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Department of Conservation and Development

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[redacted]

GEOLOGY AND RESOURCES

of the

PASCO AND PROSSER QUADRANGLES.

By

SOLON SHEDD.

SEAL

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LETTER OF TRANSMITTAL.

Hon. Erle J. Barnes, Director, Department of Conservation and Development, Olympia, Washington:

SIR: I have the honor to submit herewith the manuscript for a report on the geology and resources of the Pasco and Prosser quadrangles, Washington. This report represents the results of field work carried on during the summer of 1923 and 1924.

I recommend that this report be published as a Bulletin of the Department of Conservation and Development, and designated as Geological Series No. 32.

Very respectfully,

S. SHEDD,

Supervisor, Division of Geology

College Station
Pullman, Washington. June 1, 1925.

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GEOLOGY AND RESOURCES OF THE PASCO
AND PROSSER QUADRANGLES.

By Solon Shedd.

INTRODUCTION.

During the summer of 1923, work was begun on a study of the geology and resources of the Prosser quadrangle and the mapping of the areal geology almost completed. As the work progressed, it was found necessary to study the surrounding territory in order to explain some of the problems found in connection with this quadrangle. As a result of this, work was continued during the larger part of the summer of 1924, and the geology of the Pasco quadrangle, which lies just east of the Prosser, has also been studied and mapped. It was also found necessary, in order to better understand conditions over the area under consideration, to visit localities where typical exposures of certain formations are known to occur and to make careful examinations of these.

Considerable time was spent on the Zillah quadrangle, which lies west of the Prosser quadrangle, and two trips were made up the Naches River to study the exposures of the Ellensburg formation so well shown along this stream between Yakima and Naches.

During the summer of 1923, Mr. C. E. Carr, a senior in the Department of Geology of the State College of Washington, assisted me, and in the summer of 1924, Mr. Ray C. Treasher, a graduate student in the same institution was my assistant. I wish to acknowledge here my appreciation of

their helpfulness in this work.

For a number of years past, more or less drilling for gas and oil has been done in the Prosser quadrangle along the northeastern side of the Rattlesnake Hills. As a result some gas has been found. One of the reasons for making a study of this area was to determine, if possible, the source of this gas and the possibility of the occurrence of oil.

The previous geological work done in this locality has been largely in the nature of preliminary examinations. One of the earliest of these, the results of which were published, was by Lieut. Thomas W. Symons, who, in the fall of 1881, explored the Columbia River from Grand Rapids to the mouth of the Snake River.[1] His report includes a description of the Columbia

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[1]Symons, T. W., The Upper Columbia River, and the Great Plains of the Columbia: Forty-siventh Con., 1st Sess. Doc. No. 186, 1882.

River, and the Great Plains of the Columbia, with a sketch of the geologic history of the region. A large amount of very important work in the Columbia Plains area was done by Israel C. Russell. The results of his investigations in central Washington[1], southeastern Washington[2], northwestern Idaho[3], and the Snake River

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[1] Russell, I. C., Geological Reconnaissance in Southeastern Washington: U. S. Geol. Survey, Bull. No. 108,1893.

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[2]Russell, I. C., Reconnaissance in Southeastern Washingtpn: U. S. Geol. Survey, Water-Supply Paper No. 4, 1894.

[3] Russell, I. C., Geology and Water Resources of Nez Perce County, Idaho; U. S. Geol. Survey, Water-Supply Papers Nos. 53 and 54, 1901.

Plains of Idaho[4], have appeared as Bulletins or Water-Supply

[4] Russell, I. C., Geology and Water Resources of the Snake River Plains of Idaho: U. S. Geol. Survey, Bull. No. 199, 1902.

Papers of the United States Geological Survey publications.

George Otis Smith[5] has done a considerable

[5] Smith, G. O., U. S. Geol. Survey, Water-Supply Paper No. 55, 1901.

amount of work in the central part of Washington, and, as a result, two reports have been issued that have a very important bearing on the area under discussion. He studied the water resources of a part of Yakima County in 1900 and a report was published in this work. The most thorough detailed piece of geological work so far done in this region is that of Smith[6]

[6] Smith, G. O., U. S. Geol. Survey, Ellensburg Quadrangle, Geologic Atlas U. S. Folio 86, 1903.

and published as the Ellensburg folio. This affords a detailed description of a region where some of the same conditions must have existed as were present in times past, over the Pasco and Prosser area.

In the fall of 1902, Frank C. Calkins[1]

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[1]Calkins, F. C., Geology and Water Resources of a Portion of East Central Washington: U. S. Geol. Survey, Water-Supply Paper, No. 118, 1905.

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made an examination of the water resources of a part of east central Washington. The report on this area discusses in some detail the geology, physical features, and climate as well as the water resources.

In the fall of 1907, Gerald A. Waring[2] spent several

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[2]Waring, Gerald A., Geology and Water Resources of a Portion of South-Central Washington: U. S. Geol. Survey, Water-Supply Paper, No. 316, 1913.

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weeks in a study of the water supply being used at that time, of an area in south central Washington and the possibility of increasing this supply by sinking deep wells. The report of the investigation discusses briefly the geography, geology, and physiography of the region.

Recently J. Harlen Bretz[3] has been making a study

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[3]Bretz, J. Harlen, The Late Pleistocene Submergence in the Columbia Valley of Oregon and Washington; Journal of Geology, Vol. 27, pp. 489-506, 1919; The Satsop Formation of Oregon and Washington: Journal of Geology, Vol. 25, pp. 446-458; Glacial Drainage on the Columbia Plateau, Bulletin of Geol. Soc. of

Am., Vol. 34, pp. 573-608; The Channeled Scablands of the Columbia Plateau; Journal of Geology, Vol. 31, pp. 617-648, 1923.

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of eastern and central Washington and has published a number of articles which give a large amount of new information in regard to geological conditions in this part of the state.

The writer is indebted to a large number of people who gave information on various subjects, but especially to those who furnished data in regard to wells. To all of these persons, he wishes to express his thanks.

GEOGRAPHY.

NATURAL DIVISIONS OF THE STATE.

The State of Washington comprises seven major divisions, which are fairly distinct from the standpoint of topography and geology, as well as geography.

Coast Mountains.

In the southwestern corner of the state are the Coast Mountains, sometimes designated as the Willapa Hills. The maximum elevation of this part of Washington is about 3000 feet above sea level. On the southern margin, the Coast Mountains rise rather abruptly from the Columbia River, while on the north they gradually merge into low foot hills and these into the valley along the Chehalis River. On the east, the Coast Mountains rise from the ground level of the Puget Sound Basin through a series of foot hills, finally reaching the higher mountains while on the west, they gradually decline until they merge into the low sand hills or dunes along the sea coast.

The topography of this region is rough and irregular, erosion having cut deep gorges and canyons with sharp ridges between. The hills in most cases are soil covered, weathering having taken place faster than the decomposed material has been removed.

One prominent divide or range of hills extends diagonally across this area. On the east, it begins in the northwestern part of Cowlitz County, extends through southwestern Lewis County and terminates in the western part of Pacific County at Willapa Harbor. A number of lateral spurs extend out from this main ridge.

A large amount of precipitation occurs over this part of Washington, and, as a result of this, many comparatively short streams rise within the area and flow finally into the Pacific Ocean.

The eastern part of the area under discussion, north of the main ridge or divide, is drained by the Cowlitz and Chehalis rivers and their tributaries, while the area north of the western part of this divide is drained mainly by the Willapa and North rivers and Smith Creek. To the south of this divide,the drainage is into the Columbia River and Shoalwater Bay.

The rocks of the Coast Mountains are sedimentary and igneous. The sediments consist largely of sandstones and shales which have been,in some cases, slightly metamorphosed. Since these sediments were deposited, a large amount of disturbance has taken place and now the beds are folded and tilted at varying angles.

The igneous rocks cover considerable areas in this region and are mainly basaltic flows and tuffs. In texture, the basalts range from very fine grained dense black varieties to the very vesicular types. The formations throughout the Coast Mountains are of Tertiary age.

Olympic Peninsula.

The Olympic Peninsula includes that part of Washington west of Hood Canal and north of the valley of the Chehalis River. The most striking topographic feature of the Peninsula is the Olympic Mountains. These consist of a mass or group of mountains of almost circular outline, the central part of the mass being situated a little to the north and east of the center of the Peninsula. This group of mountains culminates in Mount Olympus, which has an altitude above sea level of 8,150 feet. Within this mass of mountains, however, are a number of other peaks with altitudes ranging between 6000 and 8000 feet. Because of its situation among these other high peaks, Mount Olympus is not an especially prominent mountain, being rarely seen from a distance except from theocean on the west.

