grass and greasewood, or thorny sage, form the principal growth. The character of the vegetation thus affords an index of the agricultural properties of the soil.

## GRAZING.

The early settlers found eastern Washington a rich grazing region. The natural growth of nutritious bunch grass was so abundant that winter feeding often could be dispensed with and cattle and horses wintered on the open range, though there was doubtless great hardship and frequent death from cold in the more inclement winters. In the eastern portion, however, there was always the great drawback common to so many of the western ranges, of scanty water supply, and during the hot months the necessity of keeping within a moderate distance of water prevented the stock from availing themselves of the entire grazing area.

Since the early days, however, the ranges of east Washington have greatly deteriorated. In this, as in most other western grazing regions, the forage plants have been eaten down so constantly that the forces of growth have been unable to compensate for the continual loss, and the evils of overgrazing have conspired with the encroachment of other agricultural industries to cause a decline in the extent and profitableness of the stock business. In consequence of the last-named cause the areas devoted to open grazing have been reduced to include only the lands unfitted by their topography, the nature of their soil, or the insufficiency of their water for the growth of hay, grain, and other crops.

The most important of the areas still devoted to grazing are the hills and the desert.

The rolling hills in the southwest part of the region and the slopes of Table Mountain constitute a large and important stock range. They have few level tracts extensive enough for economical cultivation, and the soil is generally thin and interrupted by patches of barren rock. In a state of nature the hills were abundantly clothed with bunch grass, and still afford excellent pasture where excessive grazing has not occurred. Springs and rivulets, though not abundant, are plentiful enough to render the greater part of the grass available to the stock.

The second great stock range is coextensive with what we have termed the desert, where the sandy character of the soil, combined with great aridity of climate, seems to forbid the hope of dry farming, and where there is no water for irrigation. Watering places are here few and far between. In the northeast quarter the grazing animals resort principally to Moses Lake; farther south, and near the eastern limit of the range, to Skuten Springs; in the central portion of the desert, to lower and middle Crab Creek; and along the south and west edges, for the most part, to Columbia River, although in the northwestern portion, where the stream is bordered by lofty basalt cliffs, they resort in part to springs. The dispersion of drinking places, as an inspection of the map will show, is so great that there are spots that lie many miles from any surface water.

The effects of excessive grazing are first felt in the areas near springs and streams, a fact strikingly evident to every traveler in this desert-like region. Along the borders of the streams there are broad stretches, often many miles across, where the bunch grass has been eaten down to nearly complete extermination. Farther back from water the grass is much less closely cropped, and there are areas that seem to lie almost untouched from year to year.

There is another way in which the hard conditions of life on the range are forced upon the attention of the traveler. He will soon notice that the plain is traversed by numberless straight, deep-worn trails, and further observation will show that they are arranged in systems, converging toward points on the borders of a stream canyon or of some coulee in whose depths there is a spring or lake. Following a trail in the direction of water, he will find the minor paths gathering together as do the branches of a river system, to unite finally in a broad, well-beaten track that passes down some gully affording a graded route to the drinking place. A thirsty animal at any point in the arid range, by merely falling into the nearest trail and following it to the end, may generally make his way to water by the shortest possible route. A frequent and impressive sight is that of a band of horses on the way to a drinking place, following a trail in single file and moving at a swinging trot or easy lope in order to consume a minimum of time in the necessary quest for the refreshing element. In the dry season this journey must be made daily, but in the other months, when the demands of nature are less and are partly supplied by snow and the rain absorbed by the dry grass, the stock may abstain from drinking for several days at a time.

Since the horse can cover more ground and can afford the time to make longer journeys to water, the excessive restriction of the range has been more prejudicial to cattle than to horses, and horses have therefore become much more numerous than cattle upon the open range.

Two minor classes of range land remain to be noticed. The first comprises the slopes bordering the coulees of the wheat lands. Broken by terraces and by outcrops of basalt, they are unsuited for grain culture, but bear a considerable growth of bunch grass. In the aggregate these lands constitute a large area adapted for grazing, and one that probably never can be available for any other use.

The second class comprises certain narrow strips lying along rivers and lakes and watered by their underflow or seepage. The gravelly flood plain of the Columbia supports in places a scanty growth of lupine and other weeds that are eaten by cattle. The horses prefer to range back where the forage, though less palatable than this verdant growth, can be gathered more rapidly, and thus the green fodder is left to the sluggish cattle. More important, however, are the natural meadows that border Crab Creek and some of its tributaries, with certain of the desert lakes. These meadows are covered with abundant grass, and the generous growth has led to their being appropriated, fenced off, and used for pasturing and hay growing.

## AGRICULTURE.

### GENERAL STATEMENT.

In the early days of settlement the sole agricultural pursuit of eastern Washington was grazing on the open range. Owing, however, to natural laws of development, this industry has been displaced to a large extent by others which involve the tilling of the soil, and which, while yielding immensely greater returns, acre for acre, than grazing, require less capital than is required for the inception of a profitable stock-raising business. The directions of this later development have differed in Kittitas Valley and on the Columbia Plains. This fact, while due in part to differences in soil and climate, depends in a far higher degree on the conditions of water supply. Kittitas Valley is an irrigated region, while on by far the greater part of the Columbia Plains dry farming alone is practicable. While the discussion of open grazing, therefore, has been made general for the entire region, the other agricultural industries must be described separately for Kittitas Valley and the plains.

### THE COLUMBIA PLAINS.

#### NATURAL CONDITIONS.

The cultivated portion of the Columbia Plains may be classified as plateau lands, meadow lands, and bench lands.

By far the most important in extent are the plateau lands, comprising the broad, level upland areas. The important natural conditions influencing agriculture upon the plateaus are (1) an arid climate, (2) absence of surface water for irrigation, and (3) a soil easily tilled, fertile, and peculiarly adapted to retaining and utilizing the scanty precipitation. The soil of the plateau lands is shown by chemical analysis to abound in the elements necessary to support plant life. Its peculiar virtues, however, are probably due less to its chemical than to its physical properties, its fine open texture rendering the plant food readily available and its friable character and freedom from stones making it very easy to till. Probably most important of all, however, is its behavior toward water. On the one hand, it is so porous that rain or melted snow is quickly absorbed by it, so that a smaller proportion is lost by run-off or by evaporation from puddles than would be lost if it were more clayey and impervious, and, on the other hand, it is not loose enough to allow the water to sink rapidly and become unavailable, as it does in a deep sandy soil. The spaces between the particles of the fine loam are so small that the water is held in them by adhesion or capillary attraction, and yields to the force of gravity only slowly and to a comparatively small extent. Therefore a large proportion of the slight precipitation is kept sufficiently near the surface to be used by the growing wheat, and successful grain culture is possible with a rainfall that would be insufficient in a soil of less advantageous physical constitution. Dry farming of grain is the industry found most profitable under these conditions, and absorbs by far the greatest part of the energies of the farming population in this district, as well as in eastern Washington generally.

Far less in area than the grain lands are the meadows of Crab Creek, Grand Coulee, and Harrison Springs, characterized by heavy, moist, generally alkaline soils, and chiefly devoted to hay and pasture.

The bench lands comprise a comparatively small area on the terraces of Columbia River, where the sandy alluvial soil is irrigated with river water and produces a variety of crops.

### DEVELOPMENT.

*Grain culture.*—The invasion of the land by the wheat industry has proceeded from the northeast. The settlement of the district about Ritzville, the thriving county seat of Adams County, dates back nearly a score of years, and the well-tilled farms, the numerous small but flourishing orchards, and the substantial farm buildings give this vicinity a gratifying aspect of prosperity. The villages on the Northern Pacific Railroad southwest of Ritzville and along the Great Northern are lively and growing, but glaringly new, and the hastily constructed, often unpainted frame house is the prevailing architectural type. The whole aspect of the country also speaks of its recent settlement. In the vicinity of Connell a large proportion of the wheat land has been broken in the past year, and many sections, protected from grazing by fences, still bear an abundant growth of bunch grass.

To the west also the frontier of the wheat belt is being pushed to the border of the desert. The land is dotted with the board shanties of homesteaders and with newly plowed squares that break the surface of the virgin ground. The clearing away of the strong and abundant sagebrush of this district preliminary to the first sowing is no small task, and many entire families are to be seen engaged in uprooting the shrubs, collecting them in wagons, and feeding them to blazing bonfires. The wholesale destruction of the brush is rather to be deplored, for the roots and lower stalks are used as fuel in many homes, and, while far from ideal for this purpose, must be of considerable value in a region where wood is so difficult to obtain.

The earlier settlement of the northeastern part of this region is not due to chance alone, but in part to better natural conditions, the greater rainfall giving this section a natural advantage over the country to the southwest. The appearance of the stubble after the fall harvest, as well as general report, indicates that it is superior in natural productiveness to the more arid districts. Part of the apparent superiority is doubtless due to long cultivation of the land, for the best results are not obtained until about three years after the first breaking, when the roots of the sagebrush and bunch grass are quite decomposed. But after making all allowances it still seems unreasonable to expect as good returns in the recently settled districts to the south and west as from the older land, where crops may suffer heavily in years of especially light rainfall.

Exact data concerning the yield of wheat are difficult to obtain, but the general run of crops appears to be from 16 to 25 bushels per acre. Extremely large yields are not necessary for profitable culture, for the land is low in price and so easily worked that the cost of cultivation is much less than in heavier lands. It seems necessary, however, to work a considerable holding, and the ranches are probably in a majority of cases a section or more in area. The advantages of close settlement and small farms will perhaps never be attained.

*Forage growing.*—An important adjunct to the grazing industry is the culture of hay for winter feeding. There are numerous farms along upper and middle Crab Creek where hay is gathered from the meadows, the crop being stored in large stacks and the mown fields used as pastures for some time after harvest. The greater portion of this hay is fed on the ranches, for while a minor quantity is hauled to villages in the wheat lands it can hardly compete successfully with wheat hay and hay imported from the irrigated districts to the west. Unfortunately, the strongly alkaline character of the soil is fatal to the better forage plants, and the crop is of wild hay, very inferior in nutrient qualities to timothy, clover, or alfalfa. One hay ranch, perhaps the most important seen during this reconnaissance, is located on spring-watered land at the foot of Priest Rapids. At this locality the excessive moisture of the soil is prejudicial to domesticated grasses, though they have gradually been introduced to a slight extent, and the quality of the crop is thereby improved.

*Horticulture.*—Though horticulture in this portion of the State is not an important industry, orchards for supplying the needs of a household are very generally to be found on the older ranches, and larger ones are fairly numerous in the neighborhood of Ritzville. Two were seen on Columbia River, one irrigated by a water wheel and another by a small ditch from a neighboring canyon. So far as known, no shipments of fruit are made to distant parts of the State.

The natural conditions in the wheat country are unfavorable to fruit culture in many ways. The late frosts in spring, as experience has shown, are often fatal to the growth of peaches where they have been tried. The hardier apples often attain good size and quality, especially upon high ground, and prune trees are said to yield good crops. Excellent pears are grown on the McMannamon ranch on middle Crab Creek, where the alkali of the soil is injurious to most other fruit trees. In the land bordering Columbia River there seems reason to hope that fruits may be grown with much success if extensive irrigation can be provided, for at Wenatchee, where temperature conditions are probably very similar, fruit culture is a flourishing industry.

Small fruits are said to thrive where their culture has been attempted, notably on the plateau west of Grand Coulee. Domestic vegetable gardens, with cabbage, corn, and other hardy plants, add to the comfort and convenience of many thrifty ranchers, but generally do not present a flourishing appearance.

Except at the two localities on Columbia River already mentioned, practically no fruits are irrigated in this region. Vegetables are sometimes watered by a small stream from the farm well, but no extensive, systematically irrigated gardens exist. If irrigation were possible there is no doubt that the quality and amount of fruit and vegetables raised in this region might be greatly increased. The extent to which irrigation may be practicable will be discussed later.

## KITTITAS VALLEY.

### NATURAL CONDITIONS.

The broad floor of Kittitas Valley presents a large area of alluvial soil of great natural fertility. The annual rainfall is too low to support agriculture in itself, but this deficiency is more than overcome by the conditions that have made it possible to irrigate a large portion of the land from mountain streams. The rather low mean temperature and the lateness of spring frosts is disadvantageous and makes horticulture less successful than in the Yakima region, where conditions are otherwise similar. The character of the agricultural industries of Kittitas Valley has been determined by the conditions thus briefly outlined. They may be classified as follows: (1) Growing of forage; (2) dairying; (3) grain culture, and (4) horticulture.

*Forage growing.*—In the winter feeding of sheep, cattle, and horses that range the neighboring hills and mountains a large amount of forage is consumed on the valley farms. But as the irrigated lands are eminently suited to the growing of hay and the warm dry months of summer enable the farmer to cure it thoroughly with small risk of injury by rain, a large surplus over that consumed locally is raised, the different varieties of hay, mainly timothy, clover, and alfalfa, constituting one of the most important crops of the region. It is baled and exported in large quantities and finds ready sale at prices considerably higher than those obtained for the forage grown in the more humid region west of the Cascades.

*Dairying.*—The abundance of the best fodder and the excellent pasture afforded by hay fields in the intervals of cropping are conditions favorable for milch cattle, and dairying is an industry of considerable importance. While no large farms are entirely devoted to it, the great majority of ranchers produce small quantities of milk, which is collected daily by the several creamery companies and worked into excellent butter on a large scale. There are six creameries in the county, which is among the most important dairying counties of the State.

*Grain culture.*—Grain, including wheat, barley, and oats, in order of importance as named, is a crop of considerable magnitude, the greater part being grown on the marginal portions of the valley, where there is not sufficient water for the proper irrigation of hay.

*Horticulture.*—There are probably no ranches in Kittitas Valley with horticulture for their principal dependence, but nearly every thriving farm has its garden and orchard to supply domestic needs. Nearly all vegetables do well under irrigation, and considerable quantities of small fruits and vegetables are exported. The climate, as before noted, is unfavorable to most orchard fruits. Apples are the only ones grown in sufficient quantity for export; these are of excellent appearance and flavor, and generally freer from worms and other defects than the fruit of western Washington.

## GEOLOGY.

### GENERAL STATEMENT.

The area considered in this report lies wholly within the vast territory which, in Miocene time, was inundated by great floods of basaltic lava. Throughout the greater part of the region the basalt lies not far beneath the surface. Though for the most part covered with soil in the level upland stretches and gentle slopes, it is exposed in the walls of nearly every coulee or canyon. From this rock are carved the imposing but somber cliffs of the Grand Coulee, the gorge of the Columbia at the foot of Table Mountains, and the majestic Sentinel Bluffs. Its depth appears from the fact that nowhere within the limits of this reconnaissance has it been cut through by the streams that have so deeply trenched it.

Upon the basalt, in late Miocene time, there were laid down several hundred feet of sediments belonging to what is known as the Ellensburg formation. While these beds may have been deposited over the greater portion of the area considered, they have yielded with comparative readiness to erosion, and now occupy but a fraction of the land surface. In the White Bluffs of the Columbia this formation is splendidly exposed.

Since the deposition of the Ellensburg beds the layers of rock, originally horizontal, have been tilted and folded, and the land has been modeled to its present form by the work of water, ice, and wind.

## STRATIGRAPHY.

### YAKIMA BASALT.[a]

#### DISTRIBUTION AND VOLUME.

By reason of its vast extent and great volume the basalt of the Columbia basin is one of the most important volcanic formations in the world. Its greatest thickness is not less than 4,000 feet, and its area, including portions of Washington, Oregon, and Idaho, has been estimated at about 250,000 square miles. In Washington and Idaho the area underlain by it includes practically the entire Columbia Plains and that portion of south-central Washington designated the "foothill province," as well as a considerable strip along the southern border of the State, crossing the Cascade Range and extending west to the ocean.

East of the area immediately considered here the Yakima basalt, where its edge is exposed, is underlain by Tertiary sandstones. Just south of Wenatchee the northern face of Saddle Mountain is a lofty and precipitous cliff of basalt, at the foot of which lies a belt of low hills carved from the rather soft sandstones which occupy both sides of the river at Wenatchee, but soon thin out to the north. From a short distance above Wenatchee to the mouth of the Okanogan the boundary of the lava is marked by the Columbia, whose left bank is overlooked by a precipitous wall, with a top or "rim" of basalt, immediately underlain by old crystalline rocks, such as granite, gneiss, and schist; to the north these older rocks are not exposed, the basalt forming the entire wall of the canyon.

Near the Okanogan the boundary again crosses the Columbia, and is, in general, coincident with the southern border of the Okanogan highlands. On the northeast and the east the lava reaches up the lower slopes of the mountains in Idaho, remnants of it being found along the valley of Spokane River, about Cœur d'Alène Lake, and along the lower parts of the rivers flowing into it. Along the entire northern and eastern boundaries the surface upon which the basalt was poured out is supposed to have consisted of ancient, mostly crystalline, rocks. To the south, southeast, and southwest the basalt area extends for considerable distances into Idaho and Oregon, but its delimitation in these directions need not be dicussed here.

[a] This name was first used by Mr. G. O. Smith in Water-Sup. and Irr. Paper No. 55, and is applied to the Miocene basaltic series of this region. The term "Columbia River lava," as used by Professor Russell, includes Eocene and Pleistocene lavas separated from the Yakima basalt by important sedimentary formations.

### ORIGIN.

The origin of a body of lava so vast and widespread is an interesting problem. It is a generally accepted view that the originally molten rock was forced up through great cracks or fissures in the crust of the earth; this theory is based on three kinds of evidence: (1) The volume and extent of the lava floods are so enormous that it is difficult to conceive of their eruption from ordinary craters; (2) the comparative rarity of the fragmental materials known as "tuffs," "breccias," etc., indicates a quiet welling up through fissures without the explosive action characteristic of crater eruptions; (3) the theory has received very positive confirmation of late years by actual observation of the fissures from which these floods came forth, filled with the cooled and hardened basalt and exposed by the erosion of the overlying flows. In the Cascade Mountains there is a great system of dikes in the sandstone beneath the basalt, which has been described by Professor Russell[a] and by Mr. George Otis Smith.[b]

The thousands of feet of basalt in the plains were not poured forth in one great outburst. The series is made up of a great number of layers or flows that can be distinguished in the field by means to be discussed in another section. It is estimated that about twenty such flows have been cut through by the river at Sentinel Bluffs. Each of these layers represents a distinct outpouring of basalt, the eruptions being separated by various intervals of time. In some cases these periods of rest must have endured for centuries, for at certain localities there are beds of soil between the layers on which trees have grown to considerable size, to be charred and buried by later flows. The basalt eruptions, especially in the later stages of their activity, were interrupted by periods in which there were accumulated other materials, consisting of volcanic ashes of a composition different from that of the basalt, and beds of sand, clay, or gravel, laid down in lakes or rivers.