The Olympic Mountains are so situated that they receive a large amount of precipitation in the form of rain or snow, and on account of this, there are many streams flowing from them. The drainage from this mountain mass is radial, the streams rising near the center of the mass and flowing in all directions from it. These streams have cut deep, steep sided gorges along which they flow. In many cases, the sides of these canyons are so steep that it is practically impossible to ascend them. The divides between the streams are very narrow and sharp.

Bordering the Olympic Mountains on the north and west is a more or less well defined coastal terrace. This varies in altitude, and ranges from 50 to as much as 250 feet above sea level. Between the coastal terrace and the high mountains is an area in which the altitude gradually rises until it reaches about 4,500 or 5,000 feet. Throughout this area the ridges rise to approximately a plain surface.

The drainage on the eastern side of the Peninsula is into Hood Canal. The streams on this side are short, the slopes steep, and hence the streams flow rapidly and have cut deep gorges. The lateral streams are also well developed and the divides between the streams have been eroded or weathered away until they are very sharp and jagged. The topography, as a result of weathering and stream erosion has become very rough and irregular. There is very little low land bordering the water on this side of the Peninsula.

On the south, the Olympic Mountains are bordered by the low lands along the Chehalis River, which gradually rise into the foot hills, and these merge gradually into the higher mountains. The streams on this side of the Peninsula, along the lower part of their courses, have developed valleys of considerable size. This is especially true of some of the larger streams. As the central part of the mass is approached, however, the valleys narrow and finally become steep-sided gorges. The streams flowing to the south empty into the Chehalis River and through this into the Pacific Ocean.

The Olympic Mountains are made up largely of quartzites and slates with some basic igneous rocks. The igneous rocks occur along the northern, eastern, and southern borders mainly, and are all eruptive in character. No volcanic cones occur, however, in the Olympic Mountains, nor have any granite or related plutonic rocks ever been found in place in these mountains.

Puget Sound Basin.

The Puget Sound Basin, as the term is used here, is intended to include all of that depression between the Cascade Mountains on the east and the Olympic and Coast Mountains on the west, and extends from north to south across the state.

As thus defined, the topography of the Basin is somewhat different in its northern, central, and southern parts. Islands occur in the north and northwestern part of this basin, some of which rise to a considerable height above sea level and are in some cases rough and mountainous. These islands are composed of hard rocks which have been weathered into forms characteristic of this kind of material. In the northern and central sections of the basin, the surface is largely covered with glacial drift and the differences in altitude are but slight. In the central part, especially, of the basin, the topographic features have been carved largely in this glacial material. The southern part of this trough represents an area that was not glaciated and hence, the topography is different from that in either the central or northern parts. The irregularities of the older surface are more conspicuous as they are not covered with glacial drift. The topography is such as is formed by the weathering of comparatively soft sedimentary rocks. The surface is gently undulating, is not more than about 500 feet above sea level, and gradually merges into the Cascade Mountains on the east and the Coast Mountains on the west.

Structurally, the Puget Sound Basin is a downwarp between the mountain masses, which bound it on the east and on the west. This trough varies considerably in width being about 65 or 70 miles where the foot hills of the Cascade and the Olympic mountains form its eastern and western borders respectively. South of the Olympic Mountains, this trough broadens until it has a width of perhaps 150 miles. Around Puget Sound, the topography is more of the plateau type, with steep, almost perpendicular, bluffs or sides, and flat tops.

In the glacial sediments, which cover a large part of the sound country, are many depressions, and these, where they extend below sea level, have been filled with water and constitute Puget Sound. In but few places are the older rocks exposed. The older rocks on which these glacial deposits lie, are mostly of sedimentary origin, igneous rocks having been found in but few places. The sedimentary rocks composing the floor of the sound basin have been very much folded, faulted, and disturbed, so that before the glaciers occupied the basin, it probably had a very rough and uneven surface. The glaciers, however, planed down the elevations to a greater or lesser extent and had a tendency to smooth the surface. Beneath the gravel which is found so abundantly in the sound basin at the present time, however, lie buried valleys, canyons, and hills which are older than the present ones. These older features are so thoroughly concealed that very little idea of their distribution can be even conceived. That they had a relatively bold character is indicated in places where sharply defined hills rise like islands through the glacial deposits and in places where buried gorges and channels have been found with very steep sides.

The rocks exposed on the surface throughout the Puget Sound Basin are practically all sedimentaries and belong mainly to the very late periods in the history of the earth. In a few places, igneous rocks are found associated with these sedimentaries. The most abundant of these are volcanic of Tertiary or later date. On either side of the Puget Sound Basin in the northern part of Washington, metamorphic and igneous rocks predominate and these probably extend under the basin and form the floor on which the Cretaceous and later formations rest.

The drainage of the Puget Sound Basin flows directly into Puget Sound or through the Chehalis and Columbia rivers into the Pacific Ocean. The drainage of the western slopes of the Cascade Mountains, north of the Cowlitz River, flows directly into some part of Puget Sound. The waters, from that part of the basin drained by the Chehalis River, flow into Grays Harbor, while the waters from that part drained by the Cowlitz River and its tributaries flow into the Columbia River.

Cascade Mountains.

The Cascade Mountains extend in a north and south direction entirely across Washington, and constitute a very marked topographic feature of the state. The range varies somewhat in width from east to west and is widest at the northern and southern boundaries until about the center of the state is reached, where they become the narrowest. These mountains are so situated that they receive a very large amount of precipitation, especially on the western slopes, and this has an important bearing on the topography. The whole area is one over which there has been a large amount of erosion. The warm winds heavily laden with moisture come in from the Pacific Ocean, and as they reach the Cascade Mountains and begin rising and cooling, they become over-saturated and lose a large part of their moisture either as rain or snow. As a result of this, the western slope of these mountains is well supplied with streams, many of which are large and flow in deep gorges.

In crossing the range, one is impressed with the abruptness with which the mountains rise from the lowlands, especially on the west side. Instead of a prominent ridge marking the divide with spurs or lateral ridges extending out from this, we have a divide that in some cases is even lower than many of the peaks on either side of it, and the whole arrangement of peaks and ridges is very irregular and complex, and gives to the range, as a whole, a very rough and irregular appearance.

The Cascade Mountains in the southern part of Washington differ both in geology and topography from that part of the range in northern Washington. The range in the southern part of the state is made up largely of volcanic material and as a whole is not so rough as that part in northern Washington.

Throughout the entire length of the Cascad e Mountains, many prominent volcanic cones occur, and these have played an important part in the formation of this range and are also very prominent topographic features as well. Mount Rainier, Mount Adams, and Mount St. Helens, three of these high peaks, are in the Cascades of southern Washington. These all rise from 5,000 to 6,000 feet above the surrounding mountains and are of later date than the main part of the range.

In the northern part of Washington, the main divides in the Cascade Mountains reach an altitude of from 6,000 to 8,000 feet above sea level, with isolated peaks rising considerable above this.

The most prominent of these high peaks are Mount Baker and Glacier Peak. These are volcanic cones and like those in the southern part of Washington, have been built up with material erupted through openings in these cones.

Igneous, sedimentary and metamorphic rocks are all well represented in the Cascade Mountains. The metamorphic rocks in some cases were originally sediments, while in others, they were originally igneous. The igneous rocks are partly plutonic and partly volcanic. The sedimentary rocks are represented by sandstone, shale and limestone. These rocks all belong to the late periods in the geological history of the earth, so far as known at the present time. The oldest rocks in which fossils have been found by which the age can be determined, are Cretaceous. Rocks that are thought on certain grounds to be older than Cretaceous are found in places in the Cascades, in the northern part of Washington. The Cascade Mountains in the southern part of Washington are made up of rocks that are supposed to be mainly of Tertiary age.

During the later part, at least, of the Mesozoic, the northern Cascade area must have been under water, for here we find large deposits of sandstones, and sediments of various kinds, of Cretaceous age. Closing the Cretaceous period, there was probably an elevation of the Cascades into a land area which was perhaps the outlining of the present range. Along with this elevation occurred a large amount of metamorphism and intrusions of granite masses, and various other kinds of igneous rocks. During Eocene times erosion was acting on the land area, cutting it down and furnishing the material which composed the Eocene deposits as we find them now. In the later part of the Eocene period, the first basaltic eruptions began, which were the forerunners of the greater volcanism of the Miocene. The Eocene period was closed by the elevation and folding of the Eocene formation.

Okanogan Highlands.