The average thickness of the individual flows in this region is probably between 50 and 100 feet. Their extent, considered separately, must have been enormous, for it is rare to see the edge of a layer thinning out. This fact indicates that the molten rock was in a highly fluid condition and retained its fluidity long enough to spread out for great distances.

In addition to the massive flows that form the greater part of the series there are beds of fragmental volcanic material, such as bombs or smaller angular fragments of lava. Such materials either have been thrown up to great heights and spread out upon the surrounding

[a] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 1, 1899, pp. 121–122, pl. xii.

[b] Smith, G. O., Mount Stuart: Geologic Atlas U. S., folio 106, U. S. Geol. Survey, 1904.

country, or, mixed with hot volcanic water, have formed mud flows and run out on the surface in much the same way as true lava. Their formation was perhaps due to the partial choking of fissures by congealed material, and the building of craters where the pent-up subterranean forces found constricted vents. The fragmental materials are not so generally distributed nor so widespread as the massive flows; they are most numerous and thickest in the mountains, while in the Columbia Plains they form but an insignificant proportion of the basalt series.

### LITHOLOGIC CHARACTER.

The textural and structural features of the basaltic rocks are of interest not only to the scientist, as throwing light upon the manner in which the lavas were erupted, but to the practical man also, for the deep water of this region is found chiefly in the basalt series. The lithologic characters will therefore be considered somewhat fully.

The texture of the basaltic rock, viewed in small specimens or fragments, shows a considerable range of variation expressive of the different rates at which the lavas cooled. The central portions of thick flows, where cooling has been slow, are often completely crystalline. In thin flows, or near the surfaces of thicker ones, the rock is of finer texture, is generally dull in luster, and does not show, to the unaided eye, the minerals of which it is composed. Where the basalt has been suddenly chilled, especially at the base of a flow, the lava may solidify as a black glass. From the practical standpoint, however, the most important fact in regard to texture is that the basalt is generally fine and compact, with no pores capable of allowing water to pass to any appreciable extent through the solid rock.

The structural characters of lava flows are dependent on conditions attending their eruption and cooling, and may best be described with reference to their origin.

### SURFACE FEATURES OF LAVA FLOWS.

Molten lava, as it issues from the earth, is always charged with steam. While the lava remains underground the steam is intimately mixed with the molten rock and is prevented from expanding by the enormous pressure of the overlying crust. When the lava emerges on the surface, however, there is a sudden decrease in pressure, and the steam combined with the lava expands and collects in bubbles, which rise to the surface and burst, giving off the great clouds of vapor that always rise from a moving flow of lava. The solidification of the molten rock generally takes place, however, before the steam has entirely escaped, and the bubbles in the upper portion of the flow become, as it were, frozen, so that the upper surface of a lava flow has generally a vesicular or honeycombed character. It is by this structure that the upper surface of a flow is best distinguished and the different flows distinguished from one another. The bottom of a sheet sometimes has this vesicularity in a minor degree, owing to the sudden chilling and solidification of that portion before it has freed itself from watery vapor.

Another common surface feature is that produced by the formation of a crust on the top of a flow and its subsequent disruption by the onward movement of the still liquid lava beneath. The rough scoriaceous layer, formed by the fragments of this crust cemented by other molten material, is called a flow breccia. Again, the crust formed upon the advancing front of a lava flow may often be broken and the fragments rolled under and incorporated in the bottom part of the moving sheet of molten material.

### CONTRACTION PARTINGS.

After the lava has completely solidified it is still at a temperature enormously higher than that which it must ultimately attain, and a gradual cooling progresses for a considerable time. Cooling, in the case of basalt as of most other substances, brings contraction. This necessarily leads to the formation of joints and small fissures, dividing the rocks into blocks or plates of varying size and regularity, and such contraction partings are of universal occurrence in the basalts of the Columbia basin. The forms into which the lavas are thus divided are multitudinous, but are divisible into a number of classes, each of which will be briefly described.

Columnar jointing, generally perpendicular to the cooling surfaces and therefore most often nearly vertical, is the most universal and striking structural feature of the basalt flows (Pl. III, *B*). The columns vary greatly in size and regularity of form, their diameters ranging from a few inches to 6 feet. They are sometimes so straight, sharp cornered, and clean cut as to simulate the work of human hands. More frequently, however, they exhibit imperfections of form, the sides being warped and not parallel to one another. Cross sections of the most perfect prisms are oftenest pentagonal or hexagonal, but polygons of 4, 7, or 8 sides are also common.

The main vertical columns of the basalt flows are generally subdivided by secondary partings. Most universal is a transverse jointing, dividing each column into sections of varying lengths. An extreme development of such jointing is characteristic of certain flows, mainly in the upper portion of the series, which are primarily divided into vertical columns of large size and great regularity, these in turn being divided by slightly curved, nearly parallel, and very numerous horizontal partings into scaly fragments which overlap irregularly and do not extend entirely across the columns.

Another secondary parting, which has been described by Professor

Russell[a] results in the formation of small columns perpendicular to the faces of the large vertical ones. This structure occurs where the vertical columns are irregular and especially large. In such cases the vertical cracks are comparatively wide, and probably allowed radiation and convection of heat from the sides of the columns. These were then cooling surfaces, and columns perpendicular to them were formed according to the usual law.

Lamellar parting parallel to the surface of flows is frequent near the upper and lower surfaces. This may extend for varying horizontal distances and is frequently combined with irregular vertical jointing.

### FRAGMENTAL BEDS.

The beds of fragmental material thrown out from craters are made up of rough, angular, and generally scoriaceous fragments of glassy lava, imperfectly sorted, and not clearly stratified. The scarcity of such beds in the plains has been noted, and few localities can be cited where they are to be observed. In Dry Coulee, north of Adrian, a bed of red, slaggy, and porous fragments was seen, which carries water and supplies two or three springs. The north front of Yakima Ridge exhibits exposures which, by their erosion forms, appear to be coarse, fragmental basalts. To the west, as has been remarked, finer grained materials of similar nature are more plentiful, and considerable exposures are to be seen in Shushuskin Canyon and other ravines in the hills about Kittitas Valley. The fragmental materials are uncemented, very porous, and well fitted to absorb and store up large quantities of water.

### MATERIALS INTERBEDDED WITH THE BASALT.

Materials other than basalt, interstratified with the lava, were observed only in the upper portion of the series. The most important of such beds is exposed in the escarpment of Saddle Mountain overlooking Crab Creek, and in the bluff opposite Craig's ferry. It is composed of fine grayish-white volcanic ash with very regular bedding, is about 100 feet thick, and is overlain by about an equal thickness of basalt. Similar ash beds in similar stratigraphic positions were observed on the sides of Kittitas, Squaw Creek, and middle Crab Creek valleys, but they do not seem to be continuous with the Saddle Mountain ash. The latter, indeed, is not observed on the west side of the river at Sentinel Bluffs, and seems to thin out or disappear to the east also.

About 500 feet below the top of the Sentinel Bluffs another light-colored bed about 40 feet in thickness is interstratified with the basalt and exposed at the same level in the cliffs on either side. This bed consists of what is known as an arkose sandstone, made up of grains

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 45.

of quartz, feldspar, and mica. This rock, moderately coarse grained, friable, and of open texture, is well fitted to act as a water-bearing stratum.

## ELLENSBURG FORMATION.

### DISTRIBUTION.

Lying upon the surface of the basalt at numerous localities in east Washington is a series of supposed lake beds known as the Ellensburg formation,[a] from their having been first carefully studied near the town of that name.[b]

The distribution of similar beds in the same stratigraphic position is extensive, and they are found in great volume in various places in the western and the southern parts of the Columbia Plains. That these deposits are, or ever were, continuous over this broad area can not be asserted positively, but their general similarity at the various localities points to the existence of similar conditions of deposition over an extensive strip of territory east of the Cascade Mountains in the period following the close of the basaltic eruptions.

The present distribution of the Ellensburg beds in the area covered by this report is not so easy to determine as the barren aspect of the country leads one to expect. The formation is rarely exposed except where cliffs have been carved in it by ancient or modern streams, and its boundaries are mostly concealed by a thick covering of wind-blown soil. These conditions, combined with the hasty character of the work and the lack of a good topographic base, forbade anything like accurate determination of boundaries, and those represented on the map (Pl. I) are to be regarded as but roughly approximate.

### LITHOLOGIC CHARACTER.

The character of the typical Ellensburg material of the Columbia Plains is shown by the following descriptive section of the exposure at the upper end of White Bluffs. The beds are described in ascending order.

*Section of Ellensburg beds at White Bluffs, 1 mile below Koppen's ranch.*

| | Feet. |
|---|---|
| Sand, partly consolidated, and sandy clay, mostly red, weathering in part into small spheroids | 25 |
| Red tuffaceous sandstone, fine grained (ledge) | 3 |
| Soft, reddish, medium-grained sandstone | 9½ |
| Cross-bedded sand and fine gravel; fragrants mostly of scoriaceous basalt, somewhat rounded | 5 |

[a] "John Day system" of Bull. No. 108 and Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, but so called erroneously, for the original John Day is of early Miocene age, and lies beneath the great basalt series See Merriam, J. C., Bull. Dept. Geology, Univ. of Cal., vol. 2, No. 9, p. 276. The Ellensburg formation is probably equivalent to the Mascall formation of the John Day Valley.

[b] For detailed description of this formation in the type-region, see Smith, G. O., Ellensburg, Geologic Atlas, U. S., folio 84, U. S. Geol. Survey, 1903.

| | Feet. |
|---|---|
| Fine sand and silt, with small basalt pebbles | 3½ |
| Silt, not laminated, gray to terra cotta in color, nodular in upper part | 24 |
| Fine soft sandstone, gray green to terra cotta | 20 |
| Clay, gray green to pink | 15 |
| Greenish white clay, not laminated, checking into small fragments, with feldspar grains | 70 |
| Pale terra cotta silt, not laminated | 7 |
| Greenish clay | 3 |
| Pale terra cotta silt, obscurely laminated | 5 |
| Soft greenish clay | 20 |
| Above this, but probably not of the Ellensburg formation, are: | |
| Gravel, with pebbles of basalt 5 inches or less in diameter, incrusted with limy material; matrix light-colored silt and sand, partly cemented with limy matter | 15 |
| Sand, lower part with fine wavy lamination, upper part with a peculiar chambered structure, having thin, highly contorted partitions of cemented sand stained with iron oxide, with soft unconsolidated sand between | 15 |
| Total | 225 |

The general character of this section offers some points of contrast with the typical section measured in the Ellensburg quadrangle.[a] The material in the White Bluffs is much finer, coarse sandstones being rare and coarse conglomerates entirely lacking. Cross-bedding, so common in the Naches Valley section, is not common in the White Bluffs. It is evident that the material has been carried far from its source and deposited under conditions of comparative quiet.

The Naches Valley section is characterized by a very large proportion of volcanic ash and tuff, mainly of andesitic composition. The extreme fineness of most of the White Bluffs rocks makes it difficult to prove their origin, but pumice grains and clear feldspar crystals are to be seen in some of the material, and dust scraped from a specimen of very fine grain is found, by the aid of the microscope, to consist of angular transparent fragments that seem to be volcanic glass. It is believed that ash erupted from volcanoes in the Cascade Range, carried a great distance by the upper air currents, and finally falling gently into the waters of a shallow lake, form the most important constituent of the White Bluffs beds. Certain of the sandy layers, however, were probably laid down by river currents.

The writer found no fossils of any kind in the Ellensburg formation in the region examined, though it is said that shells and bones have been found in the bluffs near Pasco.

In the Moxee artesian basin the most abundant supply of flowing water is obtained from the lower part of the Ellensburg formation. The White Bluffs section also shows an alternation of relatively per-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, 1901, pp. 17–21; and Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

meable and impermeable strata, which would seem favorable to the occurrence of artesian water, provided the requisite conditions of structure and supply are also present.

## STRUCTURE.

### GENERAL CHARACTER OF DEFORMATION.

At the close of the period during which the Ellensburg beds were deposited the rocks lay in a nearly horizontal position. Since that time they have been deformed in a manner that has a most important bearing on the artesian problems that will be discussed later on.

In his reconnaissance of a much larger area than the one here described, Professor Russell was led to the view that the characteristic orographic form of central Washington was the tilted fault block. The important economic bearing of this conclusion was recognized, as the presence of faults was held to be very discouraging to the hope of obtaining artesian water. The writer came to the field intending to investigate this point, and inclined to scepticism, for the examination of the Ellensburg quadrangle, also contained in Professor Russell's area, had shown that many of the supposed tilted blocks of the earth's crust were in reality unsymmetrical anticlines or folds in the strata.

The north face of Saddle Mountain, where it overlooks the lower stretch of Crab Creek, was cited by Russell as a very typical fault scarp. The topographic form here does indeed suggest faulting in a very striking way. South of Crab Creek a bold escarpment rises some 1,500 feet, exposing in section about 1,200 feet of basalt, overlain in order by a thick bed of white tuff, a flow of basalt, and a small thickness of Ellensburg formation proper. North of Crab Creek this lofty cliff is confronted by a low bluff of basalt, probably between 100 and 200 feet in height. A few miles to the northeast a gentle escarpment is seen, carved from the Ellensburg beds, here overlying the horizontally bedded basalt. It is obvious that we must have here either a normal fault with the downthrow to the north or a sharp flexure, the down-folded portion having been removed by erosion, leaving only the nearly horizontal strata on either side. Evidence bearing on the choice between these alternative views was gathered by examination of the Saddle Mountain front to the east and to the west of the great cliff.

On the west side of the Columbia, opposite the mouth of Crab Creek, the continuation of the mountain is bounded on the north not by a cliff, but by a steep slope, which passes continuously into the rolling surface at its base. The surface of this slope is nearly conformable to the structure of the basalt. The mountain shows no outcropping horizontal ledges, but rising through the mantle of soil, sloping backward on the spurs and forward in the gulches, can be traced the outcrop of one or more especially resistant beds of black lava, having a dip a little steeper than the slope, but in the same direction. A little north of the base of this slope basalt can be seen with a very gentle dip to the south.

At another point, some 20 miles east of the mouth of Crab Creek, the north slope of the ridge was examined again, and a similar state of things observed. Crab Creek here flows in a canyon some hundreds of yards wide, bounded by precipitous walls about 100 feet high. Just to the south Saddle Mountain rises with a moderately steep terraced slope. For a few hundred yards back from the canyon's brink horizontal basalt, corresponding to that across the canyon, is exposed. On the lower slopes of the mountain the structure is concealed by terrace deposits and soil. Behind the uppermost terrace, however, the basalt is again exposed in a gully, where it shows a northerly dip of about 50°. The evidence indicates that there is here a sharp flexure and not a fault.

While the fact is not proved beyond doubt, the writer believes that this flexure, observed both east and west of the cliff, was once continuous along the entire front of Saddle Mountain; that the cliff along lower Crab Creek was produced by erosion, and that the flexure is here concealed below the sediments in Crab Creek bottom.

The existence of a fault along the Grand Coulee, which was asserted by Professor Russell, also appears open to doubt. In support of the fault hypothesis, Russell cites in the first place the existence of a down folding or monocline, exposed in section on the east wall of the coulee, apparently without any corresponding flexure in the opposite wall. This flexure, however, is not absent to the west, but is only obscured by the alluvial deposits laid on the terraces which have been cut in the down-folded part of the basalt. The monoclinal structure was observed in a gully northwest of Coulee City. The strike here, so far as could be observed, seemed more nearly north and south than on the east side, and the relations indicated that the monocline had been continuous across the canyon, but that the horizontal projection of its axis was probably somewhat curved. It seems unnecessary to suppose that there has been faulting. Further, the fact that the western wall of the coulee below the site of the cataract is much greater than that of the eastern wall is explained by Professor Russell as the result of faulting. To the writer it seems that this fact also could be accounted for by flexure. It is always to be borne in mind that the floor of a canyon half a mile wide and more or less covered by alluvial deposits may conceal important structures.

To sum up, it appears to the writer that the steep slopes supposed by Professor Russell to be fault scarps are, in the region considered here, as in the Ellensburg area, the products of erosion and of sharp flexure in the basalt. It is necessary, however, in order to establish the view here advanced, to explain the remarkable fact that such important stream channels as the Grand Coulee, lower Crab Creek Coulee, and the canyon of the Columbia just below Priest Rapids have been intrenched along supposed lines of flexure. The most plausible explanation of this fact has been suggested by Professor Russell himself in one of his more recent publications,[a] in which he advances the theory that the location of the folds has been determined by the weakening of the crust through erosion along the stream courses. In other words, stream erosion, instead of deformation, has been the primary agent. This hypothesis appears to have much probability and to lend itself very aptly to the explanation of the course of lower Crab Creek and perhaps to the analogous position of the Columbia along the base of the ridge south of Saddle Mountain. In the case of the Saddle Mountain scarp, the surprise at its magnitude is diminished when we realize the fact, to be developed further on, that the Columbia, swollen beyond its present volume by water from a great glacier, once flowed in the channel now occupied by an insignificant and partly suballuvial stream.

### CHARACTER OF FOLDS.

Folding is then considered by the writer as the prevalent type of deformation in the region here discussed, and he does not consider it probable that the injury of artesian basins by fissures is to be apprehended. In the western portion, lying in the foothill zone, the anticlines (structural arches) and synclines (structural troughs) are relatively pronounced, but they die out to the east, and in the wheat lands the basalt has suffered only gentle tilting, often imperceptible in amount.

With regard to direction, the folds fall into two systems. The sharper anticlines, and by far the greater number, trend nearly east and west. To this system belong the anticlines of Yakima Ridge and Saddle Mountain. Coexisting with the east-west system there are broad and gentle north-south folds, exemplified in the east slope of Table Mountain and the gentle westerly dip of the basalt underlying the wheat lands.

The form of the east-west folds is characterized by a lack of symmetry, the steeper side in the area dealt with in this paper being apparently always to the north. The contrast between the north and south faces of Saddle Mountain has been mentioned, and other more striking examples occur in the foothill region outside the area with which this report is concerned.

[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho; Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 70.

The coexistence of two perpendicular systems of folds is perhaps favorable to the conservation of water under pressure, in so far as it tends to form basin-like structural depressions.

The specific structural features of the region whose general character has been discussed in the preceding paragraphs can be made plainer by the structure sections accompanying the geologic map than by lengthy verbal description.