The Term "Okanogan Highlands" includes that part of Washington which is situated east of the Cascade Mountains, north of the Columbia and Spokane rivers, and extends to the Idaho line on the east and to British Columbia on the north. This area is divided north and south into a series of more or less parallel valleys and ridges, and the whole of the country, with the exception of the valleys, is what would be termed mountainous. The main ridges or divides between the larger streams have an average altitude above sea level of about 4,500 to 7,000 feet. The streams in general flow along quite wide and deep valleys. The western part of this area is characterized by rolling surfaces, the ridges not having been weathered into sharp jagged outlines. The slopes, as a general thing, are long and gentle and the hills low and broad. Topographically, they are very different from the Cascade Mountains which bound them on the west and are sharply separated from them.

The Okanogan River is the main stream draining the western part of this area and flows from north to south across it. The valley floor is largely alluvium. Gravel terraces are a marked feature of this valley as well as of many of the lateral valleys along its course. This whole valley was at one time occupied by a glacier which has had much to do with the formation of its topographic features, giving to them a gently rounded outline. The lateral streams emptying into the Okanogan River have as a general thing cut deep, steep-sided and rather narrow gorges.

Two other streams rise outside of the area under discussion and flow across it. One of these, the Columbia, flows from north to south, while the other, the Pend Oreille River, flows from south to north across the eastern part of the area. Several smaller streams rise within this area and are important in helping to drain it. The divides between these north and south flowing streams become rough and more mountainous the farther east one goes. The country between the Okanogan and San Poil Rivers is a plateau in its general characteristics. The surface is more or less hilly, but the hills are characterized by long, gentle slopes, and gradually curved surfaces and are usually low and broad and are covered with a deep soil. The altitude through here is about 3,200 feet above sea level. The divide between the Columbia and Colville rivers on the west and the Pend Oreille River on the east is the highest of these north and south ridges. This constitutes a very prominent mountain range having a maximum altitude of about 7,000 feet. Low rolling hills border the eastern side of the Colville Valley. In places, these rise abruptly from the valley and then merge gradually into the higher mountains. On the eastern or Pend d'Oreille side, the slopes of this divide are much steeper than those on the westernside.

There is much evidence to show that the character of the topography of all of this area designated as the

Okanogan Highlands is due, partly at least, to the action of ice. The gentle slopes and rounded outlines of the hills, the terraces found along the streams in many places, and the large boulders which are found scattered over many parts of the surface, all go to show that glaciers have been present in this part of Washington in times past.

The formations throughout the Okanogan Highlands are very largely metamorphic, being quartzites, slates, schists, limestones and rocks of this character,with igneous rocks occurring as intruded masses in places. In some cases, these metamorphic rocks were originally sediments, while in others, they represent changed igneous rocks. The age has not been determined, positively, of any of these metamorphic and igneous rocks.

Columbia Plateau.

This area includes that part of Washington, south of the Spokane and Columbia rivers and east of the Cascade Mountains, except a small area in the southeastern corner of the state where the Blue Mountains occur, which extend into the state from Oregon. This area is practically surrounded on all sides by mountains which reach to greater or lesser altitudes above it, and make of it a basin area. The drainage is all finally through the Columbia River, to the Pacific Ocean. The principal streams that aid in draining that part of this area lying east of the Columbia are the Snake, Spokane, Palouse, and Walla Walla rivers, while the part lying west of the Columbia is drained principally by the Yakima, Naches, and Tieton rivers.

In the south central part of the Columbia Plateau, the surface is very gently sloping and not more than 1,000 feet above sea level. To the north, east, and west, the surface of the plateau gradually rises until elevations of from 2,000 to 3,000 feet are reached. The irregularities over the lower part of this area are not very great, but keep increasing as the altitude increases. This is due in a large measure to the fact that over the higher parts of the plateau, the streams may cut their channels deeper and well defined canyons may develop.

Standing on this plateau on any of the divides between the streams which have cut their gorges to considerable depths in the rocks, these gorges, canyons, ravines and valleys are concealed from view and what appears as a vast unbroken plain stretches almost as far as the eye can see in all directions. In some regions, the surface of the plateau is considerably roughened by more or less rounded hills from 30 to 90 feet high. This is especially true of what is known as the Palouse Country. These hills are not prominent, however, and in a general view do not detract from the impression that the surface is that of a fairly level plateau. These hills have smooth, even slopes, well rounded tops, and literally cover the whole surface of the country. In general, they are much steeper on the northeast sides than they are on the south and southwest sides. Through this part of the country the prevailing winds are from the south and southwest, and this has been a very important factor in producing the present topography of the Palouse Country, these winds having shifted to a greater or lesser extent these fine soils, removing them from the south and southwest sides of the hills and heaping them up on the north and northeast sides.

The wind, however, has been only a modifying factor in producing the topography of this region, as we find it today, the principal factor in determining its outlines having been the streams. The small gulches lead into the larger draws, these in turn into the larger valleys, and these again into the still larger ones, until we have the main valley and its smaller ones corresponding in every way with the main stream and its tributaries.

Beneath the present surface features lies an older topography, which in a few places, such as Steptoe and Kamaick buttes, is exposed on the surface. The rocks composing these older formations are quartzites and granites largely, while the surface formation throughout the Columbia Plateau is mainly basalt.

Blue Mountains.

The southeastern corner of Washington contains a part of the Blue Mountains. The main range lies to the southwest in Oregon and is much higher than that part in Washington. In Washington, the Blue Mountains consist of an elevated mass of basalt,the highest points of which do not reach an altitude of more than about 6,000 feet above sea level. This mass of basalt has been deeply eroded by streams that flow from the main divide, which has a general northeast, southwest direction. Inthe main, the area is one of deep valleys and sharp divides. These mountains rise gradually from the Columbia Plateau which surrounds them on all sides.

POSITION AND GENERAL RELATIONS OF THE PASCO AND PROSSER QUADRANGLES.

The Pasco and Prosser quadrangles are included between the parallels 46^{0} and $46^{0}30'$ north latitude, and the meridians 119^{0} and 120^{0} west longitude. They thus cover about 48 miles from east to west and about $34\frac{1}{2}$ miles from north to south, or an area of about 1650 square miles. The greater part of this area is in Benton County, Washington, and lies to the west of the Columbia River. It does include, however, an area of about 200 square miles lying to the north and east of the Columbia River that is inFranklin County. Along the western side of the area is a strip about six miles wide and $34\frac{1}{2}$ miles long, or approximately 200 square miles, that is in Yakima County.

These quadrangles are within and form a part of the great area usually designated as the Columbia Plains and which extends far to the north, east, and south and includes a large part of eastern Washington, eastern Oregon, northern Nevada, and southern Idaho. The physiographic and geologic history of the area covered by these quadrangles has many things in common with the larger area of which they form a part, yet there are a number of problems that are confined to the area covered by these quadrangles and the territory immediately surrounding.

SETTLEMENTS.

The principal towns in the area covered by the Pasco and Prosser quadrangles are Pasco, the county seat of Franklin County, Prosser, the county seat of Benton County, Kennewick, Benton City, Grandview, Mabton, Richland, Burbank and Eltopia. Pasco is situated on the northern side of the Columbia River about two miles above where the Snake River empties into the Columbia. Pasco is principally a railroad town, being a division point on the Northern Pacific. It has, according to the 1920 census, a population of 3,362. Kennewick is located just across the Columbia River from Pasco a few miles below where the Yakima River empties into the Columbia. It is about 350 feet above sea level. According to the 1920 census, it had a population of 1,684.

Prosser, the county seat of Benton County, is situated on the Yakima River about four miles from the western border of the county. It is located in a fruit and agricultural district. The population, according to the 1920 census, is 1,697. The altitude of Prosser is 661 feet above sea level. Mabton is another small town, located in the extreme western edge of the Prosser quadrangle. It has a population of about 550 people and is an important shipping point for a considerable part of the Horse Heaven Country, which lies to the southeast. Grandview is also a prosperous town in the western part of the area under discussion. The population according to the 1920 census, is 1011. It is surrounded by an agricultural country and is an important shipping point for fruit and alfalfa.

This region is fairly well supplied with transportation facilities. The main line of the Northern Pacific Railway enters the area at the northeast corner of the Pasco quadrangle and extends in a general south and slightly westerly direction to Pasco. Here it crosses the Columbia River, passes through Kennewick and on in a general westerly direction to Kiona, where it strikes the Yakima River, which it follows to the western edge of the area. There is also a branch of the Northern Pacific which leaves the main line at Gibbon and extends almost due west through North Prosser, then a little northwest to Grandview, and then almost due northwest until it passes off from the Prosser quadrangle. The Oregon-Washington Railway and Navigation Company has a branch line which extends from Wallula, Washington, to Yakima. This enters this area on the eastern side about one mile south of where the Snake River empties into the Columbia, extends westward through Kennewick, Benton City, North Prosser, Grandview, and on to Yakima. Still another railway line, the Spokane, Portland, and Seattle, helps to furnish transportation facilities for this district. This line extends from Spokane to Pasco, where it crosses the Columbia River and then follows down the north bank of the Columbia to Portland. The Columbia River is navigable from its mouth at Astoria to Priest Rapids, about ten miles above Pasco.

DRAINAGE.

Columbia River.

The largest stream in the drainage system of Washington is the Columbia River, which rises in British Columbia and enters the state on the north about 25 miles from its eastern edge. From the northern border of the state it flows in a general southwesterly direction for about 25 miles, then almost due south for about 60 miles, then in a general westerly direction for about 75 miles, after which the general direction is south for about 130 miles, and then west to the Pacific Ocean. Just before making this last westward turn, the Columbia enters the area covered by the Pasco quadrangle on its northern boundary about one mile west of the center, flows due south for about 16 miles, then southeast and passes off from the eastern edge of the area about ten miles from its southern border.

The Columbia River has a rapid current, mainly on account of the large volume of water it carries. The volume of water varies much and as a result of this, the level of the river will vary more or less, but is, on the average, about 16 feet at Pasco. Gage readings at this point during 1909 showed a change in level of 21.9 feet and for 1910, 16.3 feet, the river being highest in 1909 about the 20th of June and lowest about the middle of January, while in 1910,it was highest about the middle of May and lowest the last of February. The principal tributaries that enter the Columbia River in the area under discussion are the Snake River, which enters it from the east, and the Yakima River, which enters it from the west, a few miles above the mouth of the Snake. The Columbia River is navigable from its mouth to the foot of Priest Rapids,which are about 60 miles by the river above Pasco.

Yakima River.

The Yakima River rises in the Cascade Mountains in Lake Keechelus and flows in a general southeasterly direction to the Columbia River. In addition to Lake

Keechelus, there are a number of other lakes, such as Kachess and Clealum, the waters of which reach the Yakima River. The Yakima is a very important stream for irrigation purposes, on account of the large amount of water which it contains, the fact that floods are not apt to occur along the stream as its flow is regulated by the large lakes near its source, and the well timbered slopes of the Cascade Mountains. Even with the above conditions, the flow of the stream is far from constant. The maximum discharge for the year ending September 30, 1914 at the station near Prosser was 11,300 second-feet, which occurred in April and the minimum for the same year was 332 second-feet in August[1], while for the year ending September 30, 1920, at

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[1]Grover, Nathan C., Parker, G. L., and Lamb, W. A., Surface Water Supply of the United States, 1914, North Pacific Slope Drainage Basins: U. S. Geol. Survey, Water-Supply Paper, No. 392, p. 155, 1916.

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the same station, the maximum was 6,140 second-feet in January and a minimum of 701 second-feet in July.[2] A considerable

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[2]Ibid for 1919 and 1920, No.513, p. 207, 1923.

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part of the summer flow of the Yakima River is used for irrigation so that the normal flow below where the irrigating ditches take out water during the irrigating season is greatly reduced. The Yakima River has a number of good sized streams which flow into it. These all enter it, however, before it reaches the area under discussion.

CLIMATE

The Cascade Mountains extend from north to south across Washington, and as a result of this, the state is separated into two parts, an eastern and a western, that are quite unlike as regards climatic conditions. The prevailing winds that blow over Washington are from the west and southwest. As a result of this, the winter winds come in from the warm Pacific Ocean carrying a large amount of moisture and when they reach the cooler land, they are chilled more or less and precipitation occurs. This gives to Western Washington a wet but fairly mild climate.

In passing over the Cascade Mountains, these winds have become chilled very much, but as they come down the eastern slope of the range, they are warmed somewhat and are capable of holding all the moisture they have. As a result of this condition, the country just east of the Cascade Mountains is arid and has hot summers and cold winters. The Pasco and Prosser quadrangles are within this arid belt.

The following tables show the monthly and annual precipitation at Kennewick and Sunnyside from 1912 to 1924:[1]

Monthly and annual precipitation (in inches and hundredths) at Kennewick, Washington, from 1912 to 1924.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1912	1.88	0.60	0.60	0.73	0.82	0.51	0.10	1.26	0.02	0.64	1.08	0.29	8.53
1913	---	0.26	0.04	0.40	0.38	1.22	T	0.32	0.02	----	1.59	1.28	5.51
1914	---	1.53	----	0.82	0.49	0.42	0.45	T	0.26	0.58	0.52	0.62	5.69
1915	0.27	1.39	1.09	1.31	1.27	0.82	0.34	0.05	0.12	0.23	1.79	1.06	9.74
1916	1.99	2.43	1.53	1.17	0.25	1.23	0.77	0.02	T	0.09	1.02	1.54	12.04
1917	0.53	0.39	0.16	0.92	0.75	0.37	0.00	0.00	0.26	0.00	0.87	1.87	6.12
1918	0.96	0.63	0.43	0.27	0.61	0.24	0.20	0.67	0.08	0.60	0.50	0.62	5.81
1919	1.47	1.40	0.69	0.72	0.24	0.00	0.03	0.00	0.33	0.00	1.12	1.08	7.08
1920	1.15	0.35	0.22	1.17	T	0.56	0.09	1.53	0.33	1.08	0.74	1.25	8.47
1921	0.65	1.55	0.14	----	0.37	0.25	T	0.02	0.17	0.44	2.39	0.74	6.72
1922	0.43	0.38	1.08	0.15	0.05	0.11	0.00	0.35	0.02	0.62	0.65	1.71	5.55
1923	0.57	0.80	0.92	0.67	0.32	1.13	0.43	0.19	0.46	1.91	0.38	1.13	8.91
1924	0.84	0.81	0.51	0.05	T	0.20	0.24	0.68	0.36	0.38	1.93	1.19	7.19

Monthly and annual precipitation (in inches and hundredths) at Sunnyside, Washington, from 1912 to 1924.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1912	1.81	0.47	0.06	0.61	1.29	0.97	0.45	0.74	0.10	0.86	0.96	0.32	8.64
1913	0.72	0.27	0.09	0.23	0.96	0.48	T	0.00	0. 46	1.21	1.15	1.25	6.82
1914	1.40	0.58	0.12	0.92	1.31	0.10	0.17	0.00	0.51	1.92	0.48	0.76	8.27
1915	0.94	0.73	0.61	0.72	0.86	0.39	0.69	0.01	0.00	0.30	1.82	1.21	8.28
1916	1.01	1.40	0.77	0.62	0.16	0.58	0.86	0.02	0.14	0.03	0.88	0.74	7.21
1917	0.35	0.27	0.31	0.87	0.85	0.13	0.00	0.00	0.24	0.00	1.25	1.22	5.49
1918	0.85	0.76	0.09	0.01	0.50	0.07	0.30	0.55	0.66	0.77	0.34	0.55	5.45
1919	0.63	0.98	0.26	0.43	0.31	T	0.01	0.12	0.55	0.28	0.80	0.84	5.21
1920	1.00	0.07	0.10	0.80	0.11	0.72	0.18	0.91	0.90	0.60	1.30	0.95	7.64
1921	0.68	0.79	0.07	0.45	0.73	0.52	T	0.07	0.35	0.17	2.19	1.00	7.02
1922	0.17	0.69	0.28	0.23	0.09	0.18	T	0.22	0.16	1.16	0.36	0.71	4.85
1923	0.25	0.14	0.05	0.40	0.17	0.94	0.77	0.88	0.80	0.89	0.11	0.82	6.22
1924	0.61	0.77	0.16	0.06	0.00	0.10	0.11	0.38	0.24	0.53	2.01	0.77	5.74

T = precipitation less than 0.01 inch rain or melted snow.

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1 Department of Agriculture Report, Report of Chief of Weather Bureau.

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Although this area is north of latitude 46°, the winters in the valleys are not severe, as they lie at elevations of from about 350 to 1,000 feet. They are also more or less protected by the higher lands that tend to surround them. The winters in most cases are what might be termed "open" as the small amount of snow that does fall as a usual thing does not remain for any long period of time. Frosts may occur early in the fall or late in the spring, but in general they are not severe.

AGRICULTURE.

In the early settlement of this region, almost the whole of it was used for grazing and large bands of horses and cattle roamed over it. At present, however, this industry is much less important than formerly, though there are still considerable areas that are used only for this purpose. The irrigated lands are very productive and yield bountiful crops of forage plants, such as alfalfa, timothy, and clover. Garden vegetables, hops, apples, pears, and peaches all make valuable crops. The fruits especially are noted for quality and size.

The supply for irrigation purposes is large and fairly accessible. This in connection with the fact that markets have been developed, not only on the coast but in the east as well, has aided in the rapid development of this country. Considerable tracts of land, which are situated above the irrigation canals, are used for raising wheat by dry farming.

TOPOGRAPHY.