## PHYSIOGRAPHY.

Physiography treats of the development of the existing form of the land surface. In that development two classes of agencies have been concerned: (1) Forces, probably generated for the most part by the slow cooling and contraction of the earth, which deform the strata originally laid down in horizontal position and heave them up into the form of folds and tilted blocks; (2) the action of frost, water, ice, and wind, which modifies the masses raised up by these mountain-making forces. Agencies of the second class are mainly degrading in their effect—that is, they tend to tear down what the mountain-making forces have built up.

### RELATION OF PHYSIOGRAPHY TO STRUCTURE.

The manner in which the Miocene rocks have been deformed has been discussed under the heading "Structure." The relation between this and the form of the land surface in the region considered is unusually close. There is over the greater part of the earth's surface a lack of concordance between the topography and the dip of the underlying rocks, because erosion has so deeply modified the original form of the uplifts as to make their character unrecognizable without careful study. Here, however, the principal uplifts and the basins or troughs between them have retained, in a general way, their original form. For instance, Kittitas Valley is a striking example of a structural basin in which the rock layers on all sides dip toward the center, while the portion of Table Mountain that lies within the area considered here is a structural elevation, its east face being a clear example of a "dip slope." The profile of the south face of Saddle Ridge also is in harmony with the arching structure of the underlying basalt so clearly exposed in Sentinel Bluffs. It may be said, in general, that the extensive gentle slopes in this region, unbroken by outcrops of rock ledges, are more or less nearly parallel to the underlying strata and are expressive of the structure of the rocks. In contrast to these comparatively gentle structural slopes are the bold cliffs exposing the rocks in section. These features are mainly the work of rivers, whose effect on the topography may now be considered.

### WORK OF STREAMS.

The conspicuous features formed by stream erosion are the canyons of the Columbia and the Yakima with their tributary streams, and the dry coulees of the wheat lands. Less prominent are the features that represent the depositing rather than the cutting activity of the streams, namely, the gravelly flood plains and terraces. A study of the topographic forms that have resulted from the work of streams throws much light on certain of the later episodes in the history of this region.

#### RELATION OF STREAM COURSES TO STRUCTURE.

When we consider the relation of watercourses to the structure of the rocks, the streams of the region are divisible into two classes—those whose courses seem to have been determined by the structure of the underlying rocks, and those whose courses are independent of rock structure.

*Consequent streams.*—To the first class, which are technically designated consequent streams, belong the majority of the smaller streams of the region. The creek draining Willow Springs, for example, and that flowing from the Clerf Spring, flow down pitching structural troughs or synclines. Another large class of small streams or channels seem to have been located by water flowing down a structural slope. Examples of canyons originating in such a manner are afforded by the gulches draining Table Mountain and Saddle Ridge.

*Antecedent streams.*—The most striking examples of the second class of streams are Columbia and Yakima rivers, which in several instances cut squarely across great structural arches in the basalt. The Yakima leaves Kittitas Valley not by the lowest portion of its rim, but by a deep gorge cut across Manastash and Umptanum ridges. Lower in its course it cuts other anticlinal ridges lying outside the area of this survey. Columbia River in like manner cuts across Saddle Ridge in a direction at right angles to its crest line. Another instance is furnished by Moses Coulee, which has cut its way through the Badger Mountain uplift without regard to structure, forming a canyon whose size is especially remarkable when we consider that for ages it has not contained a perennial stream.

The formation of the gorges thus briefly described can be explained only on the supposition that the streams which formed them are antecedent to the structure, or, in other words, that their courses were established before the upfolding of the basalt and Ellensburg beds began and were maintained throughout its progress. The arches were raised up against the down-cutting rivers as a log is pushed against a whirling saw. The uplift must have been in general an extremely slow process, since in most cases there is no evidence to indicate that the rivers were ponded, as they would have been if the rise had been so rapid that they failed to maintain their courses. The sudden uplift of Saddle Mountain would have deflected the Columbia and caused it to find an outlet over the lowest point in the dam, far to the east of the gate it actually made for itself. There is some reason to suspect, however, that the river was deflected by the next uplift athwart its course, and the eastward bend at the foot of Priest Rapids may have been due to the inability of the river to cut down against the rising ridge along whose face it flows for many miles below, to clear its lower end in the great sweep to the east inclosed on the left by the White Bluffs.

The three examples cited are not the only antecedent streams in the region. Crab Creek crosses an anticlinal arch of slight elevation below Moses Lake, while its course along the western portion of Saddle Ridge was not determined by structure. If the writer is correct in discrediting the hypothesis that the cliff in that locality is a fault scarp, the antecedent character of Crab Creek may be taken as explaining its origin, according to Professor Russell's hypothesis, cited on page 39.

### ORIGIN OF COULEES.

The topographic character of the coulees in the wheat lands proves that they have been produced by stream erosion It is, however, perfectly obvious that they could not have been eroded, no matter how much time were allowed for the process, during the existence of the present arid climate. A few of the coulees have streams, perennial though insignificant in comparison with the canyons they occupy, but the majority never contain continuous surface streams, even in the rainy season. It is necessary to suppose that the coulees were eroded in a time long past, when the region had a fairly abundant rainfall. The causes which determined the formation of the Grand Coulee were, however, exceptional, and will be discussed later.

### TERRACES AND GRAVEL DEPOSITS.

In the formation of their canyons the streams did not cut down steadily and without stopping. The task was accomplished in a somewhat spasmodic fashion, with alternating periods, during some of which the streams were occupied in sinking channels into bed rock, while in others they were occupied in filling with gravel those already cut. These episodes in the history of the streams are recorded in the terraces and gravel deposits of the stream canyons.

Terraces of well-rounded basalt gravel are found along all the coulees of the wheat lands, such material being especially well exposed near Connell. Similar deposits are extensively developed near Coulee City and east of middle Crab Creek and of the foot of Moses Lake. Gravel terraces are found at high levels along Columbia River, the best examples occurring below Priest Rapids and in the gorge along the foot of Saddle Mountain. Great volumes of gravel underlie the central portion of Kittitas Valley and are well exposed in section on the banks of Yakima River.

Ancient gravels are found not only in the terraces above the present stream levels, but underlie the existing stream beds in many cases to considerable depths. At Connell records of well borings have shown that the bed of the coulee is filled with gravel to the depth of at least 180 feet. Great depths of gravel are also found in borings along other coulees. The Columbia flows on gravel through the greater portion of its channel, but has reached bed rock at Priest Rapids and perhaps also at Coyote Rapids.

The history to be read from these gravel deposits is briefly as follows: (1) There was a period during which the streams, actively cutting downward, carved a system of canyons in bed rock deeper than those which exist at present; (2) a period succeeded during which the streams were overloaded with gravel and filled up their bed-rock channels to depths attaining, in the case of the Columbia, at least 300 feet; (3) there was a second period of down cutting, in which the streams cleared out the gravel from their bed-rock channels to a greater or less extent; temporary halts in the process of down cutting are marked by the lower terraces; (4) the large and numerous streams that carved the canyons dwindled because of the arrival of the present arid climate, and the down cutting into the gravel deposits practically ceased except in the cases of Columbia and Yakima rivers.

The gravel deposits of the region are not only of scientific but also of economic interest, as the surface wells of the region are mainly located in the gravels on the valley and coulee bottoms.

### GLACIAL HISTORY.

There was a period, recent as time is measured by the geologist, but long before the beginning of human history, when the valleys of the northern Cascades and of the Okanogan highlands were filled with immense glaciers, the largest of which reached the plains before they were melted in the warmer air of the lower country.

The greatest ice river of eastern Washington flowed down the Okanogan Valley, which it filled to a depth of several hundred feet. Upon reaching Columbia River Valley this glacier expanded. It seems not only to have dammed the Columbia, but to have filled its profound canyon down to the outlet of Lake Chelan, and to have spread out over the plateau embraced by the Big Bend for about 35 miles to the east of this point. The southern limit of the Okanogan glacier is marked, according to Salisbury,[a] by a terminal moraine

[a] Salisbury, R. D., Jour. Geol., vol. 9, 1901, p. 721.

extending from Chelan Falls to a point about 5 miles north of Coulee City, in a great curve convex to the south.

The eastern end of this moraine was seen in the course of this investigation. It is a low ridge or, more exactly, a slightly elevated hummocky zone formed of material pushed up in front of the advancing glacier or carried on its surface and stranded where the ice melted. Borne thus upon the southward-moving ice were many huge blocks of basalt and fewer of granite. Some of these were stranded upon the moraine, and many are to be seen on the plateau in the vicinity of St. Andrew. One of them, an enormous block of basalt, stands near the brink of the Grand Coulee and is a striking landmark visible for many miles. In early days it served to guide travelers from the east, and was generally known as Pilot Rock. Other large bowlders are strewn upon the terraces at Coulee City and Ephrata, and seem to have been dropped from icebergs that broke from the glacier front and floated for some distance southward on the stream which then filled the Grand Coulee.

While the Columbia was dammed by the Okanogan glacier it flowed along its western side southward into Crab Creek Valley, which was probably eroded to a considerable depth before this time. During the existence of the ice dam the Grand Coulee was carved, lower and middle Crab Creek Valley was much enlarged, and extensive deposits of gravel were laid down about Ephrata and Moses Lake. When the glacier retreated up Okanogan Valley the Columbia resumed its former channel.

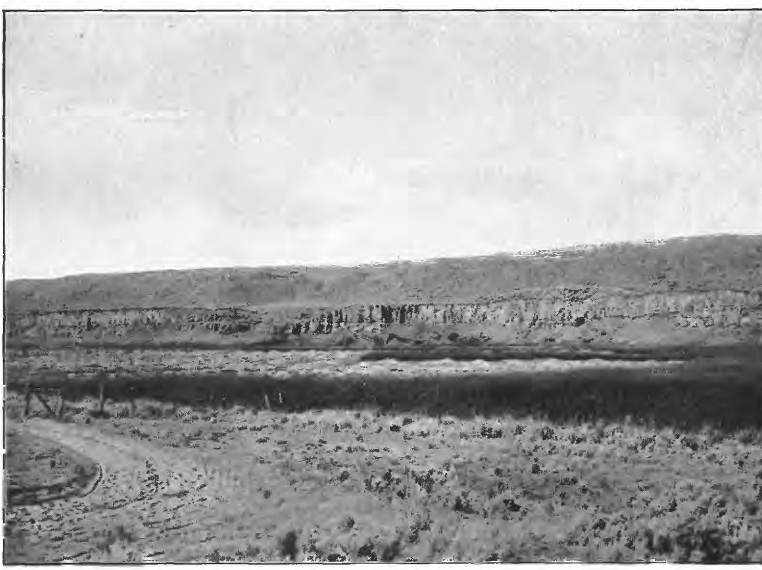
### WIND WORK.

Under the arid conditions that have prevailed in historic time water erosion has had comparatively little effect in modifying the general surface of the land. Various conditions, however, have enabled the wind to do considerable transportation; the air currents, which have a prevailing southerly direction, are strong and frequent, while the soil is dry and loose textured, and is but slightly protected by the meager growth of grass and shrubbery.

#### SAND DUNES.

The most striking evidences of wind work occur in the sandy region that borders the Columbia, where groups of sand dunes of very perfect form are to be seen. They exhibit the characteristic wave-like profile, their steep sides constantly facing in the north or leeward direction, and the process of their growth and shifting is to be seen on any windy day. Other sand dunes of remarkable size and extent are to be seen below Moses Lake, which, as before remarked, owes its existence to them. Low hillocks, built up mainly by wind action, are also to be seen on the plain south of Saddle Mountain, but the dune form in these is not so pronounced as in the

*A.* GRAND COULEE.



*B.* RECLAIMED MARSH LAND NEAR WILSON CREEK.

ones previously mentioned, probably because of the vegetation that has found a foothold upon them and allows the sand to move less freely.

SOILS OF THE WHEAT LANDS.

In the wheat lands also the wind has given the final touches in the molding of the surface. The minor branches of the dry coulees, carved originally from basalt, have had their once rugged sides mantled with fine wind-blown soil, which conceals the bed rock except in widely separated exposures. That the soil mantling the slopes of the coulees has been laid down by wind seems obvious. The present writer further believes that the thick soil of the wheat lands also is mainly wind deposited, or eolian. It has been assumed by most writers who have touched upon the subject that the typical wheat soil of the Columbia Plains is residuary, derived from the decomposition of the underlying basalt. Professor Russell, however, is the only geologist who has supported the residuary hypothesis by extended argument. In his report on southeastern Washington he advocates the view that the wheat soils are essentially residual, but superficially modified by wind action.[a] In his later description of the Nez Perces region in Idaho he reaffirms the views expressed in the earlier paper, and applies the theory of residuary origin to the wheat soils of Idaho.[b] The writer's observations in east-central Washington have led him to believe that the wheat soils are not residuary, but wind deposits. This belief is based primarily on the following facts observed in the field:

(1) The thickness of the wheat soils, as shown by well records, varies according to location from 50 feet to a minimum probably averaging something like 25 feet. They mantle completely most of the broad plateau surface and the gentle slopes, often concealing the bed rock in the smaller gullies for many miles. The greatest thicknesses, however, seem generally to be on the brows of slopes, where there are the most favorable opportunities for accumulation of wind-blown material.

(2) The physical properties of the wheat soils are highly characteristic and remarkably uniform. In texture they are fine loams, very light, open, and friable.

(3) Their prevailing color is a light tawny brown, varying according to the amount of organic matter present, but conspicuously in contrast to the deep red tints which one would expect in a soil derived from the decomposition of a rock so rich in iron oxides as basalt.

(4) When exposed in vertical sections the wheat soil is seen to preserve its surface characters with remarkable constancy down to the

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, pp. 60-64.

[b] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, pp. 44-48.

solid basalt beneath. There is rarely any lamination perceptible, such as would suggest deposition by water.

(5) In all sections observed by the writer, moreover, the division between the basalt and the tawny loam is sharp, without any transition from fresh rock, through decomposed rock and soil with rock particles, such as would be expected were the soil residuary.

The sharp definition between soil and basalt seems absolutely to forbid the belief that the soil is residuary in the strict sense—that is, resting in the place of its formation. It must, therefore, be a transported soil. The absence of lamination in the soil, the fineness of its texture, and the absence of any particles so large as to be incapable of wind transportation seem almost to demonstrate that the agency concerned in its deposition was wind. Granting this much, however, it might still be argued that the material was derived from the decomposition of basalt and only slightly removed from its source. But the wheat soil's evident poverty in iron oxide, and its freedom from any recognizable particles of basalt, are facts which strike the observer in the field as discordant with such a supposition, and the results of detailed chemical analyses give additional evidence in the same direction.

*Comparative analyses.*—There are on record many analyses of the wheat soils of the Columbia Plains, made in the agricultural experiment stations of Washington and Idaho. It appears, however, that they are generally analyses merely of the portion soluble in hydrochloric acid, and while they may serve the purpose for which they were made they do not give the true chemical composition of the samples and throw but little light on the question of their origin. Partial analyses of basalt and of the overlying soil from Dayton, Wash., have been made by Dr. G. P. Merrill and are published by Professor Russell,[a] but the soil analysis differs so markedly from all those emanating from the experiment stations as to throw increased doubt upon their availability.

In view of these facts analyses were made in the chemical laboratory of the Geological Survey of a typical wheat soil and of an undoubtedly residuary soil. The following tables are designed to facilitate the consideration of the available chemical evidence bearing on the origin of the wheat soils. In Table A the results of the last-mentioned analyses are exhibited side by side with an analysis of basalt similar to that underlying the wheat lands from the Mount Stuart, Washington, quadrangle. In Table B the analyses given in the first table are presented in a condensed form for more ready comparison with the analyses given by Professor Russell.

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 61; and Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 44.

TABLE A.—*Analyses of basalt, residuary soil, and wheat soil made in Geological Survey laboratory.*

| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ | 54.50 | 52.95 | 65.43 |
| $Al_2O_3$ | 14.43 | 15.69 | 13.96 |
| $Fe_2O_3$ | 2.17 | [a]11.85 | [a]5.35 |
| FeO | 8.80 | | |
| MgO | 4.24 | 2.05 | 1.54 |
| CaO | 8.01 | 4.40 | 2.90 |
| $Na_2O$ | 3.05 | 2.09 | 2.42 |
| $K_2O$ | 1.29 | 1.11 | 2.08 |
| $H_2O$ at 105 | .29 | 2.19 | 2.32 |
| $H_2O$ above 105 | 1.09 | 4.01 | 2.42 |
| $TiO_2$ | 1.69 | 2.57 | .87 |
| $P_2O_5$ | .21 | .19 | .20 |
| C | ...... | .63 | .49 |
| Total | 99.77 | 99.72 | 99.98 |

[a] Comprises all iron oxide reckoned as $Fe_2O_3$.

I. Basalt, Mount Stuart quadrangle; Hillebrand, analyst; contains also small quantities of $SO_3$, MnO, BaO, and SrO, aggregating 0.36 per cent.
II. Residuary soil, Hanson Creek; Steiger, analyst.
III. Virgin soil (surface), south of Krupp, Wash.; Steiger, analyst.

TABLE B.—*Analyses of Table A (condensed) compared with analysis given by Professor Russell.*

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| $SiO_2$ | 47.35 | 54.40 | 52.95 | 65.43 | 63.58 |
| $Al_2O_3$, $Fe_2O_3$, etc | [a]34.38 | [a]28.28 | [a]30.30 | [a]20.38 | [a]22.36 |
| MgO | 4.43 | 4.24 | 2.04 | 1.54 | 1.82 |
| CaO | 8.27 | 8.01 | 4.40 | 2.90 | 2.76 |
| $Na_2O$ | 2.55 | 3.05 | 2.09 | 2.42 | 2.02 |
| $K_2O$ | 1.33 | 1.29 | 1.11 | 2.08 | 2.27 |
| Ignition | .95 | 1.38 | 6.83 | 5.23 | 4.37 |
| Total | 99.26 | 100.75 | 99.72 | 99.98 | 99.33 |

[a] Comprises all iron oxide reckoned as $Fe_2O_3$, plus the $P_2O_5$ and $TiO_2$.

I. Basalt; Merrill, analyst; given by Russell.
II. Basalt, Mount Stuart quadrangle; Hillebrand, analyst.
III. Residuary soil, Hanson Creek; Steiger, analyst.
IV. Virgin soil (surface), south of Krupp; Steiger, analyst.
V. Surface soil, wheat field near Dayton, Wash.; Merrill, analyst; given by Russell.

Upon comparison of the analyses in Table B it is evident that I and II are very similar, and in view of the fact that the basalts of the Yakima series do not vary widely in petrographic character, analysis I in Table A may be taken as sufficiently representative of the basalt series for the present purpose. The similarity also of the soil analyses IV and V is astonishingly close and strongly suggests that the two soils are of the same nature. Comparison of the analyses in Table A should therefore give some valid evidence in regard to the general question of the origin of the wheat soils.

A mere glance at the table shows a general similarity between I and II and a general dissimilarity of III from either of the others. When we proceed to more detailed comparison of the proportions of the various oxides, the most significant facts brought out seem to be the following:

(1) The alumina in III is slightly less than in I and II.

(2) The iron oxides are about equal in I and II, but are much less abundant in III.

(3) The alkalies in II show, as compared with I, a notable decrease, relatively greater in the case of potash; III contains little less soda than I and more than II, while the potash is 60 per cent more abundant than in I.

Residuary soils generally show, as compared with the parent rocks from the decomposition of which they are derived:

(1) Increase in the proportion of alumina. In calculating the percentage of each constituent lost in the process of decomposition the alumina is generally assumed to remain constant.

(2) Equally or more abundant iron oxide, except where organic matter is present and reduces the iron to the soluble protoxide. There is no evidence, however, that the conditions in this region ever favored the removal of iron oxides by leaching.

(3) Greatly decreased percentage of alkalies, which are the most soluble constituents of the rock.

It is sufficiently obvious that the differences between the wheat soil and the underlying basalt are not only considerable, but, what is much more significant, are not of the character naturally to be expected if the wheat soil were derived from the basalt. The discrepancies between the facts of the case in point, on the one hand, and the usual results of weathering, on the other, if they do not quite invalidate the residuary theory, at least require explanation. In the writer's opinion, the chemical data available appear to agree with the field observations in supporting the theory that the soils in question were not derived from the decomposition of the basalt.

*Transporting power of the wind.*—The competency of the wind as a transporting agent must be considered, however, in judging of the validity of the theory here advanced. That wind is, in the Columbia

Plains, a transporting agent of importance is a fact which must impress anyone who travels through the region. Winds of prevailing southerly direction blow with strength and frequency, while the soil is but very imperfectly protected from them by vegetation. Blinding dust storms are by no means rare, and clouds of fine dust envelop every traveler who drives along the roads. On the whole, there appears no reason to doubt that the wind is capable of doing the work assigned to it under the hypothesis here advanced.

*Source of the soil.*—The argument, however, would not be complete without suggesting a source for the material if we reject the supposition that it was mostly derived from basalt. The writer believes that the principal source lies in the desert southwestern quarter of the Columbia Plains, where the basalt is overlain by the soft sedimentary beds of the Ellensburg formation. This material is thought to have been washed down and loosened by the agency of water, and thus put in such form that it might readily be transported by wind.

## HYDROLOGY.

### INTRODUCTORY STATEMENT.

The remainder of this paper is devoted to the consideration of water supply proper. The various kinds of water resources will be described and their availability considered, and the attempt will be made to show how the water supply of the region may be increased. The sources of supply available in the region are streams, springs, and wells, which will be considered in the order named. The first two classes of water resources will be treated rather briefly, but the wells, being more important, will be discussed more fully.

The wells may be divided into two classes—first, surface wells, generally dug by hand in loose materials like soil, sand, and gravel, lying on the surface of the bed rock; second, deep wells, including those in which the underlying older rocks are penetrated, generally by means of a dril, to a considerable depth. Surface wells derive their supplies from rain or snow that falls in their immediate vicinity and percolates downward until some impervious material is reached, while deep wells generally tap beds of porous rock saturated with water that has been absorbed at some distant outcrop and has traveled underground often for great distances.

The most important question dealt with in this paper is that of the capabilities of deep wells, one of the principal objects of the investigation having been to determine whether in any part of the region examined deep wells could be made to yield artesian flows. In discussing this problem a number of districts may be marked out, in each of which the conditions affecting the deep underground waters are similar. For each of these districts the artesian conditions will first be discussed from the theoretical standpoint; the evidence afforded by the wells actually sunk will then be presented, and conclusions will be drawn in regard to the probability of obtaining surface flows. Suggestions will next be presented with a view to directing intelligent tests for artesian water and to economically using all the water obtainable. The paper will end with a brief recapitulation of the important conclusions and suggestions in regard to deep wells.

The preceding portions of this paper have been designed mainly to serve as an introduction to the portion on hydrology proper, as the discussion of the artesian problems will involve frequent reference to the facts regarding the character and structure of the rocks underlying the region.

## STREAMS.

### COLUMBIA PLAINS.

#### CRAB CREEK.

From the fact that the valley of Crab Creek was eroded by a much larger stream than occupies it at present it has resulted that the existing stream has been unable to maintain a graded channel. Certain irregularities in the ancient channel and modifications produced by the drifting in of sand and silt have been sufficient to cause ponding in certain localities, with the consequent formation of marshes, and in some cases the water of the creek vanishes during at least a part of the dry season beneath porous surface deposits, to reappear in full force at a lower point.

The meadows used for the growing of hay and as pasture are generally sufficiently watered by the underflow of Crab Creek, but in certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

On the other hand, some considerable areas of marshy land have been or are being reclaimed by drainage, a notable instance being afforded by the marshy tract extending from Krupp to Wilson Creek. This is being gradually drained, and a large amount of certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

#### COLUMBIA RIVER.

The use now made of Columbia River water, in its course through this region, is comparatively insignificant. A small amount of water is raised by water wheels, three or four of which are situated on the right bank of the Columbia below Priest Rapids. The availability of this method is limited by the comparatively small amount of land low enough to be watered by such means. In only one instance is any other means of irrigation used. This is in the case of the Babcock ranch, near Trinidad, where one of the lower terraces has become the site of a hay ranch, which is irrigated successfully by means of a gasoline pump and a number of windmills.

It is natural for the traveler in this region to be disappointed at the slight utilization of Columbia River water and to inquire into the possibility of bringing more of it upon the bordering arid lands, especially the extensive tract between the Saddle Mountains and the easterly stretch of the Columbia, the general elevation of this tract being about 300 to 400 feet above the Columbia at Sentinel Bluffs.

Two possible methods of accomplishing this suggest themselves. The first involves the construction of a ditch from some point on the upper Columbia or on some tributary of the Columbia. This idea, when scrutinized, offers great engineering and financial difficulties. To reach a point on the Columbia of sufficient elevation would necessitate the construction of many miles of flume along precipitous portions of the river gorge. To bring water from one of the tributaries flowing into the Columbia from the Cascade Mountains on the west would involve obstacles which, if less serious than those presented by the first-mentioned plan, would still be extremely formidable.

The second apparently possible method is to raise the water from the Columbia by pumping, obtaining the power by utilizing the considerable fall of the river through Priest Rapids. The practicability of such a scheme must be determined by experienced engineers after examination of the ground, and the suggestion is made here only tentatively.

It is said that surveys were once made for a ditch to head at Sentinel Bluffs, with the hope of irrigating a large part of the sandy land below the great bench, but it was found that the ditch level abutted against the escarpment of a terrace about 150 feet above the river and fairly close to its shore at a point a few miles east of the Harrison ranch. The project was therefore abandoned, as it was considered that the small area of land irrigable by such a ditch would not justify its construction, while to secure an increase of elevation sufficient to overcome the obstacle mentioned would require that the ditch be begun above the Sentinel Bluffs and far up the rocky gorge north of Crab Creek.

## KITTITAS VALLEY.

### *YAKIMA RIVER AND TRIBUTARIES.*

The greater part of the arable land in Kittitas Valley is more or less efficiently irrigated. The ditches may be divided, according to the source from which they derive their supply, into two classes: (1) those leading from Yakima River, and (2) those obtaining water from the tributary streams that head in the mountains to the west, north, and east. The ditches of the first class are nearly all controlled by corporations, and data concerning them are comparatively accessible. Those of the second class include only two incorporated ditches and a large number of private ditches, concerning which it is difficult to obtain accurate information.

*Canals from the Yakima.*—The oldest large canal on Yakima River is that known as the Ellensburg ditch, controlled by the Ellensburg Water Company. The construction of this ditch was begun in 1885, and the greater portion of it was completed in 1887. It was enlarged and extended 3 miles in 1892. The cooperative plan upon which the controlling corporation was organized is typical for the Ellensburg region.

The ditch was built by the farmers in the irrigation district covered by the ditch, stock in the corporation being given in payment for the labor performed. The original value of the stock was placed at $5 per share, of which 8,000 were issued. The ownership of each share entitles the holder to one-half a miner's inch of water. The price of water is fixed each year and the money received applied to the payment of current expenses, which are low, and to the liquidation of indebtedness incurred in the construction of flumes. The present price of water is about $1 per inch, or 50 cents per acre, but it is expected, after the indebtedness is cleared off, to reduce this to about 50 to 70 cents per inch.

The intake of the canal is at a point on Yakima River about 7 miles above Ellensburg. It sweeps about the eastern side of the valley, doing duty for most of its entire length of about 20 miles, and terminates at a point about 5 miles southeast of Ellensburg. Its fall is 22 inches to the mile. The total area irrigated by this canal is about 8,000 acres.

The Bull canal is named for Walter A. Bull, by whom it was first constructed in 1885 for the irrigation of his own farm. It was afterwards enlarged and used by a score of farmers, who organized a corporation, to which the water rights of the ditch were transferred in 1898. The plan of organization was cooperative, and similar to that of the Ellensburg Water Company. There are 50 shares of capital stock, each valued at $75 and entitling the holder to 20 inches of water. The capacity of the canal is thus about 1,000 inches, or sufficient for the irrigation of some 2,000 acres. The charges for water are extremely low. They average about 20 cents per inch per annum, and attained in 1898 the merely nominal figure of 5 cents per inch.

The water is taken from Yakima River, and first does duty in supplying power for the flour mill at Ellensburg. From the tailrace of the mill the water is led into the lower part of Wilson Creek channel, and this natural trench is made to serve the purposes of a ditch.

The only other large ditch from Yakima River is that of the West

Side Irrigation Company, which begins about 2 miles above Thorp and irrigates about 7,000 acres on the west side of the river. It has a capital stock of $30,000, divided into 600 shares of $50 each. A share entitles its holder to 6 inches of water. The cost of maintenance is about $1,000 a year, or about 35 cents per inch of water delivered.

The Cascade Canal Company has just completed a canal higher than any previously constructed. It has been financed locally and is to be operated on cooperative principles. The intake of the canal is at Dudley, about 4 miles above Thorp, and its total length is about 42 miles. The company has built a dam across the outlet of Lake Kaches that will raise the water about 15 feet above low-water mark. The cost of the canal is about $125,000, and it will irrigate about 16,000 acres of land. The same company expects to construct a higher canal in the near future.

*Canals from tributaries of the Yakima.*—Of the canals that take water from the mountain streams, only two are incorporated. These are the Taneum and the Manastash ditches, named from the streams from which they derive their respective supply. They are among the oldest ditches in central Washington, both having been constructed about 1875.

The larger of these is the Taneum ditch. It was constructed on a cooperative plan. The cost of construction was a little more than $1,000, and the corporation was capitalized at $2,000, divided into 40 shares. The value of water is so great, however, that $500, or twenty times the par value, is now paid for a single share. The capacity of this ditch at high water is about 5,000 inches, but the supply often becomes deficient in late summer.

The Manastash ditch irrigates a smaller area than the Taneum. Its maximum capacity is 1,200 inches; after July 1 the supply is cut down to half this amount. The capital is about $1,500, but the actual value of the ditch is now estimated at about $25,000.

In addition to the canals above described, there are a great number of private ditches taking water from the small streams. It is supposed that the total acreage irrigated from these ditches is larger than that supplied by the larger incorporated ditches. However, those who are dependent on the supply of the mountain streams often suffer from an insufficiency of supply in the latter part of the summer, there being generally no more than enough to mature grain or a single crop of alfalfa.

## CONSERVATION OF THE SUPPLY.

For the amelioration of this condition it is to be hoped that storage reservoirs in the mountain canyons may be constructed at some future time, so that the abundant run-off of the rainy months can be stored and allowed to come down to the thirsty valley lands in the dry season, when it is needed. The writer is unable to suggest any sites where reservoirs can be constructed economically, but believes that future necessity may stimulate the discovery and survey of suitable reservoir sites.

It is also a matter of the highest importance to make certain that the means supplied by nature for the equalization of the run-off by the storage of water in snow banks and in the sponge-like mantle of humous soil and rootlets that is spread over the shaded forest areas shall be preserved to the fullest possible extent. It is probable that the regulations in regard to the pasturing of sheep in the forest reserves might advantageously be made more stringent. Greater pains should also be taken to prevent the spread of forest fires and to secure the punishment of those who start them. There can be no doubt that the origin of a great number of forest fires is traceable to criminal neglect, if not to the deliberate intention of those whose interest is furthered by the clearing of the land. There is much testimony to the usefulness of the foresters in checking forest fires, but it is also certain that the present force is inadequate to prevent immense annual destruction under existing conditions.

## SPRINGS.

In the early days of the settlement of the arid Columbia Plains water for the use of man and beast was almost entirely derived from springs. Even up to the present time many families are entirely dependent upon springs for their supply, which they not infrequently haul for many miles either in barrels or in specially constructed tank wagons. The more provident farmers have cisterns sufficiently capacious to contain several tank loads, and are thus enabled to hold a supply in reserve to tide over periods when time can not be spared for hauling.

The springs of this region may be classified as surface, canyon, and fissure springs. The great majority belong to the first two classes.

### SURFACE SPRINGS.

The term surface springs is applied here to springs in surface deposits overlying the basalt, supplying water that has not sunk to any considerable depth. These in many cases appear to be formed by the gathering of surface water that has percolated down through the soil mantle and, flowing slowly over the underlying surface of comparatively impermeable rock, has become concentrated in the stream channels that furrow its surface. The water, small in amount, is for the most part concealed in the alluvium and the wind-blown silt with which these channels are filled, and emerges only in exceptionally favorable localities. Springs of this character are observed on the line of the Northern Pacific at Paha, and are of especial importance on the slope leading from Coulee City to the plateau northwest. It is probable that at this locality they are largely in the material of the great moraine that terminates in this neighborhood. In the sloping gullies these springs are numerous enough to furnish the domestic supply for the ranches there situated.

### CANYON SPRINGS.

What are designated canyon springs are generally situated in the walls of coulees. In genetic character they do not differ widely from springs of the first class. The water supplying them has come from no great distance. In some cases they are supplied by rain water that is absorbed by the soil and finds its way slowly through crevices in the columnar basalt to a porous layer of scoria underlain by relatively impervious rock; favored by a slight slope, the water then flows to some outlet in a canyon wall. In other cases it is probable that much of the supply is absorbed at another edge of the water-bearing stratum exposed on the slope of a not far-distant canyon from which there is a decided dip toward the spring. Black Rock Spring, in the first coulee south of upper Crab Creek, appears to be a case in point. The water there rises, apparently under slight pressure, through the alluvium at the base of the northern wall of the coulee. At Wilson Creek, on Crab Creek just north of this spring, the basalt has a dip of 5° to the south, and it is possible that some water falling on the side of Crab Creek Canyon finds its way to Black Rock Spring.

The number of canyon springs observed was very large. In the valley of Crab Creek near Krupp a spring in a small gully has been improved by digging, and by a system of piping has been made to supply excellent water to a house and barnyard. One of the most important springs in the region is that known as Skooten Spring, which is situated near the eastern end of Saddle Mountain, and supplies a small pond without outlet, and consequently strongly alkaline. There is no other surface water within some 15 miles, and therefore the horses that graze within that radius resort to this watering place in great numbers.

Professor Russell has suggested a method of increasing the flow from the springs that issue from sedimentary layers in the basalt series by driving horizontal tunnels in the water-bearing strata. No springs improved in this way were observed, although small well-like pits have been sunk in many places. It is probable that horizontal tunneling might be employed to advantage in many cases, but the springs generally seem to occur in comparatively thin layers of scoriæ or cinders, so that the digging of a tunnel would be considerably retarded by the resistance of hard rock above and below.

There is a water prospect of peculiar history on the northeastern slope of Saddle Mountain. Tradition has it that the sounds of rushing water used to attract the attention of passers-by, and tunneling was undertaken in the hope of tapping the subterranean stream. The writer visited the abandoned and caved-in excavation, which had penetrated only the mantle of soil and basalt rubble, but could not detect the faintest whisper of the alleged underground current.

### FISSURE SPRINGS.

There remain to be described two very large springs, one of which is certainly a fissure spring from a deep source, while the other is only doubtfully to be classed as a fissure spring. The first of these is Clerf Spring, in Kittitas Valley, the second is a group of springs on a terrace of the Columbia overlooking the foot of Priest Rapids.

#### CLERF SPRING.

The salient features of Clerf Spring have been mentioned by Mr. George Otis Smith.[a] It is situated at the side of a small canyon emptying into the east end of Kittitas Valley. The natural flow has been increased about fourfold by an excavation that affords a good exposure of the rocks from which the spring issues. Fine shales and shaly sandstones of the Ellensburg formation here rest upon the vesicular surface of a basalt flow. The water boils up from the bottom of the excavation, which has penetrated the basalt to a slight extent, and probably emerges from crevices in the rock concealed by fine débris. The water is of good quality, but noticeably warm, the temperature being 62° F. An irrigating ditch leads from the spring along the side of the canyon to the side of the main valley. The supply from this fountain, which is all utilized in the dry season, is estimated to be about 120 miner's inches.

The high temperature of the water and the mode of its emergence show that this spring is, in effect, a natural artesian well and that its water is forced up by hydrostatic pressure from a considerable depth. The facts point unmistakably to the existence in this vicinity of conditions favorable to obtaining flowing artesian water. An experiment in this direction has been made, and boring has been begun within a few rods of the spring in the hope of obtaining an additional supply of water. The well has been carried to a depth of about 40 feet in the basalt, and water has been obtained which, on a test, rose just above the surface. The drilling was done with poor machinery

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 45.

and evidently by an inexperienced driller. The progress in the solid basalt is said to have generally been less than a foot a day, or about one-sixth of the rate attained by experienced drillers in the wheat country. The well was finally abandoned and has caved in about the top so as to be at present useless.

### HARRISON SPRINGS.

At the southwest extremity of the arid plain that stretches south from the base of Saddle Ridge there is a strip of land about 3 miles long by one-half mile wide which is green with a luxuriant growth of swamp hay. On the border of this oasis there are clustered a group of farm buildings and corrals and a strip of old orchard, flourishing and bearing abundantly. A large force of farmers and cattle men live upon the place, which is generally known as the Harrison ranch.

Along a line in the central part of the hay meadow there are a number of small ponds bordered with tules and other aquatic plants. The ponds are very deep in proportion to their small area, and are perennially supplied from beneath with living water colder than that of the river and of good quality. The overflow originally escaped to the river from both ends of the meadow, but since the east end is now banked by a sand dune the escape is mainly to the west, where it falls over the terrace in a stream of probably several hundred miner's inches.