Relief

As stated before, the area under discussion forms a part of what is usually designated as the Columbia Plain, but this is by no means a plain in the strict sense of the word. In the northwestern part of the Prosser quadrangle in the Rattlesnake Hills, an altitude of 3621 feet above sea level is reached, while the lowest point of the area is on the eastern edge of the Pasco quadrangle on the Columbia River, where the altitude above sea level is only 302 feet. This makes a difference in altitude between the highest and the lowest points of the area of 3319 feet. On account of this great difference in altitude, one might expect the surface to be a very rough uneven one as a rusult of a large amount of erosion. The surface, however, is not as a general thing badly cut up with a large number of deep gorges, and this is due largely to the climatic conditions that exist in this part of Washington.

This area, as a whole, is made up of broad valleys, high hills and ridges and large areas of comparatively smooth tracts having a considerable altitude above sea level. These latter tracts have a fairly uniform slope, which in the main is toward the southwest, and as a result of this, the drainage is in that direction. The main valley of this area is the Yakima Valley, which extends from the western side of the Prosser quadrangle to about the center of the Pasco quadrangle. The most prominent ridges are the Rattlesnake Hills, which extend from the northwest corner of the area to a little below the

the center on the eastern side, and the Horse Heaven Hills, which enter the Prosser quadrangle on the western side a little below the center and extend in a northeasterly direction almost to the eastern side of the quadrangle where they turn to the southeast and continue across the Pasco quadrangle.

Upland Areas.

There are two principal upland areas on these quadrangles. One of these lies to the south of the Yakima River and is known as the Horse Heaven Plateau, while the other is that part of the area in these quadrangles that is situated between the Rattlesnake Hills on the north and the Yakima Valley proper on the south. The Horse Heaven Plateau has an extent on these quadrangles from east to west of about 42 miles and an average width from north to south of about ten miles or an area of about 240 square miles. The other upland area lies entirely within the area of the Prosser quadrangle and is much smaller than the Horse Heaven area and contains approximately 130 square miles.

Horse Heaven Plateau. The Horse Heaven Plateau has an altitude along its northern border of about 1800 feet. This plateau rises precipitously from the Yakima Valley in what are known as the Horse Heaven Hills. These hills extend along the south side of the Yakima Valley from the western boundary of the Prosser quadrangle to about two miles east of Badger or about eight miles east of the western border of the Pasco quadrangle. West of the vicinity of Badger, the slope is steep and not more than about one and a half to two miles long, while to the east of Badger, the slopes are much less steep and are about six miles in length. Beginning on the western border of the Prosser quadrangle, the Horse Heaven Hills extend in a general northeasterly direction to within about three miles of the eastern boundary of the quadrangle, where they turn to the southwest and continue across the Pasco quadrangle.

The Horse Heaven Plateau, which lies south of the Horse Heaven Hills, when viewed from certain positions, appears almost level, though there is always a gradual slope toward the south and east. Along the northern side of this area the elevations range from about 1600 to 2000 feet above sea level, while along the southern border, it is 1500 feet at the western side and decreases to the east until at the center, the altitude is only about 700 feet above sea level. Farther east the altitude increases again until the southeast corner of the area has an altitude of about 1200 to 1400 feet above sea level.

The Horse Heaven Plateau contains a number of deep draws or ravines, the most prominent of these being the area in which Glade Creek occurs. One branch of this begins on the eastern side of the Prosser quadrangle at the northern edge of the plateau and extends in a southeasterly direction to its southern border. The other branch begins on the eastern side of the quadrangle at the northern edge of the plateau and extends in a southwesterly direction and unites with the other branch about three miles south of the southern edge of the area under discussion. Most of the ravines that occur on that part of the area covered by the Prosser quadrangle, with the exception of the area in which the west branch of Glade Creek occurs, are comparatively shallow.

In most cases, the bottom of the ravine is not more than 40 to 60 feet below the plateau. The ravine in which the west branch of Glade Creek occurs, however, is much deeper, the bottoms in places being as much as 600 or 800 feet below the upland. The gorge is comparatively narrow and the sides steep. The eastern part of the Horse Heaven Plateau or that part covered by the Pasco quadrangle is rougher than that to the west. The canyons are more common and they are deeper on the average. The extreme depth, however, is not so great as in the case of Glade Canyon. Some of the most prominent of these canyons are Taylor Canyon, Prospect Canyon, Bofar Canyon, Fourmile Canyon, and Spukshowki Canyon. None of the canyons or ravines on the Horse Heaven Plateau contains permanent streams, water flowing down there only during the period of melting snow or for a short time following heavy rains.

<u>Rattlesnake Plateau</u>. The area included under this head is situated to the north of the Yakima River and begins in the northwestern part of the Prosser quadrangle and extends in a southwesterly direction, practically across the entire area under discussion. To the northeast, these hills descend precipitiously, while to the southwest, the condition is very different. On this side, the slope is a long gentle area that begins near the crest with a dip of about 12 to 15 degrees, but gradually grows less and less

and finally merges into the low lands of the Yakima Valley. The direction of drainage of this area varies somewhat, that of the western part being to the southwest, that of the central part being almost due south, while that of the eastern part is to the southeast. There are, however, no permanent streams flowing across the area. There are a number of deep prominent canyons on this area and in these, streams flow during the melting of snow or at the time of heavy rains. The bottoms of some of these gorges are as much as 250 to 300 feet below the general level of the surrounding country. Black Rock Canyon, in the western part of the area, Snipes Creek Canyon and Corral Canyon in the eastern part of the area, are among the most prominent of these canyons.

Between the Rattlesnake Hills proper and the Yakima Valley is an area that is from about 1,000 to 1,600 or 1,800 feet above sea level. This tract is narrow in the eastern and western part of the area, but has a width in the central part of the Prosser quadrangle of from 6 to 8 miles. This is much smoother than the Rattlesnake Hills proper and some parts of it are cultivated.

Cold Creek Valley lies on the northeast side of the Rattlesnake Hills and has an altitude above sea level of about 500 feet. For about four or five miles toward the hills, the slope is almost uniform and quite gradual until an altitude of 1500 feet is reached, then the slope becomes steeper and finally becomes very abrupt. There are no streams of importance draining this slope of these hills and the northeast face is a comparatively smooth area.

Valley Areas.

The area under discussion contains only two valleys of any importance. These are the Yakima Valley and the Columbia Valley. A part of Cold Creek Valley is also included within the bounds of the area but this is a small valley as compared with the other two and of little importance at present. In the northern end of this valley, however, artesian water has been found and that part of the valley is being settled.

Yakima Valley. The YakimaValley is a very pronounced feature of the area under discussion. It extends from west to east entirely across the Prosser quadrangle. The widest part of the valley is in the west where it has a width of about twelve miles. On the south it is bordered by the Horse Heaven Hills, which rise abruptly from the valley in very steep slopes. On the north side, however, the valley merges gradually into the Rattlesnake Hills. The larger part of the valley is on the north side of the Yakima River, only a small tract on the western side of the area covered by the Prosser quadrangle being south of the river. Down stream, the valley narrows and about four or five miles west of Benton City, it becomes a narrow gorge with comparatively steep basaltic cliffs on either side. At Benton City, the stream turns almost due north and flows for five miles in a gradual northerly direction along a narrow valley cut through the Rattlesnake Hills, after which it flows along a narrow valley in a northeasterly direction to secs. 3 and 4 of T. 10 N., R. 27 E., where the river makes a sharp bend, commonly known as the "Horn," and from this point flows in a southeasterly direction through the Columbia River Plains and empties into the Columbia River about four miles above Kennewick.

The Yakima Valley is generally treated under the head of the Sunnyside Valley and the Reservation Valley. The Sunnyside Valley is that part of the Yakima Valley on the north and east side of the Yakima River below Union Gap, while the Reservation Valley lies to the west and south of the Yakima River between the Atanum and Toppenish ridges. The Reservation Valley as thus defined does not occur on the area under discussion, but the Sunnyside Valley does. This begins on the western side of the area and extends about one-third of the way across it.

The part of the Yakima Valley included in the area considered here is comparatively smooth, having but few relief features of importance. In some places, however, the surface is more or less hummocky and cut by small drainage channels. Most of the valley is floored with deposits of gravel, sand, and silt,these being overlain by alluvium, in part at least, washed from the higher slopes. In some places in the valley, the soil becomes very sandy and in some places it is absent and basalt occurs on the surface. South of the YakimaRiver, between Mabton and Prosser, the soil as a general thing is thinner than on the north side.

Columbia River Plains. The term Columbia River Plains, as used here, is applied to a wide expanse of territory that lies east of the Columbia River and north of the Snake River and a smaller area west of the river and between it and the YakimaRiver and Cold Creek. The area which lies on the west side of the Columbia River is a low plain but little above the level of the river, the greatest altitude being between 550 and 600 feet above sea level or about 200 feet above the river. This, however, is the extreme height and by far the larger part of this area is not more than 50 to 100 feet above the Columbia River. On the east side of the river, bluffs appear along the stream and the land rises to form a plateau. From Byers Landing, north to Ringold, a distance of eight miles, very steep bluffs rise about 500 feet above the river, and on account of the color, these have been designated and are known as the White Bluffs.

The surface of both the eastern and western part of the plains area is in general only gently undulating. In the eastern part, the highest point is on Jackass Mountain, situated in the north central part of the area, and having an altitude above sea level of 915 feet. The area east of the Columbia River has a general southeast slope, but has no perennial streams flowing across it. In the southern part of this area, large deposits of gravel occur, while in the northern part, thick deposits of sediments, which belong to the Ringold formation, cover a considerable area. The soil that lies over parts of this area resulted from the decomposition of the Ringold formation and this is fine grained, light and easily tilled. Much of the area, however, is covered with a very sandy soil.

That part of the Columbia Plain west of the Columbia River is a nearly level sage brush covered area. The eastern part along the Columbia River is low, rising only a few feet above the river. The greatest elevation reached on this area is about 550 to 600 feet. The highest part of the area is in the northern part, a little west of the center. The slope is fairly uniform to the east, south and west, from this high part of the area. Near the Columbia River, considerable areas of gravel and cobbles occur, which in many cases are covered with a loose sandy soil. Only in a very few places in this area are the rock formations exposed on the surface. Over the western part of the area, the soil is a little less sandy than in the eastern part and finer in texture. There are no streams flowing across this area and the surface is free from deep gulches or canyons.

Cold Creek flows along the western side of the tract in a fairly broad and shallow valley. This valley was probably at one time occupied by the Columbia River.

Flood Plains.

No flood plains of importance occur on either the Prosser or Pasco quadrangles. A few small areas of marsh or swamp lands occur along the lower parts of the Yakima and Columbia rivers on the Pasco quadrangle, but these are of no especial importance.

DESCRIPTIVE GEOLOGY

The Miocene Period.

The geology of the area as far as stratigraphy is concerned is fairly simple. During Tertiary times in the western part of the North American continent, volcanic activity was very pronounced and the products of this volcanism are very much in evidence on the Pasco and Prosser quadrangles. The Yakima basalt of Miocene age underlies the whole of this area and in many places has a thickness of more than 2,000 feet. The contact between the basalt and the underlying surface on which it rests is nowhere exposed but it was probably more or less irregular. These irregularities, however, were soon completely obliterated as the molten rock which poured out on the surface first filled the valleys and finally overflowed the highest hills.

The successive flows of basalt finally changed the area from one of hills and valleys to a more or less monotonous waste of dark basaltic rock. During the time that elapsed between the flows, soils probably would form on the surface of the basalt and vegetation grow in these soils until the next flow when everything would be inundated again.

Near the close of the Miocene period, the basaltic eruptions in this area ceased, a subsidence occurred, forming a basin in which sedimentation took place. Streams flowed into this basin and deposited their loads of sand and gravel on the surface of the basalt. The material composing these deposits was of foreign origin and consisted mostly of volcanic ash and products of decomposition of light colored andesitic lavas. This condition probably continued to the close of the Miocene period, a considerable part of the area under discussion being occupied by a lake during this time, and sedimentation continued until in some parts of central Washington a thickness of at least 1,600 feet of material had accumulated. These sediments constitute the Ellensburg formation.

The Pliocene Period.

Practically the same conditions may have continued at the beginning of Pliocene time but early in this period, according to George Otis Smith[1], movements began which

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[1]Smith, G. O., U. S. Geol. Survey, Ellensburg Quadrangle, Geologic Atlas U. S. Folio 86, p. 2, 1903.

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eventually took the form of flexing both the basalts and sediments of Miocene age into gentle arches with a general east-west direction. This period of arching is thought to have been of comparatively short duration after which streams and weathering agencies began their work of wearing down this surface. The soft material would be removed from the ridges first after which the harder underlying basalt would be attacked.

This condition is thought to have continued for a considerable time after which arching of the surface again took place mainly along lines for the most part coincident with those of the earlier folding. At this time the whole region was slowly elevated, giving renewed force to the streams.

In case the arches of the warped plain extended across the stream course it was necessary for the stream to deepen its channel as rapidly as the elevation took place or change its course. In the case of the larger streams they were able to keep the same course and are examples of typical antecedent streams.

The Pleistocene Period.

During parts, at least, of the Pleistocene period, considerable areas in central Washington, including the larger part of the Pasco and Prosser quadrangles, were under water. The extent of these water bodies is not definitely known, but sediments, the age of which has been fairly definitely determined as Pleistocene, are found at various places over this part of Washington.

Age and relation of the Satsop. The Cascade Mountains in northern Washington are thought by some to record a warped and dissected peneplain. Willis and Smith[1] have called this the Methow peneplain and have

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[1]Willis, Bailey, and Smith, George Otis, Contributions to the Geology of Washington: U. S. Geol. Survey, Prof. Paper 19, 1903.

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identified it as Pliocene in age. The relation of the deposits composing the Satsop formation to this peneplain has been determined by Bretz[2] and he says: "Little hesitation

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[2]Bretz, J. Harlen, The Satsop Formation of Oregon and Washington: Journal of Geology, Vol. 25, p. 456, 1917.

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is felt in correlating the eroded surface named the 'Methow peneplain' with the eroded surface beneath the Satsop." In this same article he says the Satsop formation lies unconformably on the tops and flanks of at least some of the anticlinal ridges through this part of Washington. He has also shown that the surface in other places on which the Satsop rest is irregular and does not represent a plain.

Stratigraphically the Satsop in eastern Washington is found to lie on rocks of Miocene age with an erosional unconformity between the two formations. In some cases the Miocene formation is represented by the Ellensburg and in others by the Yakima basalt. After the Satsop deposits were accumulated, another disturbance took place and the east-west ridges which had been formed during Pliocene time were reelevated and deformation of the Satsop occurred.

The age of the Satsop formation has been determined from fossil leaves to be Quaternary, at least on the western slope of the Cascade Mountains. The evidence shows that the Satsop formation was deposited "before the present Cascade Mountains were folded and therefore long antedates the Champlain epoch.[1]

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[1] Bretz, J. Harlen, Pleistocene Submergence in Columbia Valley: Journal of Geology, Vol. 37, p. 491.

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Ringold formation. After the period of deformation which followed the deposition of the Satsop formation large deposits of fine clay and sand were deposited and these have been called the Ringold formation and are determined to be of Pleistocene age.

<u>Glaciation</u>. A large part of Washington has in times past been subjected to the action of glaciers. The extent of the ice sheet has not been very carefully determined but probably the entire highland area north of the Columbia plateau was buried beneath a sheet of ice and the southern limit of it, so far as known now, was probably not far from the central part of the state.

The glacial period in Washington as in other places, seems to have had times of advance and retreat or glacial and interglacial intervals. In some cases, these glacial and interglacial periods represent a long time and the ice during the interglacial interval may have completely disappeared. According to Bretz[1] there must have been at least three glacial

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[1]Bretz, J. Harlen, Glacial Drainage of the Columbia Plateau: Bull. Geol. Society of America, Vol. 34, p. 580, 1923.

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periods: "At least three times the Cordilleran ice forced a crossing of the Columbia Valley and advanced onto the plateau." The earlier of these glacial periods has been called by Bretz the Spokane epoch while the later period he has called the Wisconsin epoch. The exact limits of the early ice sheets has not been accurately determined as no well marked terminal moraine has been found. According to Bretz[2] it is known

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[2]Bretz, J. Harlen, Glacial Drainage of the Columbia Plateau: Bull. Geol. Society of America, Vol. 34, p. 580, 1923.

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to have crossed the Columbia and Spokane valleys from the north and pushed south for 12 to 15 miles, at least, in the vicinity of Spokane.

During the later period, the Wisconsin, glaciers occupied the Cascade Mountains to the west and to the north, and the Okanogan country to the north and to the east. Out from the main mass, great streams of ice flowed down the valleys to the plains below. Of these, the ones occupying the Okanogan Valley and the gorge that Lake Chelan now occupies, were probably the most important. Ice filled the Columbia gorge from the mouth of the Okanogan River to the foot of Lake Chelan and here joined the Chelan glacier. These glaciers probably united with the Okanogan glacier and spread east to the Grand Coulee, over the plateau embraced by the Big Bend. When the ice melted, the rock material that it had been carrying was deposited and may now be seen on the plateau from Grand Coulee west to the Columbia River.