In its original state the area now occupied by this oasis was a marshy lake, which has only been made available for agriculture by artificial drainage. Even now the meadow land beneath the surface is saturated with water and quakes in many places beneath the foot. It is therefore unfit for growing grain or alfalfa. The present crop is chiefly of wild swamp hay, but an endeavor is being made to improve the quality of the forage by gradually supplanting it with domesticated grasses. The crop is mainly used on the ranch for the winter feeding of cattle and horses, whose summer range extends over a large part of the desert to the north. About 1,500 head of stock were wintered here in 1901–2.

The waste of the large surplus of water from these springs, in a land where water is so precious, must strike anyone as a thing to be regretted, and gives rise to the inquiry whether more of it might not be used. The hope of this does not appear to be very good. The strip of land between the meadow and the river is not in general more than 5 feet above the springs, and might, perhaps, be irrigated readily by windmills, but the soil is very gravelly and apparently infertile, so that it is doubtful whether the expense of irrigating it would be repaid. The ranch is situated on the lowest terrace above the actual flood plain of the river, and there seems to be little or no land that can profitably be irrigated from the springs by gravity alone. On the other hand, however, it appears possible to extend the area of hay land by draining some of the broad shallow ponds at the eastern end of the meadows.

The geologic conditions which give rise to these springs can not be observed directly, for the bed rock in this vicinity is mostly concealed. A few small outcrops of basalt are seen north of the oasis, and this rock forms the bed of the river at Priest Rapids. The riverward escarpment of the terrace upon which the springs are situated

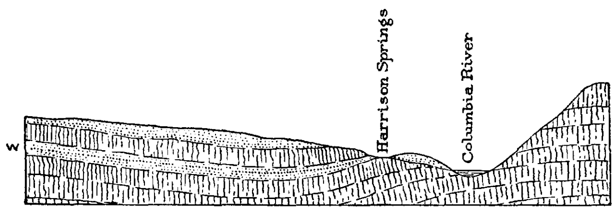



FIG. 2.—Section illustrating explanation of Harrison Springs on the hypothesis that the water-bearing stratum has been tapped by erosion.

is of gravel, without rock exposures. The rock from which the water issues is not exposed. From the rather meager observations two explanations of the phenomena observed seem possible. Under either hypothesis the water is supposed to flow from some porous reservoir stratum (possibly the white tuff bed exposed near Sentinel Bluffs) fed by rain and snow falling on Saddle Mountain.

According to the first hypothesis, illustrated in fig. 2, the water-bearing stratum has been tapped by erosion. The fact that the water issues along a comparatively short line may be explained on the sup-

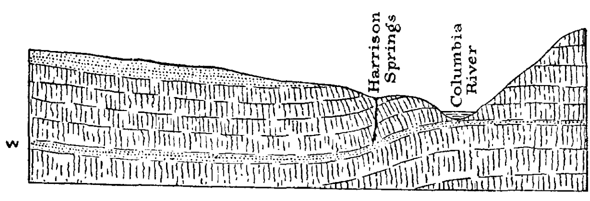



FIG. 3.—Section illustrating explanation of Harrison Springs on the hypothesis that the springs are situated along a break in the basalt.

position that the water-bearing stratum is lenticular, and that a tongue-like projection has been cut off here. The tuff bed already mentioned appears, indeed, to have a lenticular form, since it is not seen west of the river at Sentinel Bluffs nor south of it at Priest Rapids.

An alternative explanation may, however, be given for Harrison Springs. (See fig. 3.) The fact that the springs are in a straight line parallel to the structural ridge across the river strongly suggests that they may be situated along a break in the basalt formed by the earth forces that produced the ridge. This hypothesis is, perhaps, on the whole, somewhat more probable than the one already given. The coolness of the water, however, shows that it does not come from a great depth. The fracture, if it exists, may therefore be a minor one in the basalt above the water-bearing stratum, produced by the rather sharp bending of the basalt and not extending indefinitely downward like a true fault fissure.

## SURFACE WELLS.

The numerous farm wells in Kittitas Valley belong mainly to the surface type and are sunk in valley alluvium. There are some, however, which penetrate Ellensburg sandstones for short distances and probably derive their supply from distant sources, thus being classifiable genetically with the deep wells. Their discussion, therefore, will be deferred to a later section.

The surface wells proper of the valley perhaps require no description. The few wells very near Columbia River, and the more numerous ones in Crab Creek bottom, which derive their supply from the underflow of the neighboring streams, may also be passed with brief mention.

The great majority of the shallow wells in the Columbia Plains are sunk to depths varying from 13 to 75 feet in the alluvial deposits that floor the dry coulees and their tributary gulches. The suggestion advanced in the discussion of springs, that the water on reaching bed rock has been concentrated in the old subsurface channels according to natural laws of drainage, is equally applicable in the case of these wells, for the nature of springs and of surface wells is, in fact, essentially the same, save that in the former the configuration of the ground is such that the water-saturated bed emerges on the surface.

A notable well of this class supplies the small village of Ephrata. Just west of the town a canyon opens out upon the gravelly plain. There is a small surface flow in the lower part of the canyon, which vanishes in the broad delta-like alluvial fan below its mouth, where a shallow well taps the sunken stream, and a windmill pumps it into a tank, from which it is distributed through a system of pipes. There are several other wells in the neighborhood of the town, generally from 50 to 75 feet deep, and gathering their supply from gravel that was probably laid down by the Columbia in Glacial time.

Of more especial interest are the fairly numerous wells on the plateau west of Coulee City. These have all been dug by hand, for the most part in the sand, clay, and gravel brought down by the ancient glaciers from the north. Two such wells are situated in sec. 14, R. 25, T. 27 E., one of which penetrates 42 feet of gravel, clay, and sand and 18 feet of basalt, while the other attains a depth of 65 feet without reaching basalt.

The quantity and stability of the supply from surface wells vary widely in different cases. The wells last mentioned appear to meet all demands except when the wind for the windmills fails for a considerable time. The wells in the coulees often give an abundant supply; one in Lind Coulee, notably, met the domestic needs at one time of a score of families. On the other hand, some surface wells often fail to meet the demands made upon them in the dry season, and it may be said in general that the chances of obtaining a generous and reliable supply of water are smaller in surface wells than in deep borings in the basalt.

## DEEP WELLS.

### INTRODUCTORY STATEMENT.

Historically the deep well represents the latest development in the methods of obtaining water on the Columbia Plains. When the fertility of the plateau lands was recognized their settlement became inevitable, but the question of water supply was at first a serious one. The waste of time and labor involved in hauling from the widely scattered springs, often necessitating the pulling of a heavy tank over miles of deeply rutted and hilly road, led the wheat growers to seek a method by which a sufficient supply of water could be obtained at any desired point, even upon the summits of the plateau. The deep drilled wells solve the problem successfully, and they are being put down by all who are able to meet the expense, which is often considerable.

The charges for well drilling in the southern part of the wheat lands are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), $2.25 per foot for the first 300 feet and 50 cents per foot additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville the terms are slightly higher; for the first 300 feet the charge is there $2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from $800, though it reaches a maximum of over $2,000.

The rates charged for drilling appear fairly reasonable considering the cost of machinery, the risk of loss, and the degree of skill required. The hardness of the rocks is such as to call for very careful tempering of the drills and skill and patience in manipulation.

There seems to be a strong personal factor in the success of drilling operations, many drillers having records unmarred by loss of tools or failure to obtain water, while the work of others seems frequently to end in disaster.

In Kittitas Valley deep wells have never attained importance as a source of water supply. This fact is due to the more favored condition of the valley. In the lower portion shallow hand-dug wells have been found adequate to supply the wants of the house and barnyard. The much larger demands of irrigation have been supplied more or less satisfactorily with water from the Yakima and its tributaries. Thus, although it has long been recognized by intelligent observers that the basin-like structure of the valley is favorable to artesian water, the demand for an artesian supply has not been strong enough to give rise to energetic prospecting. The two borings that have been made were unsuccessful and have thus tended to destroy the hope of obtaining flowing wells in the valley, but, as will be shown later, these experiments were so inefficiently carried out as to have little evidential value.

The purpose of the following discussion is primarily economic, and it will attain its object if it helps the reader to decide to what extent he can profitably invest in deep borings. It is the scientific questions involved in this problem that the writer proposes to treat here. It will be shown, for one thing, to what depths, approximately, it is necessary to go in a given part of the district for a sufficient supply. But a question which is perhaps more important, and whose solution requires scientific investigation of a special kind, is whether artesian water exists in the region. The fact that no flowing wells exist at present is not conclusive evidence for a negative answer to this question, since the all-important rules for the proper casing of wells have been generally ignored. Furthermore, an endeavor will be made to show that underground pressure, even though insufficient to raise water to the surface, may often advantageously be utilized by proper casing.

Since this paper is intended chiefly for the benefit of nonscientific readers, it will be necessary, in order to make the discussion of artesian problems clear, to insert at this point a statement of the principles upon which artesian flow depends, and to show how those principles should be applied in prospecting for artesian waters and in constructing artesian wells.

## GENERAL THEORY OF ARTESIAN WATER.

The conditions that usually determine the flow of an artesian well may be illustrated as follows: Suppose two water-tight basins of similar form are so fastened together as to lie one within the other, with a small water-filled space between. Let the upper basin be perforated, and let the perforation be tightly fitted with a tube. According to a simple and familiar law, the water will rise in this tube to the height at which it stands in the space between the basins, and if the mouth of the tube be lower than the rim of the lower vessel and the latter be kept full by some external supply a constant stream will issue from the pipe. Such an arrangement as is here described would be a working model of an artesian basin. The construction of our model might be slightly modified, however, without essentially changing the principles involved. For the basin-shaped space we may substitute one between two superposed troughs or between two inclined boards, provided that the space is closed except along its upper edge. In either case a flow would be obtained from any aperture below the lowest point of the rim of the reservoir space. The essential principle illustrated in this simple manner is expressed by the familiar saying that "water seeks its own level."

In natural artesian districts, however, the conditions do not have the ideal simplicity of our primitive model. A number of additional factors come into play, materially complicating the problem. We

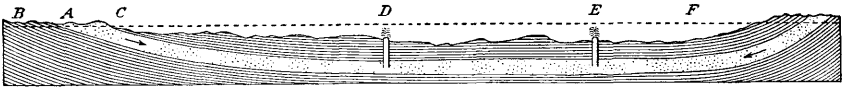



FIG. 4.—Ideal section illustrating the requisite conditions for artesian wells. (After Chamberlin.)

have now to show to what extent natural conditions are represented by our model, and in what respects the difference of actual from ideal conditions leads to modification of the simple rules of artesian flow.

Suppose a basin-like valley, underlain by a stratified series of rocks that have a basin structure, so that the form of the layers corresponds in a general way to that of the surface of the ground. Suppose that in this stratified series there lies a bed of porous material, such as a coarse, open sandstone, capable of absorbing and storing a large quantity of water, and that this porous bed is overlain and underlain by some material, such as compact clay shale, which is practically water-tight. If the upturned edges of the sandstone stratum are exposed along the slopes of the hills surrounding the valley, they will absorb a portion of the rain falling upon the hills, and, in some cases, of streams flowing over the outcrop. The porous bed will become saturated with water and constitute a great underground reservoir, from which an artesian flow may be obtained by sinking a well at some point lower than the exposed area where the bed absorbs its supply. (See figs. 4, 5, 6.)

While the conditions in the basin valley are similar to those of the simple model in the most essential respects, there are two noteworthy particulars in which the natural and the ideal conditions differ.

In our working model we have for a reservoir an open space, and the basins that form its walls are water-tight. In nature the reservoir is generally constituted by an aggregation of minute but connected pores between the grains or fragments that constitute the water-bearing bed, and the confining strata are never absolutely impervious. Both these modifications of ideal conditions have an important influence upon the flow of artesian streams.

First, the water flowing to a well through the small interstitial spaces encounters a notable amount of frictional resistance, which has the effect of retarding the flow. In order to counterbalance the consequent loss of artesian pressure and obtain a generous flow the well must be situated at a point considerably lower than the area of absorption and the depression must be increased in proportion to the distance from the source of supply.

Second, leakage through the confining strata, by diminishing artesian pressure, acts in the same unfavorable way as frictional resistance, though loss from this source is not likely to be serious if the region between the area of supply and the wells is elevated.

When, therefore, we inquire as to whether the stratigraphic conditions in a given region are favorable to the hope of obtaining artesian water we must not look for absolute impermeability in the strata confining the water beds. It is necessary only that the resistance which the water must overcome in escaping through the confining strata be large in comparison with that which it encounters in flowing through the porous stratum. In other words, the stratigraphic conditions are fulfilled when we have a relatively permeable stratum confined between strata that are relatively impermeable.

We have still to consider another difference, perhaps even more important, between theoretical and actual conditions. We have assumed up to this point the absence of any exposure of the water-bearing stratum affording opportunity for leakage lower than the mouth of the artesian wells. It is probable that this condition is

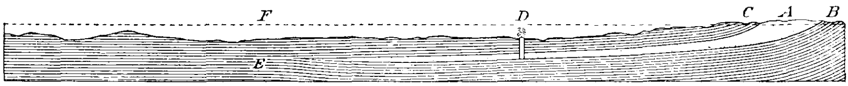



FIG. 5.—Section illustrating thinning out of a porous water-bearing bed. (After Chamberlin.)

rarely fulfilled in nature. Most valleys are drained by streams, and the gorge by which a river leaves a basin-like structural depression will cut the water-bearing stratum and expose it at a lower elevation than any point on the valley floor. An ideal artesian basin must be topographically an undrained basin, and that is an exceptional topographic form. It is probable that in the great majority of artesian districts the water-bearing stratum is cut at points lower than any of the wells.

The effect of such leakage upon the behavior of artesian water must therefore be inquired into and the reason shown why it does not destroy underground pressure in the imperfect reservoirs. It is a more or less familiar truth that moving underground water follows the path of least resistance. More definitely and specifically, we may say that the water at any given point in an artesian basin will tend to escape to the surface by the route on which it will have to do the least work in overcoming resistance. The resistances to be overcome are friction and gravitation. It is readily conceivable that in the area near a well the water can more easily overcome the gravitative resistance and rise to the surface as an artesian flow than the great frictional resistance it would encounter in passing to a distant low outcrop, even though aided by gravity.

An illustration of the principle here involved may be cited which is familiar to the experience of everyone. In a city house furnished with a system of wate pipes, the turning on of faucets in the lower stories will not generally stop the flow from the faucets on the floors above, though it may materially diminish its force and volume.

The considerations set forth in the later paragraphs have been recognized by others,[a] and Professor Russell, from whose paper[b] the accompanying figure (fig. 6) has been taken, has proposed for the form of reservoir in question the term "artesian slope." It seems to the present writer, however, that it has not been sufficiently recognized that leakage in natural reservoirs is almost universal. When a district is examined with reference to artesian conditions, hope of obtaining artesian flows should not be abandoned on finding that the water-bearing strata were exposed at low levels, but an attempt should rather be made to estimate the degree to which the existing natural leakage will injure the artesian reservoir. It will be interesting to discuss briefly the data upon which such estimates may be based.

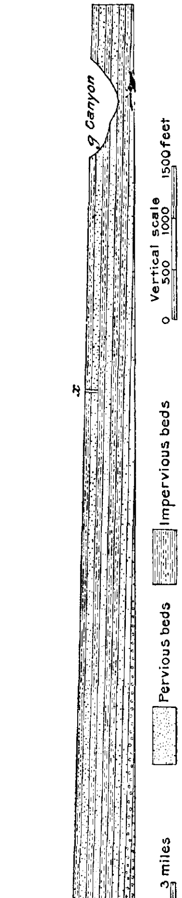


FIG. 6.—Section of an artesian slope. (After Russell.)

It is obvious, in the first place, that the danger from leakage is great in proportion as low outcrops are extensive. In the case of a basin valley, for example, it is desirable that the

[a] Chamberlin, T. C. Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1884, p. 142, fig. 17.

[b] Bull. U. S. Geol. Survey No. 199, 1902, p. 157.

gorge through which the river emerges be narrow in proportion to the size of the expanded part of the valley. Another fact, perhaps less evident, is that it is disadvantageous for the river to have cut down deeply below the general level of the valley floor. In such a case the water-bearing stratum may be very extensively exposed, and the artesian basin indeed be divided into two scoop-shaped segments with the water bed exposed along the entire edge of each. By a similar course of reasoning it may be perceived that in a given artesian district porous beds lying low down in the series will in general be less extensively exposed along the rivers than higher beds (see fig. 14, p. 65).

The effect of leakage is dependent, in the second place, on the proximity of the low-level outcrops to the place where the well is to be sunk. In the close vicinity of such outcrops the route of escape by the natural exposure of the porous stratum may offer less resistance than must be overcome in rising through the wells. At points more remote from the region of leakage, on the other hand, the loss of pressure will be much less serious, and at great distances it may become negligible. In a long synclinal valley, underlain by a water-bearing stratum having the form of a trough with open ends, the chances of obtaining an artesian flow in the central portions of the depression would generally be excellent, and loss of pressure by leakage need be apprehended only near the ends of the trough. In the case of an inclined stratum exposed along the greater portion of its lower edges the danger from leakage would probably reach a maximum. The diminution of pressure from leakage would be greatest near the low outcrops; but, on the other hand, those situated farther away would generally be at a disadvantage from being on higher ground, and the most favorable location for wells would be in an intermediate zone where conditions were somewhat balanced.

From the foregoing discussion it should be evident that the prospector for artesian water may, according to his judgment and experience, make a more or less approximate estimate of the effect of natural leakage. Each case must of course be considered for itself, yet certain rough generalizations can be made. In the central portion of a basin valley, from which a river flows by a narrow gorge and does not deeply trench the valley floor, or in the middle of a synclinal trough of great length, the loss of pressure by leakage is not likely to diminish the pressure in a fatal degree. On the other hand, a well sunk to an inclined stratum extensively exposed at a low level will generally not succeed unless the stratum is of very great extent and other conditions are favorable. The effect of leakage is, however, at best a somewhat indefinite factor in the artesian problem.

The discussion to this point has related to the structural, stratigraphic, and topographic conditions influencing artesian flows, or, in other words, to the nature of the reservoir. Of no less importance is the supply which fills this reservoir and supplies the loss from wells and springs. In order that a well shall continue to flow, the water level in the artesian reservoir must be kept higher than the mouth of the well. This supply, as has been briefly noted, is chiefly from rain falling upon the high exposures of the porous stratum and immediately absorbed. It may, however, be augmented by a considerable amount not falling directly upon the area of absorption, but flowing over it for short distances in temporary rills, and by leakage from streams that flow across the outcrop of the porous stratum. A case illustrating leakage from a stream is cited by Mr. George Otis Smith in his description of the Moxee-Atanum basin.[a] In this manner areas remote from the zone of outcrop may contribute to the artesian reservoir.