At times, especially during the interglacial periods, large volumes of water would be set free, from the melting of the ice, and this flowing south became ponded and covered considerable areas in central Washington. In these bodies of water sediments were accumulated and these deposits are found at present over parts of the Pasco and Prosser quadrangles.

Erratics. Scattered over the Pasco and Prosser quadrangles are granite boulders which vary in size from small pieces up to masses as much as ten feet in diameter. They were found by the writer at an altitude of 1100 feet and have been reported by Bretz[1] from the Columbia Valley at an altitude of about 1250 feet. As there is no evidence

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[1]Bretz, J. Harlen, Glacial Drainage of the Columbia Plateau: Bull. Geol. Society of America, Vol. 34, p. 605, 1923.

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that glaciers ever occupied this part of Washington, this cannot be given as a means of transportation for this erratic material. It was probably carried by floating ice and when this melted, the material was deposited. In some cases, the icebergs would be stranded in shallow water and considerable amounts of material be deposited in one place but in the case of many of the ice masses, they floated and melted gradually and distributed more or less the material being carried.

IGNEOUS ROCKS.

Columbia River Basalt.

Distribution. The area under discussion here forms a part of the large lava field which covers the most of Washington south of the Spokane and Columbia Rivers east of the Cascade Mountains, eastern Oregon, and adjacent parts of Idaho, Nevada, and California. To this large series of effusives, the general term Columbia River lava has been applied. This term was used by Isreal C. Russell to include basalts of both Eocene and Miocene age.[1]

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[1]Russell, I. C., Geology of the Cascade Mountains in Northern Washington: U. S. Geol. Survey, Twentieth An. Rept. Pt. II, p. 129. A Reconnaissance in Southeastern Washington: U. S. Geol. Survey, Water-Supply Paper No. 4, p. 29.

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Yakima Basalt.

The term Yakima Basalt was adopted by George Otis Smith for that part of the Columbia River lava that has been determined to be of early and middle Miocene age.[2] It

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[2]Smith, G. O., U. S. Geol. Survey, Geol. Atlas, Ellensburg Folio, No. 86 p. 3, 1903.

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includes the great series of lavas poured out over the Columbia River Basin in late Tertiary times.

Origin. The Yakima basalt was poured out in a molten condition from openings in the earth's crust in practically the same way that volcanoes at the present time are discharging similar material. This material probably came to the surface through fissures in the earth and not through single vents, such as Mount Hood and Mount Rainier. The material was probably in a highly liquid state when it reached the surface, then flowed rapidly away from these fissures.

In many places, streams have cut deep canyons in this basalt and have exposed a great thickness of this material. In these canyons, the fact is revealed that this great thickness of basalt is not one large flow, but is made up of a number of beds varying more or less in thickness. These different layers may be separated by more or less scoriaceous layers and other materials. In some cases, these flows are separated by layers of sand, clay, and old soils.

In case the lava came through fissures, dikes should be found cutting through the lower sheets of lava and leading up to the upper layers. In some localities, especially near the edges of the basaltic area, large dikes have been found. Over much of the area, however, conditions are such that it is not possible to locate such dikes if they do occur. In only comparatively small areas are the edges of the layers of basalt exposed. Even where streams have cut deep canyons in the basalt it has decomposed in most cases until a considerable thickness of soil mantles the slopes and conceals from view almost completely the underlying rocks.

<u>Extent</u>. This molten rock material spreads out over the area between what is now the crest of the Cascade Mountains on the west and the mountains of Idaho on the east.

On the north it extends to what are usually designated as the Okanogan Highlands, which is that part of Washington east of the Cascade Mountains and north of the Columbia and Spokane rivers and the Blue Mountains of Oregon on the south. This basalt which occurs over this large area did not all come to the surface at one time but flow after flow occurred until, in places at least, a thickness of 4000 to 5000 feet of this material had accumulated. In some cases, long periods of time elapsed between these flows - long enough for the whole mass to cool, decomposition to take place and form soils, and vegetation to grow in those soils. This is proven conclusively by the finding in places of solidified tree trunks between the basalt layers. The number of successive flows probably varies in different parts of this area, but in some places as many as ten distinct flows have been recognized.[1]

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[1]Smith, George Otis, Geology and Water Resources of a Portion of Yakima, County, Washington: U. S. Geol. Survey, Water-Supply Paper No. 55, p. 15.

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Character of the rock. The Yakima basalt is the underlying formation over the whole of the Pasco and Prosser quadrangles. In this locality, it is a dark colored, hard, compact and heavy rock. When weathered, the color changes and becomes, as a general thing, somewhat brownish. The texture of this rock varies much in different places, in some places being very dense and compact, while in others it is more porous. This variation is due largely to different conditions under which the lava solidified. The tendency would be for the material at the bottom of a flow to be more compact than the material at the top of the flow. The individual flows also vary more or less in different parts even at the same depth.

The texture of this rock was determined by such things as composition of the molten material, pressure under which it solidified, fluidity of the molten mass, and rate of cooling. Only in cases where the molten magma cooled very quickly and under a minimum pressure did it assume a glassy form. The more slowly it cooled, the more coarsely crystalline it became. As a result of this, the tendency is for the central portions of the flows to be more crystalline than the surface.

Much of this basalt has a characteristic porphyritic texture, that is, a texture in which a part of the rock is in a more or less glassy condition and disseminated through this are crystals of the various minerals that make up a considerable part of the rock mass. In some cases, these minute crystals are visible with the unaided eye, while in others, they are visible when thin sections are viewed with the aid of the microscope.

<u>Columnar structure</u>. One of the very noticeable features of this basalt rock is the way in which the joint plains break it up into long prismatic columns. In some localities, these columns are almost perfect hexagons with sharp edges and almost even sides. In many cases, the basaltic columns are jointed horizontally so that they are separated into blocks of comparatively uniform size. These cracks in the basalt are a result of strains developed in the mass as a result of shrinkage or contraction when it was cooling.

<u>Surface on which the basalt rests</u>. The indications are that the surface of the Columbia Plateau area, before the basaltic overflows, was a very rough uneven one. This is shown in the fact that in places the older formations, on which the basalt rocks rests, rise above the surrounding plateau and have not been covered by the basalt. Throughout the area are these high points which rise from 500 to 800 feet above the surrounding country. These are prominent features of the landscape at the present and must have been much more prominent before the lava flows. The Snake River, in places along its course, has cut through the overlying basalt and exposed the older formations below. From these exposures of the underlying formation, we are able to determine that the surface on which the basalt rests was a very rough and irregular one.

The eruptions began and the liquid rock material began welling out and filling up gradually the depressions and finally the surface became much smoother than it had been, so that with the cessation of the eruptions, the surface was generally level over a large area but more or less rough in detail. Then began the work of the weathering agencies, such as winds, frost, changes in temperature, and running water, all of which modified the topography more or less. Soils formed vegetation spread over the area, and then another outpouring of lava would take place and the previous conditions would be repeated.

SEDIMENTARY ROCKS.

Sedimentary rocks are exposed on the surface in but few places over the area covered by the Pasco and Prosser quadrangles. Sedimentary formations, however, probably occur in places where they are covered with other formations, so that they may be more common than would appear from surface exposures. Deposits of this character undoubtedly covered a much larger part of this area at one time than they do now.

Ellensburg Formation

Distribution. Certain sedimentary beds have been described and named the Ellensburg formation by George Otis Smith.[1] These deposits are well exposed in the Kittitas and

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1 Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg Folio No. 86, p 2, 1903.

Yakima valleys and cover large areas, especially in the

Yakima Valley. In the main, this formation occurs in the valleys where it is largely covered by alluvium. It may be seen in places along the banks of streams and where irrigating ditches have exposed it. Probably the very best exposure of the Ellensburg deposits is on the north side of the Naches River, along the lower part of its course. Beginning about two miles above the mouth of the Naches, these beds occur as high bluffs and continue up stream for miles.

Smith[2] gives the following as regards the condition under which these sediments were accumulated:

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[2]Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg Folio No. 86, p. 3, 1903.

"The composition of the conglomerate beds and the prevalent stream bedding indicate that the formation is of fluvatile rather than lacustrine origin. At several points, boulders of andesite measuring several feet in diameter have been found in the Ellensburg conglomerate, indicating that powerful streams acted in the transporting of the material. The original thickness of the material cannot be stated. The section measured in Naches Valley shows nearly 1,000 feet of sediments, while the Wilson well in Wide Hollow penetrates over 1200 feet of the Ellensburg formation. In both of these localities, it is evident that erosion has removed the upper part of the section. The earlier sediments interbedded with the basalt vary considerably in thickness. Thus, on the Naches River section, the thickness is 26 feet, while on the east side of Selah Gap, there are sandstones and conglomerates 130 feet thick below the Wenas basalt."