The amount of water supplied to an artesian basin depends on the area of the zone of absorption and on the amount of precipitation along that zone. The zone of absorption is necessarily higher than the flowing wells and consequently lies usually in a region of greater rainfall. Its area, however, is generally small in proportion to that of the whole artesian basin, and the amount of water that can be drawn from the underground reservoir, far from being unlimited, is very definitely determined by the average precipitation on a comparatively small area. If the amount drawn off by wells and springs exceeds the amount annually furnished by rain and snow, a diminution of artesian pressure must result. Many wells that gave a powerful stream at the beginning have ceased to flow when borings have multiplied in their vicinity. This danger of wasting the artesian supply has been recognized by the legislature of the State of Washington,[b] which has framed a wise law compelling owners to cap their wells during the rainy season (from October 1 to April 1) and to use only such amounts during that period as are necessary for domestic purposes and stock.

We may now recapitulate the necessary conditions of artesian flow, as follows:

(1) A porous stratum capable of absorbing large quantities of water and allowing it free passage.

(2) Relatively impermeable strata above and below, capable of confining most of the water under pressure.

(3) An exposure of the edge of the porous stratum where it may absorb water falling upon it, and, to some extent, that of rills and streams flowing across it.

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[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr Paper No. 55, U. S. Geol. Survey, 1901, p. 56.

[b] Stat. Washington, chap. 121 (H. B. No. 203).

(4) An inclination or folding of the water-bearing stratum and a corresponding slope of the surface of the ground, so that the proposed wells may be located below the zone of supply.

(5) Absence of low-level outcrops sufficiently extensive and sufficiently near the proposed wells to cause great loss of pressure by leakage.

(6) A sufficient supply of rain water to maintain the artesian head.

## DATA CONCERNING DEEP WATERS.

### ARTESIAN DIVISIONS OF THE REGION.

We may now proceed to discuss, in the light of the general principles just laid down, the artesian problems for the region here considered. In this discussion we must use the facts already set forth concerning the natural conditions of the region and, further, the well records that give direct evidence regarding the occurrence and behavior of underground waters.

The facts can not be discussed for the region as a whole, since conditions vary considerably in different portions. A division can be made, however, into districts in each of which the natural conditions are fairly uniform. Those in which deep wells already exist are designated (1) the Connell-Ritzville district, (2) the Hartline district, (3) the Quincy district, and (4) the Kittitas Valley district. In the desert area traversed by Saddle Ridge there are no deep wells, but the natural conditions will be discussed separately for the portions of the desert south of and north of that prominent structural feature.

### STRATIGRAPHIC CONDITIONS IN COLUMBIA PLAINS.

The stratigraphic conditions are so uniform throughout the Columbia Plains that it will be profitable to consider these conditions from the artesian standpoint before proceeding to discuss the special features obtaining in each of the districts just blocked out, all of which lie within the Columbia Plains except the Kittitas Valley, where the stratigraphy is somewhat different and must be discussed separately.

In that portion of the Columbia Plains considered in this report the Ellensburg beds are so distributed as to afford little ground for the hope that an artesian supply can be obtained from them. The obstacles to such a hope are the facts that the high outcrops receive but a very small supply of atmospheric water, and that the beds are too extensively dissected by the canyons and coulees.

If artesian water is to be obtained in this portion of the plains it must be from the basalt series or from beds of sandstone intercalated with the basalt. In discussing the artesian problem for this area, therefore, it is important to consider whether the manner in which the basalt series is built up is favorable to the storage of deep water and its conservation under pressure. The required condition, it will be remembered, is that strata capable of containing much water and of allowing it to pass with comparative freedom shall alternate with strata that are comparatively impervious.

The lithologic character of the basalt, including its texture and the structural features of the massive flows and pyroclastic beds, and the character and extent of the materials other than basalt intercalated with the upper layers of the series, have been described in a previous section. The facts pertinent to the present purpose may be recapitulated briefly as follows: The lava series is built up mainly of a great number of massive flows with rough vesicular surfaces. The massive lava is universally cut up by joints developed in the process of cooling into columns, plates, and irregular blocks. Intercalated with the massive flows are beds of porous tuff and breccia, which, however, occur in small volume as compared with the true lavas. A few beds of acid tuff and of sandstone are interbedded with the upper layers of the series, but are very rare in the lower portion of the section.

To the hasty observer the vesicular or "honeycombed" upper portions of the basalt flows might seem well adapted for the storage of water, but a little thought will show that such an idea is largely fallacious. The vesicles of the amygdaloids are not connected, but are inclosed chambers incapable of receiving water except by slow infiltration and quite incapable of allowing its free passage. To quote the language of Chamberlin, the porosity of a water-bearing stratum should be of an "interstitial and not a vesicular kind."

But if the vesicular portions of the flows are not available for water storage there seems reason to believe that there are spaces between the lava flows, thin and irregular but extensive, that might serve as reservoirs. The surface of a freshly cooled lava flow, though level and monotonous in its broad aspects, is rough in detail. A second flood rolling upon a surface thoroughly cooled will probably not generally completely fill the inequalities of the preexisting surface. The crust forming upon the top and front of the liquid flow, broken and rolled under by its advancing motion, will often form a rough layer that does not fit closely into the minor unevenness of the cooled lava beneath. It is believed that waterways are often constituted by the spaces thus left by the failure of a more or less viscous flow to fill completely the roughnesses of the surface upon which it was poured. Though small in the beginning, these subterranean spaces may subsequently become enlarged by the solvent action of deep waters.

The ability of the porous tuff beds and breccias to absorb and contain water is evident to anyone familiar with their character, and it is believed that they probably contain the most generous supplies of water to be found in the basalt series in the region here considered.

Some of the beds of siliceous tuff and sandstone already described are probably well fitted for water storage, but they are apparently of only local importance. They may be found a source of water in the low-lying southwestern portion of the region, but the records of wells and observations of natural sections go to show that sandy beds are so rare in the eastern and northeastern portion as to be practically negligible.

We have next to consider whether the massive basalt is capable of confining under pressure the water stored in the porous beds.

The massive compact basalt is in itself a practically impermeable rock. The universal presence, however, of crevices, due to contraction partings, has led some observers to believe that the basalt is in general incapable of confining water under pressure. With this view the writer has been led to disagree, mainly by certain facts learned from well records.

Water in the deep wells of the plains is never found in any useful quantity in the massive basalt itself, but always in softer material between the compact layers. It is known to exist under pressure sufficient to raise it 250 feet in certain localities where there is no evidence of any strata of clay or silt which could have been efficient in preventing its escape from the pervious bed. It is concluded, therefore, that the basalt does to a notable extent have the ability to confine water under pressure. The crevices in the massive rock, especially in the case of flows where the columns are small and irregular, are believed to be not only minute but generally not continuous throughout the flow, and to allow the passage of water in but comparatively small amount. At the same time it is admitted that jointed basalt is probably less efficient material for a confining stratum than clay or fine shale.

To sum up, then, it appears that the basalt series presents an alternation of strata of differing permeability favorable to the storage of artesian water, though the stratigraphic conditions are probably not so favorable as they are in a series of open sandstones alternating with beds of fine shale or clay. The water-bearing layers in the basalt series consist of acid tuffs and sandstones, thin irregular spaces between the flows, and basaltic tuffs and breccias. The massive basalt, although universally creviced, is considered to be of low permeability in comparison with these porous layers.

## CONNELL-RITZVILLE DISTRICT.

By this name we may designate that portion of the wheat lands which lies south of upper Crab Creek. This area, though very extensive, is characterized by a similarity of conditions that justifies its treatment as a unit in the discussion of deep wells.

*Structure.*—The structure of the basalt underlying this district is not easily made out except through a broad study of the region, because the inclination of the lava flows, as observed in the walls of the coulees, is almost imperceptible in amount, and its direction and degree can not generally be determined except by careful instrumental observations, which the writer was not able to make. The interpretation of the structure is based largely on topographic grounds. The general surface of the land east of the Northern Pacific, lying at an elevation of nearly 2,000 feet above sea level, probably coincides nearly with the original surface of the basalt, or is below that surface, which may have been largely reduced by erosion. The desert area to the west and southwest, lying at a considerably lower level, is underlain in part by Ellensburg beds, which cover the basalt to a depth of several hundred feet. The surface of the basalt is, therefore, farther below the surface of the ground in this region than in the more elevated lands to the northeast. It may therefore be inferred that the basalt underlying the Connell-Ritzville district has in general a very gentle inclination to the southwest.

*Topography.*—The upper portion of the basalt series in this district is trenched by a large number of coulees, having a maximum depth below the surface of about 400 feet, though when the thickness of the gravel deposits in their bottoms is considered it appears that the trenches in the bed rock have depths as great as 600 feet. The average depth of the coulees is greatest in the southwestern portion of the district, which is nearest the master streams of the Columbia Plains, the Snake and the Columbia. Far to the west the basalt is deeply cut into by Columbia River, which exposes strata many hundred feet below the top of the series.

The general intrenchment in the wheat lands has an important relation to the deep wells. It is evident that any porous strata existing in the basalt series at horizons above the general level of the neighboring canyon bottoms would be extensively exposed to leakage along the canyon walls, and that while it might at some localities carry considerable water, it could not be expected to contain it under artesian pressure.

*Supply.*—The writer is unable to present any information based on detailed observation in regard to a region of supply for the deep-lying porous strata under the eastern wheat lands. Study of maps and level lines shows that along the eastern boundary of Washington and in northern Idaho there is an elevated region which receives a more abundant rainfall than the district considered. Part of this region was seen by the writer in traveling by rail between Ritzville and Spokane. It is a surface of erosion with many inequalities that would probably increase its efficiency as a gathering ground. Some of the lower beds in the basalt series may be exposed there, and may absorb a portion of the rainfall. A supply may also be furnished from the edge of the basalt formation at the base of the mountains in Idaho, though that region is so far distant that it seems doubtful whether it may be assumed that any porous beds extend continuously thence to the Ritzville region.

*Well records.*—The reader may gather from the facts above stated that the natural conditions, considered apart from experimental evidence, in the Connell-Ritzville district do not seem greatly to encourage the hope of obtaining artesian water. There are several factors of uncertainty in the theoretical problem, however, that make it desirable to scrutinize all the evidence obtainable from wells that have already been sunk. The appended list gives the data collected by the writer in regard to these. The list does not include by any means all the wells in the district, but it is believed that the expenditure of time necessary to make an exhaustive list would not have been justified, and that the data obtained will serve the main purposes of the examination.

A few words applying to all the data for the Columbia Plains may also be prefaced in regard to the fullness and reliability of the well records obtained. Owing to the fact that the rock penetrated is mostly basalt, not intercalated with any considerable amounts of tuffs, sandstones, or shales, it has not become customary to keep any regular records of the material through which the drill passes. There has been simply a differentiation between "rock" and "dirt," for the purpose of reckoning charges. Any more detailed information that has been gathered, therefore, has been supplied from the memory of drillers or of others interested in the wells. In regard to depth, the figures have in some cases been taken from written records, but in others from the memory of owners and drillers. It is believed, however, since most of the wells are of comparatively recent construction, that the figures given are substantially accurate.

*Partial list of wells in Connell-Ritzville district, Washington.*

| Owner. | Location. | Depth. | Depth to surface of water. | Depth of soil, etc. | Remarks. |
|---|---|---|---|---|---|
| 1. Northern Pacific R. R. | Eltopia | 151 | 115 | | |
| 2. Do | Lake | 354 | 284 | | |
| 3. J. W. Gover | Sec. 24, T. 13, R. 30 | 311 | 297 | | |
| 4. Jas. Elgin | Sec. 33, T. 13, R. 32 | 323 | 283 | [a] 84 | Water at 310 feet. |
| 5. Brayden Bros | Sec. 32, T. 13, R. 32 | 674 | 629 | 14 | |
| 6. M. C. Moore | Sec. 21, T. 13, R. 32 | 78 | | | Supply not abundant. |

[a] 80 dirt; 4 gravel.

*Partial list of wells in Connell-Ritzville district, Washington*—Continued.

| Owner. | Location. | Depth. | Depth to surface of water. | Depth of soil, etc. | Remarks. |
|---|---|---|---|---|---|
| 7. H. C. Baker | Sec. 29, T. 13, R. 33 | 575 | 551 | 23 | |
| 8. Northern Pacific R. R. | Connell | 228 | | [a] 6<br>[b] 180 | |
| 9. H.W. Brummond | Sec. 8, T. 14, R. 32 | 410 | 395 | 42 | |
| 10. Eugene Adams | Sec. 6, T. 14, R. 32 | 510 | | | |
| 11. Wm. Mittelstadt | Sec. 35, T. 15, R. 31 | 318 | 293 | 30 | |
| 12. Wm. Dickinson | Sec. 25, T. 15, R. 31 | 360 | 330 | 75 | |
| 13. Wm. Brown | Sec. 13, T. 15, R. 31 | 425 | 325 | 50 | |
| 14. Town | Hatton | 300 | 7 | 37 | Water rises. |
| 15. Andrew Newland | Sec. 35, T. 16, R. 31 | 430 | 380 | 50 | |
| 16. Cunningham | Sec. 10, T. 16, R. 32 | 255 | 150 | | In bottom of coulee. |
| 17. C. S. Hedrick | Sec. 34, T. 16, R. 32 | 300 | 250 | 40 | |
| 18. Merrill | Below Lind | | 320 | | |
| 19. McMannaman and Van Marten | East of Lind | 130 | 100 | | |
| 20. Northern Pacific R. R. | Lind | 225 | 32 | 25 | Water rose to top of basalt. |
| 21. Town | do | 286 | 30 | 10 | |
| 22. Adam Buehler | Sec. 15, T. 18, R. 33 | 363 | 328 | 14 | |
| 23. Louis Pflugard | Sec. 14, T. 18, R. 33 | 318 | 298 | 35 | |
| 24. Fred Scheel | Sec. 8, T. 18, R. 36 | 297 | 172 | 25 | |
| 25. Chas. Lakes | Sec. 32, T. 19, R. 33 | 300 | 250 | 40 | |
| 26. | Sec. 30, T. 19, R. 33 | 110 | 20 | 20 | In coulee. |
| 27. Dan Scott | Sec. 35, T. 19, R. 34 | 358 | 258 | 50 | |
| 28. Henry Myers | Sec. 32, T. 19, R. 34 | 350 | 250 | 70 | |
| 29. A. Johanson | Sec. 32, T. 19, R. 34 | 250 | 235 | 70 | |
| 30. City of Ritzville | Sec 23, T. 19, R. 35 | 360 | 200 | 50 | Elevation, 1890. |
| 31. J. W. Johnson | Ritzville | 180 | | 46 | |
| 32. Scott | 6 miles west of Ritzville. | 358 | 270 | | |
| 33. Odessa Mill | Sec. 5, T. 21, R. 33 | 137 | 40 | 23 | |
| 34. | Sec. 26, T. 21, R. 30 | 211 | 206 | 31 | Water in red "honeycomb rock;" lateral flow washed away drillings. |

[a] Soil. [b] Gravel.

A few general statements may be deduced from the list concerning these wells.

In comparing depths, allowance must be made for the fact that some wells are sunk from the high plateau surface of the wheat lands, while others are situated in the coulees, from 50 to 400 feet below the general upland levels. Comparing the average depths of wells in the uplands, we obtain the following results: For the thirteenth and fourteenth rows of townships, 406 feet; for the fifteenth and sixteenth, 367 feet; for the eighteenth and nineteenth, 327 feet. There is thus, in general, a slight increase in average depth from north to south. The explanation of this fact is probably to be found in the greater depth of the coulees in the southern portion of the district, which is near the master stream of the region, where the ancient streams were most deeply intrenched.

The figures in regard to depth of soil have interest, though without direct bearing on water-supply problems. The soil is seen to be in general very deep, apparently attaining its greatest depth on the brows of slopes, where the conditions are most favorable for wind accumulation. Some indication of the amount of hardpan was gathered from descriptions of wells. This material seems to be thickest in the neighborhood of Ritzville. The depth of gravel in certain of the coulee bottoms is also given by the well records.

In regard to the character of the rock in which water is found, the information is, of course, not very definite, since it is based upon the relative ease with which the material is penetrated by the drill and by the appearance of small fragments brought up by the sand pump. No case is recorded, however, where the water-bearing stratum is sandstone, a material that could hardly fail to be recognized. The water-bearing material is always softer than the massive rock, and is usually described as "honeycomb," less seldom as "brown gravel," or "bowlder formation," etc., but no true waterworn gravels were seen in any of the natural exposures of the basaltic series. The testimony all seems to indicate that the deep water is generally found in porous or fragmental basalt.

The third column, headed "depth to water surface," contains data that are of the highest interest, because they give the most positive evidence obtainable in regard to artesian conditions. Drilling is usually stopped almost immediately upon obtaining a good supply of water, and any considerable difference between the corresponding figures in the third and fourth columns usually indicates that the water has risen from the water-bearing stratum. Such a rise indicates that the underground water is under pressure and, therefore, in the general sense of the word, artesian.

This artesian rise of water varies in different portions of the region. To the south it attains 70 feet in the railroad well at Lake. But nowhere in the southern portion of the district is the rise considerable enough to give much hope of obtaining artesian flows.

The most encouraging information was obtained in the vicinity of Lind, where the town well has water standing within 30 feet of the surface, having risen some 250 feet by artesian pressure. Another well was recently bored there for the Northern Pacific Railway Company to a depth of 225 feet. The water was in a porous rock which extended from within 60 feet of the surface to the bottom, where the principal flow was obtained. The water rose 200 feet, to the top of bed rock. Another well in Lind Coulee, a short distance below the town, tapped water which quickly rose to within 3 feet of the surface, but sank afterwards some 20 feet. The latter fact is accounted for on the supposition that the loose surface material was packed and rendered partly impervious by the friction of the drill rope, but became porous again after the water had washed the fine material from the sides of the bore. A consideration of this case should enforce the important lesson that the failure of the water to reach the surface may often be due, not to lack of sufficient pressure, but to leakage through porous material forming the sides of the upper portion of the well. There seems to be very good reason for the hope that artesian water, at least in small quantity, might be obtained at Lind by properly casing the wells.

Northward, in the neighborhood of Ritzville, a rise generally occurs. The water seems to lie at an average depth of about 300 feet below the upland surface, from which depth it is forced up by artesian pressure from 50 to 100 feet, resting from 250 to 200 feet below the general plateau level. In the town well at Ritzville the water surface lies less than 100 feet below the nearest point in the coulee bottom. In the mill well at Odessa the water has risen within 40 feet of the surface, or within 17 feet of the top of the basalt. In a well 110 feet deep in sec. 30, T. 19, R. 33, the water comes within 20 feet of the mouth, and probably escapes by leakage. Attention is called to the importance of the fact that a rise of water in the wells is very general throughout the region. This matter will receive further discussion in the sequel.

Another phenomenon indicating the distant source of the water is a lateral flow noted in one or two cases and shown by the washing away of the drillings.

In regard to the quality and quantity of the water a few general statements may be made. Nearly all of the deep wells, so far as known, yield a supply sufficient to meet all demands for present uses, and one that remains constant throughout the year. The largest supply known to have been furnished was given by the Ritzville city well, which was guaranteed by the contractors to furnish 5,000 gallons an hour and which has, in fact, furnished a stream of that volume for twenty-four hours without perceptible lowering. The quality of the deep waters is generally excellent and far superior to that of surface wells or springs, the underground water being soft and of good flavor. Regarding temperature, the data gathered were too meager to form the basis of discussion, but there is as usual a general increase of temperature with depth.

### HARTLINE DISTRICT.

The Hartline district is defined as comprising the western part of the valley traversed by the branch line to Coulee City, in which lie the villages of Parnell, Wilbur, and Hartline.

*Structure.*—The layers of basalt beneath Hartline Valley have been gently flexed into a synclinal or trough-like form, limited on the south by a low, gently arching swell and on the north by a plateau. The western end of the valley meets the Grand Coulee almost at its own level and is faced by the moderate slope up which the road to the plateau beyond is laid. This slope is in a measure conformable with the structure of the basalt underlying it, the layers of basalt being turned up in such a way as to close up the western end of the syncline. The eastern end of the Hartline trough was not visited, but observations from a moving train give reason to believe that its bottom rises in that direction and that the syncline dies out upon the high plateau land. The Hartline district therefore seems to lie in a spoon-like structural depression, a fact which in itself favors the hope of obtaining artesian water.

*Topography.*—The greatest imperfection in the Hartline basin is its deep dissection by the Grand Coulee. The northern portion of the coulee lies nearly 400 feet, and the southern portion below the old cataract nearly 800 feet, lower than the floor of the valley at Hartline. The close proximity of a chasm so deep must have a very considerable effect in reducing pressure in the basin by affording opportunities for leakage from the water-bearing strata.

*Supply.*—In regard to the source of the underground water of the district, the remarks on that matter in the description of the southern wheat lands apply equally in this place. The principal area of absorption probably lies on the high land to the east, but the writer can supply no data based on actual observation.

*Well records.*—Theoretical consideration of the conditions in Hartline Valley do not, on the whole, indicate very decisively the existence of a true artesian basin, and the evidence of the wells, as in the case of the southern wheat lands, will be useful in aiding a judgment on the possibility of obtaining surface flows. Most of the data exhibited in the following table have been supplied by Mr. J. A. Wilburn, of Hartline, one of the principal drillers of the district.

*Partial list of wells in the Hartline district, Washington.*

| Owner. | Locality. | Depth. | Depth to water surface. | Thickness of soil. | Remarks. |
|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Feet.* | |
| 33. Wasapa | Sec. 14, T. 24, R. 29 | 400 | | | No water. |
| 34. H. Childs | Sec. 19, T. 24, R. 30 | 203 | 173 | 16 | |
| 35. Tom Elder | Sec. 18, T. 24, R. 30 | 147 | 115 | 28 | |
| 36. Do | Sec. 12, T. 24, R. 30 | 168 | | | |
| 37. Rodgers | Sec. 7, T. 24, R. 30 | 168 | 138 | 22 | Water in a crevice. |
| 38. J. Harris | Sec. 4, T. 24, R. 30 | 210 | 196 | 22 | |
| 39. Sinclair Bros | Sec. 29, T. 25, R. 30 | 137 | 83 | 20 | |
| 40. Do | Sec. 33, T. 25, R. 30 | 293 | 193 | 13 | |
| 41. Jim Hill | Sec. 6, T. 25, R. 30 | 242 | 42 | 32 | |
| 42. A. J. Burke | Sec. 25, T. 25, R. 29 | 116 | 65 | 45 | |
| 43. John McDonald | Sec. 24, T. 25, R. 29 | 184 | 40 | 28 | Do. |
| 44 Buckhannon | Sec. 11, T. 25, R. 29 | 173 | 40 | 16 | |

The water is said by Mr. Wilburn to occur generally in "brown gravel," though it is more probable that the material thus designated is fragmental or scoriaceous basalt rather than true alluvial gravel. In two cases, however, the water was found in a crevice, which may have been either a joint opening or a space between two flows, formed in the manner described on page 68.

The figures in the third column are of especial interest. In the last 4 wells of the list the water has risen to within short distances of the surface, varying from 40 to 65 feet. In the Hill well it is within 10 feet of the top of the basalt. In the other wells on higher ground the water has generally risen, but the pressure has not been sufficient to lift the water as near the top as in the other cases. The general rise of water indicates considerable underground pressure, and gives reason to hope that artesian flows might be obtained from the lower wells if they were properly cased.

### QUINCY DISTRICT.

This district comprises the northwest quarter of what has been termed the desert, upon the northern border of which lies the small hamlet of Quincy, where 4 drilled wells have been sunk.

*Structure.*—Quincy lies in a structural depression, though the fact is not evident at once, since the basin is a broad one and has been greatly marred by erosion. Just north of the village a structural slope rises to the ridge overlooking Willow Springs, and 18 miles to the south a low arch forms the opposite side of the east-west trough.

Far to the east the basalt rises to the wheat-lands plateau, and to the west the lava flows are turned up, forming the long gentle slope of Table Mountain.

*Topography.*—If, however, only the upper portion of the basalt series is considered, it appears that the Quincy basin is merely a trough, open at both ends. The Grand Coulee and its southern continuation have cut down at least 150 feet, and the Columbia 800 feet, below the top of the basalt series. The proximity of the river gorge is, of course, disadvantageous.

*Supply.*—Only a small amount of water can be supplied to the upper strata of the basalt series from the ridges north and south of the Quincy basin, on which the rainfall is extremely light. There may be a slight contribution from middle Crab Creek, though there is no positive evidence of the fact. The deeper-lying porous beds may draw a supply from the far-distant elevated land east of the Ritzville region, but it is doubtful whether there are any such beds continuous for so great distances.

*Well records.*—On the whole, the uncertainty of supply, combined with the deep dissection of the basin, discourages the hope of obtaining surface flows, at least any of moderate depth, in the Quincy district. The well records, of which a list follows, confirm these inferences:

*List of wells in the Quincy district, Washington.*

| Owner. | Location. | Total depth. | Depth to water. | Depth of soil, etc. |
|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Feet.* |
| | Sec. 12, T. 20, R. 24 | 194 | 190 | 40 |
| | Do | 194 | 190 | 40 |
| | Do | 260 | 190 | 40 |
| Marble | Sec. 6, T. 20, R. 24 | 330 | 190 | 22 |

The water is found in soft material that seems to be basaltic tuff. Two soft layers were penetrated in the Marble well and one in the wells in the town itself.

## AREAS WITHOUT DEEP WELLS.

*Desert near lower Crab Creek.*—In the region between Saddle Mountain and the next ridge north the conditions are very similar to those that obtain in the Quincy district. Between these two anticlinal ridges is a synclinal trough, rising in a general way toward the wheat lands at the east and closed at the west by the structural slope of Table Mountain.

Topographically this area is generally lower than the Quincy district. It is bordered on the west by Columbia Canyon, which here is not very deep, and is trenched by Crab Creek coulee in its central and southern portions.

The conditions of supply for this desert section seem to be unfavorable, for it is bordered on all sides by arid country. A large portion of the front of Saddle Mountain is a cliff, along which no water could be furnished to the porous beds underlying the region north of it.

The conclusion reached by consideration of natural conditions and by comparison with other districts is that, while water could probably be obtained from deep wells sunk down as far as the level of Crab Creek, there would be no reasonable hope of obtaining artesian flows in this portion of the desert.

*Bench south of Saddle Mountain.*—This broad unwatered area is underlain by Ellensburg beds, which in turn lie upon basalt, with interbedded acidic tuff and sandstone. The base of the Ellensburg and portions of the upper layers in the basalt series are exposed along the slope of Saddle Mountain and far to the east. The district is on the marginal portion of a great structural basin, in which lie Pasco and the Rattlesnake Desert.

The strata underlying the broad expanse of this bench are so extensively dissected by the Columbia that there seems nothing to warrant expectation of their containing water under sufficient pressure to rise to the surface. There is little doubt, however, that water could be obtained in this district from wells of moderate depth. The abundant flow of cool water from Harrison Springs appears to indicate the presence of a saturated bed at no very great distance below the surface, but the water in this layer, finding such free outlet at the springs, can not be under sufficient pressure to raise it very far above their level.

The terrace land near the head of White Bluffs and across the Columbia is lower, and therefore more favorably situated. It has not been sufficiently examined by the writer, however, to entitle him to a very definite opinion in regard to the prospects of artesian water. The arid character of the surrounding country and its dissection by Columbia, Yakima, and Snake rivers are unfavorable features.

Two experimental borings have been made in this region. One is at Pasco, where a well has been sunk and cased to a depth of about 400 feet in sandstone without obtaining a flow. The second is on the right bank of the Columbia, below Craig's ranch, where a boring 400 feet deep has been made without any successful result. This hole had been abandoned at last accounts, owing to the loss of the drilling tools. Neither of the borings described reached basalt, and neither seems to furnish conclusive evidence that artesian water could not be obtained in the low arid region south of the area examined in this reconnaissance.

### KITTITAS VALLEY.

*Stratigraphy.*—Sections of the Ellensburg beds, wherever studied, have shown an alternation of layers varying in coarseness, which is favorable to the conservation of artesian water under pressure. In the White Bluff section such alternation has been noted. In Kittitas Valley the Ellensburg beds exposed in numerous sections are found to consist of gravels, sandstones, and fine silty stuff in frequent alternation. The lowermost part of the section, according to Mr. George Otis Smith, contains a large proportion of gravel, and is therefore especially adapted to store a large quantity of water, which would be confined between the basalt below and the silty materials above. The basal portion of the Ellensburg in Kittitas Valley therefore seems well fitted by its lithologic character to serve as an artesian reservoir.

The Ellensburg beds underlie the floor of Kittitas Valley to a depth of several hundred feet, possibly a thousand feet or more. In the Moxee basin artesian water is found, at depths generally ranging between 600 and 1,000 feet, near the base of the Ellensburg formation. It is probable that if artesian water is to be found in Kittitas Valley it will probably be in the same stratigraphic position and at about the same depths.

*Structure.*—The structure of Kittitas Valley may best be comprehended by reference to the map and structure sections. It will be seen that the dips on all sides of the valley converge toward its center, and that the basin structure is complete though not simple. The form of the basin may be roughly reproduced by taking a sheet of paper and pinching up a wrinkle in one end, when a scoop that will hold water will be formed. The wrinkle is represented by the anticlinal ridge between Clerf Springs and the main southeastern continuation of Kittitas Valley, known as the "Badger Pocket."

*Topography.*—The structural conditions here seem to fulfill the artesian requirements almost ideally. The cross section of the valley shown in Pl. II might well serve as a diagram of a typical basin. Like nearly all structural basins, however, its rim is cut by a stream which exposes the edges of the water-bearing series from top to bottom, and we have to consider to what extent the pressure is thus diminished by leakage. General considerations already stated in the theoretical discussion of artesian conditions lead to the belief that the exposures in the narrow canyons by which the river enters and leaves the broad valley are not extensive enough to cause great loss of pressure. Another consideration urged by Mr. Smith[a] may also be noted here.

The Moxee artesian basin is cut by Yakima River in exactly the same manner as the Kittitas basin. Mr. Smith considers that leakage at the low outcrops in the Yakima gap has been to a large extent prevented by the action of mountain-making pressure, which has produced intense folding along the southern side of the Atanum-Moxee valley, and has incidentally compacted and indurated the beds of sandstones. Mr. Smith cites evidence of similar intense dynamic action at the head of Yakima Canyon, and suggests that leakage at this point may be largely prevented in the manner indicated. While the present writer is hardly inclined to concede to this agency the degree of efficiency that Mr. Smith ascribes to it, he believes that it may, by increasing the resistance to leakage, help to maintain pressure in the water-bearing strata.

*Supply.*—The supply of water for the reservoir strata in this case must be imbibed along the outcrop of the base of the Ellensburg on the surrounding hills. This supply will not consist solely, however, of rain water falling on the slopes and immediately absorbed, but may be largely augmented by leakage from the bottoms of streams that flow across the upturned edges of the sandstones.

Probably the greater portion of the water that finds its way into the Ellensburg sandstones of this valley comes from the slopes of Table Mountain to the north and northeast. The outcrop along this slope is probably washed by more rain than falls in other portions of the valley, and is crossed by a great number of streams which can hardly fail to make some contribution to the underground supply. On the whole a large amount of water must enter the Ellensburg sandstones along its very extensive high outcrops, and should be sufficient to supply many flowing wells.

*Well records.*—As may be gathered from the preceding paragraphs, the conditions of structure, stratigraphy, topography, and supply all seem to favor the hope of obtaining artesian water in this valley. But to many practical persons it may seem that the conclusions arrived at by theoretical deduction are less valid than evidence derived by actual experiment. Some attempts have been made to obtain artesian water in this district, without any positive success. It will be well to review the results of well digging in the Ellensburg sandstones, and to try to judge the value of the evidence derived in this manner.

Information was obtained from Mr. Joseph Preece of several hand-dug and drilled wells in the southeastern part of the valley. They penetrate the Ellensburg sandstones to slight depths only, and prob-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 41.

ably do not approach the base of the series by hundreds of feet. On the Stoney ranch, 6 miles southeast of the Preece ranch, there is a well 150 feet deep in which the water rose 25 feet after the water-bearing layer was first struck.

In an old well 45 feet deep on the Preece ranch, dug by the owner, the water rapidly rose 10 feet from the bottom, though the sides had remained perfectly dry until the water-bearing stratum was struck. The water was soft, noticeably warm, and maintained a constant temperature throughout the year, so that it would "steam" in the cold air of winter. The warmth of the water at so moderate a depth indicates its derivation from a distant source, and its sudden rise from the water-bearing layer shows it to be under pressure. In short, the water is artesian in the broad sense of the word. No attempt was made to case the wells or to determine by a test how far the water would rise in an open tube connected with the porous stratum if it were prevented from escaping except by way of the tube.

The Sanders well, north of Ellensburg, which is the only deep boring ever sunk in Kittitas Valley, is said to have reached basalt after passing through 700 feet of sandstone and clay. The tools were lost at that depth and the well was abandoned with the water standing 40 feet below the surface. The negative result of this experimental boring has been pretty generally accepted as demonstrating the futility of any further attempts to obtain artesian water in Kittitas Valley.[a]

Before we accept this discouraging view, however, we should ascertain whether the record is trustworthy and whether the well was properly cased. On neither point has the writer been able to obtain satisfactory information. There is reason to believe, however, that the driller was both inexperienced and incompetent, and altogether unfit to be intrusted with the important task of boring an experimental well. The evidence afforded by the Sanders well, therefore, should by no means be accepted as conclusive.

But we are not without positive evidence in a strong degree contradictory to that just considered in the phenomena at the Clerf Spring. Clerf Spring is, in effect, a natural flowing artesian well. A well was bored near the spring in 1900 in the hope of augmenting the supply obtained from the spring, with the result that water was obtained at a depth of 40 feet below the surface of the basalt, which rose to the surface in an open pipe. The drilling at this point was made with poor machinery and by an incompetent driller. The hole has been abandoned and allowed to cave in about the top, though it is probable

[a] Russell, I. C., Geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 69.

that a more generous supply could be obtained by going deeper. The well as it stands gives no new evidence, however, beyond that afforded by the spring, which demonstrates the existence beneath this locality of underground water under pressure sufficient to force it up to a level considerably higher than that of the floor of the valley.

After a consideration from a theoretical standpoint of the natural conditions obtaining in the district and an examination of the evidence afforded by existing wells, the writer is confident that artesian flows would be obtained at most points in the valley floor lying below the level of Clerf Spring by properly constructed wells reaching to the base of the Ellensburg series. Anyone intending to prospect for an artesian supply should, however, intrust the task of boring to a driller of known skill, experience, and integrity.

If the possibility of tapping an artesian reservoir be admitted, however, it still remains open to question whether the expense of deep borings would be justified, in view of the prospective construction of high ditches from the upper Yakima River. When the proposed ditches shall have been built they may efficiently supply all the area above and beyond the present irrigation ditches that could be benefited by an artesian supply. It may, however, be considered desirable to have a town water supply from a deep source free from the danger of polution, which is never entirely absent from surface streams.

## SUGGESTIONS IN REGARD TO DEEP WELLS.

A few suggestions may appropriately be given here to guide drillers and others interested in deep wells, and especially to direct intelligent prospecting for artesian water.

### TESTING ARTESIAN PRESSURE.

It is remarkable, in view of the encouraging indications of underground pressure afforded by certain wells in the vicinity of Hartline and of Lind, that no tests whatever have been made in the wheat lands to determine definitely whether artesian flows might be obtained from properly cased wells. A few such tests, intelligently made, might show, at no great expense, the existence of an important natural resource in the region. The development of flowing artesian water would not only benefit the landowners, but the drillers as well, for it would enhance the demand of their services. It would therefore be to the interest of drillers to provide themselves with the simple apparatus necessary and to test the underground pressure wherever there appears reasonable hope of obtaining a surface flow.

A general description of the kinds of apparatus used and of the methods and principles involved in such tests is given in the following extract from Chamberlin's admirable essay on artesian wells:[a]

*Control of flow.*—It is clear, upon consideration, that perfect control may be obtained by putting down a tube to the densest portion of the upper confining bed, if, by some device, the space surrounding it may be closed up so that no water can rise outside of the tube. Formerly this was done by a very simple and ingenious device known as the seed bag (fig. 7). A long, stout leather bag is made in the form of a cylinder, open at both ends, and just the size of the well bore. This is slipped on the lower end of the pipe, and the bottom of the bag securely fastened about the tube by wrapping with marline. A thimble just above the tie will aid in preventing slipping. It is then filled with dried flaxseed, and the upper end likewise closed around the tube. When thus adjusted it is lowered into the well to the point determined upon and supported there until the seeds swell by absorbing water. This enlarges the bag so as to fit the bore tightly and shut off all water from rising outside the pipe, and so all is compelled to ascend through the tube to the surface, or at least as high as the pressure is competent to force it.