But few exposures of the Ellensburg formation were found over the area covered by the Pasco and Prosser quadrangles and none of them covered large areas. In most cases, the outcrops are so small that it is not possible to represent them on the map without exaggeration. The largest exposure found was on the western side of the Pasco quadrangle along the bluffs just west of Cold Creek. This exposure occurs in secs. 8, 18, 19, T. 10 N., R. 27 E., and sec. 24, T. 10 N., R. 28 E. This deposit outcrops along the bluffs more or less continuously for a distance of about four or five miles and in places shows a thickness of as much as 100 feet. These deposits are overlaid by a great thickness of basalt.

Other small exposures of Ellensburg sediments are found on the area covered by the Prosser quadrangle. One of these small outcrops occurs in sec. 6, T. 8 N., R. 25 E., on the south side of the Yakima River, about two miles below Prosser. A quarry has been opened in the deposit at this point, and some material taken out and used for building purposes. This material is lead-gray in color, medium fine grained, and but poorly compacted. It occurs as a thick bedded deposit composed largely of pumiceous material. The face of this quarry exposes about 20 feet in thickness of this material and the bottom of the deposit is not shown.

In secs. 14 and 23, T. 9 N., R. 25 E., is an outcrop of sedimentary material that probably belongs to the Ellensburg formation. This exposure is on the north side of the Yakima River about seven miles below Prosser. It is exposed in the bluffs on the west side of the small gulch, which occurs here and along which the highway passes under the railroad. The top of this layer of sedimentary material is about 40 feet above the bottom of the gulch, but as the bottom of the deposit is not exposed, it is not possible to state how thick it is. In the bottom of the gulch, however, basalt is exposed. The outcrops extend along the sides of the gulch for only a hundred feet. The beds have a dip of about 2° to the south. This is a fine grained, sandy, pumiceous material with a brownish-gray color. The basalt lies over the sedimentaries and the contact between the two is well shown.

Another exposure of sedimentary material occurs in secs. 8 and 17, T. 9, N., R. 26 E., on the north side of the Yakima River about three miles below the one described above. This is in the southeast corner of the section and just by the side of the highway. This deposit has an exposure of about 20 feet in thickness and extends along the side of the bluff for about 150 feet. The deposit shows rather indistinct stratification with the beds lying practically horizontal.

This material is almost pure sand and is only slightly consolidated.

Small exposures of sedimentary material which appear to be Ellensburg were also found in sec. 26, T. 12 N., R. 23 E. These are along the Sunnyside and White Bluffs road on the northern slope of Rattlesnake Hills about one and a half or two miles from the summit. This material, as found here, occurs in stratified deposits and it is not possible to determine very much as to its extent. It is very fine grained, light gray or light buff in color, and is mostly volcanic glass or pumice.

The above are the only exposures found on the area under discussion that are thought positively to belong to the Ellensburg formation. Undoubtedly, however, this formation at one time covered a large area through central Washington and may still be present in places in the valleys and lower parts of the Pasco and Prosser quadrangles, but in most cases, the valleys over this area are covered with valley alluvium which would cover the Ellensburg formation, should it occur. The altitude of the exposures found along the Yakima River is about 750 feet above sea level and only about 100 feet above the floor of the valley.

The outcrops on the eastern end of Rattlesnake Hills are about the same altitude, but are about 200 feet above Cold Creek Valley.

Lithologic character. The typical Ellensburg formation, according to George Otis Smith[1] "is composed

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Smith, G. O., U. S. Geol. Survey Geol. Atlas, Ellensburg Folio No. 86, p. 3, 1903.

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largely of volcanic sediments, which are of foreign origin. Pebbles or boulders derived from the underlying basalt are only rarely seen, the conglomerate beds being composed of pebbles of light gray and purple hornblende andesite and of white pumice of the same composition, while the sandstones and shales of the Ellensburg formations consist of finely comminuted andesite material, which represents in part the volcanic dust from explosive eruptions." He says,[2]

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Smith, G. O., U. S. Geol. Survey, Water-Supply and Paper No. 55, p. 17, 1901.

"this series includes partly consolidated sandstones, shales and conglomerates, with unconsolidated sands and gravels and represents sediments deposited upon the basalt immediately after the cessation of the eruption."

The character of the material occurring in the outcrops of the Ellensburg formation on the Pasco and Prosser quadrangles is fairly typical. These exposures show a considerable range in texture, in some cases being very fine grained appearing sandstones, while in others, they are much coarser, many of the grains being more than one-tenth of an inch in diameter. These beds, as far as the outcrops show, are all made up almost entirely of volcanic material of an andesitic nature and light gray in color. None of the coarser material, such as pebbles and boulders or light gray and purple hornblende andesite or of pumice were found in these beds. Only comparatively small outcrops were foumd, however, and it is barely possible that these pebbles and boulders may be present.

<u>Conditions at the time of deposition.</u> The conditions under which the sediments composing the Ellensburg formation were laid down probably varied more or less at different times and over different

parts of the area where sedimentation was going on.

The great basalt flows occurred in early Miocene time and immediately following these eruptions a large area in central Washington was covered with water, but as yet, it is not possible to say just how extensive this body of water was. At times the "deposition apparently took place in shallow water, since the stratified beds of sand and gravel show the effect of currents which could not have existed in deep waters. The beds of finer material, however, are more perfectly stratified, showing that at times deposition took place in more quiet waters."[1]

[1] Smith, G. O., U. S. Geol. Survey: Water-Supply Paper No. 55, p.22, 1901.

As already stated, only small exposures of the Ellensburg formation were found on these quadrangles and on account of this fact, it is not possible to say positively what the conditions were at the time these deposits were formed. Much of the material, however, is made up of extremely small particles and indicates still, deep water deposits. The indications are in favor of lacustrine rather than fluvatile deposits. The depth of the body of water in which these sediments were laid down cannot be stated positively, but the indications are that the water was fairly deep, as shown by the absence of markings found in deposits formed in shallow water.

In none of the outcrops found was it possible to determine the thickness of these deposits, as in no place was the upper and lower contact of these beds with the basalt exposed.

Ringold Formation.

This is the name given by Merriam and Buwalda [1]

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[1]Merriam, John C., and Buwalda, John P., Age of the Strata Referred to the Ellensburg Formation in the White Bluffs of the Columbia: Univ. Cal. Pub., Dept. of Geol, Bull. Vol. 10, pp 255-566.

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to certain formations that had formerly been considered the equivalent of the John Day beds in Oregon and the Ellensburg of the Yakima Valley.

Previous Knowledge. The White Bluffs section was thought by Russell [2] to be the equivalent of the

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[2]Russell, I. C., A Geological Reconnoissance in Central Washington: U. S. Geol. Survey, Bull. 108, p. 97, 1893.

John Day beds and considered by him the most typical section of that formation to be seen in Washington. Russell used the name John Day to designate certain beds that have later come to be known as the Ellensburg and so presumably he considered the Ellensburg and the White Bluffs approximately contemporaneous. He reported a thickness of 500 feet of these beds, exposed in the White Bluffs, consisting mainly of loose unconsolidated sands, clays, and pure white volcanic dust. Later George Otis Smith[1] referred to the White Bluffs exposure

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[1] Smith, G. O., Contributions to the Geology of Washington: U. S. Geol. Survey, Professional Paper No. 19, p. 18, 1923.

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described by Russell as follows:

"Along Naches River over 1500 feet of the Ellensburg formation are exposed, and the formation is characterized by coarseness of material, together with its characteristic andesitic composition and also the common occurrence of stream bedding. A section of this formation exposed at White Bluffs on the Columbia River is described by Professor Russell as consisting of fine, thin-bedded sand and clay with layers of pure white volcanic dust. The field evidence, therefore, indicated that in the Yakima region the Ellensburg formation is to be considered as of fluvatile origin while farther east along the Columbia, the formation is plainly of truly lacustral type. The cross stratification or stream bedding shows that the material was distributed by eastward-flowing streams.

These stream sediments vary considerably in thickness within short distances, as would be expected, and at some points the stratification is so confused that the individual beds cannot be traced far. At localities, both in the Ellensburg and the Mount Stuart quadrangles, boulders of andesite measuring at least five feet in diameter have been found in the Ellensburg conglomerate, proving that powerful currents must have transported the material."

In the fall of 1902, F. C. Calkins[1] made a

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[1]Geology and Water Resources of a Portion of East Central Washington: U. S. Geol. Survey, Water-Supply Paper No. 118, pp. 34,36, 1905.

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study of a part of east-central Washington, and in his report published in 1905, he discusses the White Bluffs. He measured a section of the White Bluffs at the upper end and records a thickness of 225 feet, consisting of clays, sands, with some ashy material. He states that "The character of the typical Ellensburg material of the Columbia Plains is shown by the following