FIG. 7.—Seed bag. *a*, Delivery tube, leading to the surface of the well, and terminating below the seed bag; *c*, a leather bag filled with dry flaxseed; *b*, marline wrappings to secure the end of the seed bag. (After Chamberlin.)

A better and more convenient, but more expensive, packing takes advantage of the expansion of rubber disks when pressed together, instead of the swelling of flaxseed. A series of thick, washer-like rings of rubber are fitted about a section of pipe, so adjusted between iron disks that, after being put down, they can be screwed together and so caused to expand laterally and completely fill the bore.

The construction of the parts and their adjustment are sufficiently indicated in the accompanying figures, which illustrate one of the forms in use.

In a form employed in the oil regions the expansion of the rubber disks, or of a single cylindrical one, is accomplished by pressing a conical hollow wedge between the pipe and the rings, thus forcing them out against the walls of the well.

In this case the packing is supported by a perforated tube—an "anchor"—reaching to the bottom of the well. As the packing in artesian wells is often located near the top, the necessity for support from below excludes this form in most cases.

*Detection of flow.*—It has been remarked above that the water may rise from the bottom to some higher portion of the well and there find escape by passing off laterally through the upper strata. In the absence of control the water does not always rise and overflow. It is a matter of some practical moment, therefore, to know when a stream is struck which may yield a flow at the surface when put under proper control. (1) Such a stream usually discovers itself by a rise of water in the well, but this is not always the case. (2) Some

[a] Chamberlain, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 131–172.

influence on the action of the drill is liable to be felt, which may arouse suspicion. (3) In any instance of a strong flow the drillings are apt to be carried away, so that when the sand pump fails to bring these up, or brings only coarser material, there is good reason to believe that a stream has been struck, and the proper tests should be made. In enterprises that do not require a voluminous flow, tests should usually be made when such indications appear.

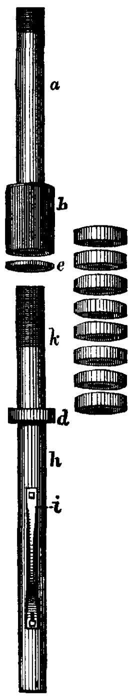


FIG. 8.—Rubber packing, shown apart. *a*, Section of delivery tube, extending to the surface; *b*, a large thimble into which *k* screws; *e*, an iron washer; *c*, a set of rubber disks fitting on *k*, between *b* and *d*: *k*, a section of pipe on which is turned a long screw fitting in the thimble *b*; *d*, a disk forming the head of the screw *k*; *h*, a section of pipe extending about 2 feet below the packing; *i*, a spring to press against the walls and hold the pipe *h* while the section *a* and thimble *b* are screwed upon *k*. (After Chamberlin.)

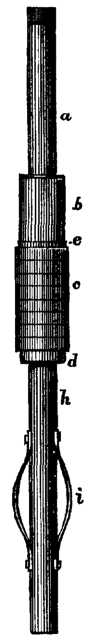


FIG. 9.—Rubber packing, shown screwed together as it is in the well. (After Chamberlin.)

It is ordinarily desirable to test the capacity of any stratum which gives any of these or other indications, before sinking to a lower one. It is advisable to make provision in the contract for such tests, since it is not always to the interest of the driller, once his machinery is set up and well at work, to stop at the more limited depth. The capabilities of the flow may be tested by the use of a tube and seed bag, or by rubber packing, as explained above.

*Negative and false tests.*—It is possible, in perfect honesty, to make both a negative and a false test. Suppose the two porous beds, *A* and *B* (fig. 10), separated by an impervious layer, are traversed and the testing of the first has been neglected, either because it failed to give encouraging indications or for other reasons. It is now desired to test these. Suppose the seed bag or rubber packing be placed above the upper one. Now, if both bear a water level equally high, the test will be fairly made and the result will indicate their combined capacity, or if both heads are at least as high as the surface at the well the test may be accepted. But suppose that the bed *A* has been cut into by erosion, or been reached by crevices, or is otherwise defective, while the other, *B*, remains intact and bears an elevated fountain head. Under these conditions the water may flow from *B* through the bore into *A* and escape laterally through it, as illustrated in the figure. Now, in this case the result may be either simply negative or positively false and misleading. If the lateral leakage through the stratum *A* effectually disposed of the flow from *B* and there was no leakage in the upper portion of the well, the water in the test tube would stand during the test at essentially the same height as before, and the result would be negative, merely failing to indicate a possibility that really existed. If, on the other hand, there was lateral leakage through the upper strata as well as through *A*, neither alone being quite competent to dispose of the flow from *B*, then the introduction of the test pipe would cut off the upper leakage, leaving the bed *A* unable to dispose of the entire flow. In this case there would be a rise of water in the tube, and possibly a flow. The mischievousness of a test of this sort lies in the fact that it appears to be a true test, while in reality it is false and misleading. The true test in this case can only be made by placing the packing between the porous beds *A* and *B*.

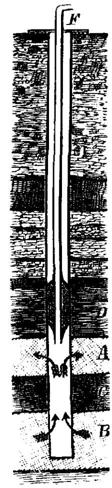


FIG. 10.—Section of well illustrating a negative test.

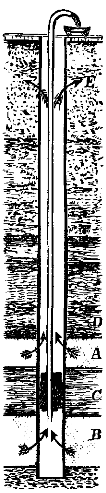


FIG. 11.—Section of well illustrating a partial and misleading test.

2. Take another instance where two porous beds, as *A* and *B* (fig. 11), have been traversed. Let the packing be placed between these. Then (1), if *A* equals *B* in productive capacity, water will stand at the same height within and without the test pipe if there is no leakage in the upper beds. (2) If the failure to flow was due to such leakage, then a flow will result from *B*, but the additional flow which might be secured from *A* is lost (see figure). (3) If *A* has a greater head than *B*, and if there is no loss above, the water in the test pipe will actually be lower than that outside, as illustrated in fig. 12. This may be said to be an inverted test, and is less misleading than the false and negative tests, since it plainly indicates an error of manipulation. I have known of such a case of reduced head as the result of an attempted test. (4) If, however, there is in this case considerable lateral waste in the upper strata, the valuable flow from *A* will be lost, just as before the test was made, while *B* may give a rise in the tube, or even a flow, which would foster the impression that a fair test had been made, while in reality the greater flow has been lost. (5) If *A* gives a feebler flow than *B*, but has an equal head, the test will fail of being completely satisfactory only in excluding the feebler flow from *A*. (6) If, however, *A* has a lower head and is a possible means of escape

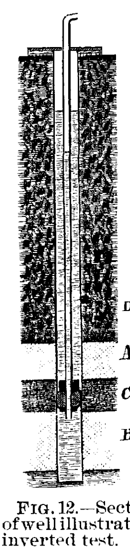


FIG. 12.—Section of well illustrating inverted test.

for the flowage from *B*, then the packing has been placed at the right point and the test gives the best results.

3. In still another case let *A* and *B* represent porous beds (fig. 13), the lower of which is so conditioned as to drain the upper one by virtue of a lower outcrop in the manner previously explained and illustrated. (1) If the drainage loss below is not complete, and if the packing is placed above *A*, as shown in fig. 13, *I*, the result will be negative if there is no leakage in the upper strata. (2) Should there be considerable loss there it will be cut off by the tube and packing, and some rise in the tube will be the result in most cases. In either instance the result is misleading, particularly in the last, because the small rise of the water is apt to allay any suspicion as to the effectiveness of the test. The real fact, however, remains that the flow from the productive stratum is mainly lost below. (3) Suppose that the packing is located between *A* and *B*, as in fig. 13, *II*, it will then shut off the flow from *A*, while that in B, because of a lower outlet, will fail to flow. Now, if there is opportunity for lateral leakage in the upper strata the water from *A* will rise in the well outside of the test pipe and pass off into these open upper beds. (4) But if no such opportunity is afforded it may rise to the surface and overflow outside of the test pipe, while the water within the test pipe will probably be found to be lower than before the test was made.

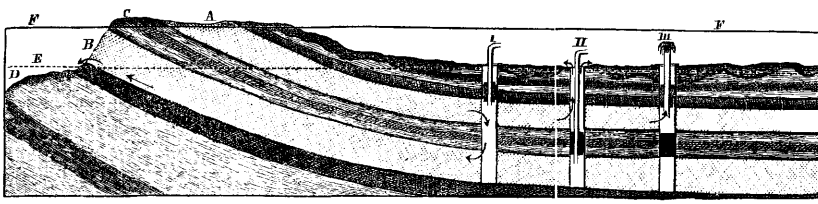


FIG. 13.—Section of strata and three wells, showing one correct and two erroneous tests.

The proper method of testing wells known or suspected to present these conditions is to sink a simple bag of seed or other obstruction to a point in the impervious stratum between *A* and *B*, which, when it tightens in its place, will shut off the flow below. Then a tube with packing sunk to a point above *A* will effectually cut off all leakage in the upper strata and the full capacity of the water bed *A* will be tested.

These examples, while not exhaustive of possible cases, illustrate the nature of defective tests and the deceptive conclusions liable to be drawn from them. The remedy is manifest. Test each water-bearing stratum as it is encountered, or else vary the final tests so as effectually to exclude all liabilities to error.

Some comment may be made on the special application of these directions in this region. In Kittitas Valley the strata encountered in the downward progress of the drill outcrop along the neighboring hill slopes at successively higher elevations, so that there does not seem to be much danger of leakage from a water-bearing stratum to the one beneath, and a plug inserted just above the highest strong flow should be sufficient. In the wheat lands, where conditions are less thoroughly understood, more care should be taken to make the tests exhaustive.

It has been noted that in wells sunk from the plateau levels of the wheat lands water is generally found at about the same depth as in the bottoms of the neighboring coulees. An artesian flow could hardly be expected at a less depth, for the extensively dissected upper strata would be too leaky to hold water under pressure. Wells on high ground, therefore, should be sunk lower than the bottom of any neighboring coulee and the test plug inserted below all porous layers that are exposed in the coulee walls. In wells sunk in canyon bottoms it would perhaps answer in most cases to insert the plug in the first layer of compact basalt below the loose and porous surface material.

By way of summarizing this brief consideration of artesian tests it is desired to state emphatically the following important points:

(1) The fact that the water does not overflow from an uncased well does not prove that an artesian flow might not be developed under proper conditions.

(2) A well in which water rises appreciably is worthy of being exhaustively tested, unless the nonexistence of artesian conditions in its neighborhood has been proved, and the tests should be carried out with an understanding of the principles that govern artesian flow.

(3) It is unnecessarily wasteful to case a well before it has been tested. The preliminary tests may be made with inexpensive apparatus, thus saving the heavy expense of casing until it is known to be justifiable.

### DEPTH OF EXPERIMENTAL BORINGS.

It is a question of some moment to what depth it is proper to carry experimental borings. An idea is widely prevalent that the chances of obtaining artesian water increase with the depth of the well, and even that artesian water may be obtained at any place if the well goes deep enough. This notion has a certain basis in the fact that deeper strata are less liable to be tapped by erosion than higher ones. Under certain conditions, however, which are illustrated in fig. 14, the deeper strata may be less likely to yield a flow than those above.

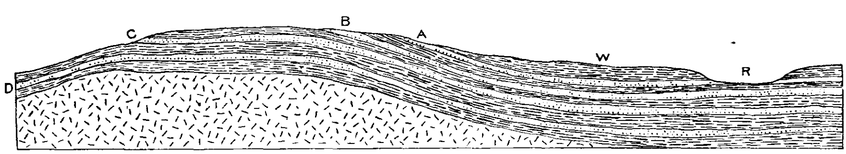


FIG. 14.—Ideal section showing relative probability of obtaining artesian flow at various depths. The stratum A is tapped by the river at R, while C and D are unfavorably situated for receiving a supply. B is capable of imbibing a good supply along its upper edge, and is not cut by the river, so that it is likely to yield a flow from a well sunk at W.

Many drillers in the wheat lands have thought that it would be worth while to sink wells to a depth of from 1,000 to 1,500 feet, in order to reach below the strata that are extensively exposed in the river canyons. Such a belief should not be adopted hastily. These deep strata would probably be less exposed to leakage, although the writer is not sufficiently acquainted with the region to the east to speak positively, but it is doubtful whether they are favorably exposed to take in a supply available in the wheat lands. The doubt existing on this point in the present state of our knowledge should be frankly faced by anyone who contemplates putting down a very deep well. Before any such costly experiments are made some of the more favorably situated wells of the present moderate depths should be thoroughly tested. In wells to be sunk in the future each water-bearing layer should be tested as soon as reached, and if a satisfactory flow is developed at any point the owner should rest satisfied and not tempt fortune by continuing to greater depths.

### CASING NONFLOWING WELLS.

If upon test a flow be developed, the well should be cased down to the point at which it is found that the packing is most advantageously located. But it does not seem wise or economical to confine casing to those wells that develop a surface flow. Suppose a well in which the underground pressure is sufficient to force the water in an open tube, inserted with a tight joint above the porous water-bearing layer, to within 50 feet of the surface, but that in its rise through the uncased well it meets a leaky, porous bed through which it escapes at 100 feet from the surface. In such a case as this the windmill or other pumping engine must raise the water 100 feet, when, if the underground pressure were fully conserved, the water need be lifted only half that distance. There is a clear waste of 50 per cent of the power, for, as is evident to all who are acquainted with the elementary principles of mechanics, a pump capable of lifting 1,000 gallons per hour through a vertical distance of 100 feet could lift 2,000 gallons per hour through half that height. The comparatively slight expense of packing the lower end of the pipe might in many cases be repaid time and time again by the saving in power where power is a source of considerable expenditure, or by the increased yield of water where all the water developed can be used to advantage.

Two qualifying phrases in the last sentence require some further explanation. In the vast majority of the deep wells now existing the pumping engines are windmills, and the cost of power is confined to the small annual expenditure for repairs, oil, etc., plus the ordinary wear and tear on the machine. Moreover, the amount of water furnished by a single mill is usually sufficient for all farm uses. Under such circumstances as these, where the running expenses are almost nothing and the supply meets all demands, there seems to be little inducement to make even a small outlay for packing the well pipe.

Where, however, a large and constant supply, such as is required to furnish a town water system, is demanded, a gasoline or steam pump is generally used. The necessary fuel is then a constant source of expense, and, consequently, a possible saving of power, such as may be accomplished by packing, is worthy of careful consideration.

In the second place, if the rancher were able to use economically a large quantity of water it would be desirable for him to draw from his well the greatest amount that his windmill could supply under the most favorable conditions. It seems to the writer that such a use for the surplus above what is needed for ordinary farm uses is to be found in the irrigation of fruits and vegetables. While in the region east of the Columbia the conditions are such that horticulture will probably never become a leading industry, it seems certain that vegetables, small fruits, and certain orchard fruits might be produced in greater quantity and of much better quality than they are at present if the fullest use were made of the possibilities of irrigation from wells. If such a use were found for all the water available, the desirability of packing in all cases where the water level in the well could thereby be materially heightened is evident.

Efficient and systematic irrigation of gardens from deep wells would involve the construction of reservoirs, either wooden tanks or excavations lined with masonry or sod. The methods of irrigation can not, however, be dealt with in this paper. Those interested in the subject will do well to refer to Mr. Newell's recent work on irrigation,[a] where all the branches of that important art are treated fully.

## CONCLUSION.

This report may be closed appropriately with a brief recapitulation of the more important points developed in the preceding pages on the deep wells of east-central Washington.

In the wheat lands the records of numerous wells demonstrate that abundant water of good quality can be obtained from porous layers in the basalt series at depths varying from 40 to 670 feet. In general, the average depth at which a good supply is reached increases gradually toward the south.

The water generally rises in these wells to a greater or less extent, which proves that the deep waters beneath the wheat lands are under pressure, and that they are, therefore, in the broad sense of the term, artesian. Despite these encouraging manifestations, however, no instance is known in which an attempt has been made to measure the effective head of the artesian streams, nor has any well in the region been cased to prevent leakage through porous beds above the confining stratum of compact basalt. There is good reason to believe that

[a] Newell, F. H., Irrigation in the United States, New York, 1902.

there are wells in the wheat lands in which the water fails to reach the top solely on account of leakage through loose surface material.

It is strongly urged, therefore, that the more favorably situated wells be tested thoroughly in order that definite information may be obtained regarding artesian pressures. Directions for making such tests have been given in the appropriate place. All wells which then prove capable of giving a surface flow should be efficiently cased.

It is thought advisable not only to case any wells that will give a surface flow, but to pack the bottom of the pipe in many other wells in which the water surface could, by that means, be raised materially. Such a procedure would be economical where, on the one hand, a gasoline or steam pumping engine is used and the running expenses for fuel, etc., are considerable; or where, on the other hand, a windmill is used and the running expenses are insignificant but it is desired to augment the supply by this means if use can be found for all the water that can be obtained. It is suggested that irrigation of gardens and orchards from deep wells would afford a profitable means of utilizing most of the water that can be developed in excess of the requirements of stock and the household.

There seems to be a fairly good chance of obtaining artesian fountains in the vicinity of Lind and of Parnell and in the coulees west of the Lind-Ritzville district, but the artesian pressures are probably insufficient to raise water to the general plateau levels of the wheat lands.

In the arid range land just east of the Columbia water could be found at comparatively moderate depths, but conditions do not favor the hope of obtaining artesian flows. A number of stock wells could probably be sunk in this region to advantage, and if located at points far from any of the natural drinking places might render available some areas now largely neglected by the stock because of their distance from water. The excessively grazed stretches near the streams and springs might then have an opportunity to recuperate if the number of animals on the range could be kept within a reasonable limit. The ruin of this range seems imminent, however, unless those who have grazing interests there adopt a conservative policy. The wastefulness and shortsightedness of overstocking has too often been demonstrated by experience and only realized when the evil was past remedy.

That there would be better chances of obtaining artesian flows on the Columbia Plains by very deep borings than from some of the moderately deep wells now existing is doubtful. Deep experimental borings in the basalt are to be regarded in the present condition of our knowledge as involving considerable financial risk. The searcher for artesian water should make careful and exhaustive tests of the upper water horizons before he sinks capital in a deep boring.

The writer believes that wells sunk in the lower portions of Kittitas Valley to the base of the Ellensburg series and properly cased would yield artesian flows. If, however, a properly conducted experiment resulted in failure to obtain a flow from the Ellensburg series, the advisability of continuing the boring into the basalt underneath would be doubtful. Granting, however, that the chances of obtaining surface flows are good, the wisdom of prospecting for artesian water in Kittitas Valley must depend upon the answer to the question whether, if an artesian supply were obtained, it could be used economically.

# INDEX.

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Reference.

**U. S. Dept. of the Interior.**

see also

**U. S. Geological survey.**