descriptive section of the exposure at the upper end of the White Bluffs" which shows that he followed other writers in correlating the White Bluffs exposures with thr Ellensburg.

Calkins does bring out the fact, however, that there are some differences between the typical section measured in the Ellensburg quadrangle and the White Bluffs section. The materials in the White Bluffs exposure are finer than in the typical Ellensburg, coarse sandstones being rare while coarse conglomerates do not occur. Cross-bedding, which is common in the Ellensburg is very rare in the White Bluffs section. Tufaceous material so common in the Ellensburg formation is not common in the White Bluffs.

The statement is made that "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 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."

Calkins found no fossils in the White Bluffs deposits.

In the summer of 1916, John C. Merriam and John P. Buwalda made a visit to the important localities in souch central Washington, where the Ellensburg formation is known to occur. The purpose of this expedition was to try and add, if possible, to the scanty representation of vertebrate remains known from these beds. A small collection was obtained from the type area of the Ellensburg near Yakima. The White Bluffs along the Columbia River, were also visited and a considerable amount of mammalian material of a more or less fragmentary nature was collected in the section of sediments appearing in these bluffs in the vicinity of Hanford and Ringold, which had generally been considered as one ofthe greatest of the typical Ellensburg exposures.

After a stydy by Merriam and Buwalda of the collections made at Hanford and Ringold School, they reached the following conclusion:[1]

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[1]Ibed, p 260.

"There is every reason for considering that the collections secured near Hanford (loc. 3031) and near Ringold School (loc. 2757) represent approximately the same horizon in the White Bluffs sediments. The best preserved specimens from both localities seem to furnish definite evidences of very late Cenozoic age. The ground-sloth jaw from the Hanford locality and the Equus teeth from the Ringold School locality both represent types generally considered characteristic of the Pleistocene.

"As the separation between the Pliocene and Pleistocene is not yet clearly determined on a faunal basis in the Great Basin region, one might admit for the present the possibility of including in the latest Pliocene the faunal stage represented in the White Bluffs exposures. Not even the latest faunas referred to the Pliocene up to the present time includes horses of a stage as advanced as that of the Ringold School fauna, and the evidence on the whole favors Pleistocene rather than the latest Pliocene."

Fossil leaves collected from the Ellensburg formation in the vicinity of the City of Ellensburg show this formation to be upper Miocene in age.[1]

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[1]Russell, I. C., A Geological Reconnaissance in Central Washington, U. S. Geol. Survey, Bull, 108, pp. 103-104.

Merriam and Buwalda[2] say the "Ellensburg

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[2]Ibid, p. 256.

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formation is evidently Miocene to early Pliocene in age," and that the evidence in regard to the Ringold School section of the White Bluffs de posits "favors Pleistocene rather than the latest Pliocene."

The following paragraph gives Merriam and Buwalda's idea of this relation of the Ellensburg and Ringold formations.[3]

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[3]Ibed, p. 264.

"In view of the difference in age between the Ellensburg and Ringold faunas, it is important to know the stratigraphic relations of the formations in which they occur. It is probable that the two sets of beds come in contact on the western border of the Ringold, and perhaps at other points, but none of these localities have been examined. If the very even surface extending eastward from the White Bluffs be correctly interpreted as an original surface of deposition, the Ringold strata probably lie approximately flat along the flanks of the ridges consisting in part of folded Ellensburg strata. Such field data as have been obtained taken with the palaeontologic evidence indicating differences in age, suggest unconformity between the two formations."

During the summer of 1921, Olaf P. Jenkins made an examination of the region about White Bluffs and Hanford to determine the source of the underground water supply for the lands of the Soldier Settlement Project. During this investigation, he noticed what appeared to him to be an angular unconformity in the deposits exposed in the vicinity of White Bluffs and Hanford on the east side of the Columbia River. A closer examination confirmed this impression as is shown by the following:[1]

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[1]Jenkins, Olaf P., Unconformity Between the Ringold and Ellensburg Formations, Washington, Univ. Cal. Publ. in Geol. Sciences, Vol. 15, pp. 45-48, 1924.

"Along the bluffs on the opposite side of the river from the towns, between a point northeast of Hanford and a point southeast of White Bluffs, such an unconformity does really exist in well defined exposures. The lower shales and sandstones dip at a marked angle in a northeastward direction into the bluffs, while the Ringold formation overlies them in horizontal layers. The dip of these lower beds conforms with the general direction of the dip of the basalt beds on the west side of the river, indicating that in the folding of the basalt, these sedimentary beds, which appear to overlie the lava, were folded with it."

Distribution. The Ringold formation consists of sedimentary beds that are typically exposed along the east bank of the Columbia River in the north central part of the area covered by the Pasco quadrangle. This exposure begins about ten miles above Pasco on the east side of the river and continues for more than 25 miles up the river. These bluffs rise about 500 feet above the river and are a very conspicuous topographic feature of this part of Washington. This exposure along the river, on account of its color, is known as the White Bluffs. This formation is not known, positively, to occur west of the Columbia River on either the Pasco or Prosser quadrangles. A few very small exposures of what may be Ringold were found on the bluffs along the western side of Cold Creek Walley. These deposits are so small, however, that it is not possible to represent them on the map. They are composed of a light colored, poorly compacted material, lying on the basalt.

The Ringold formation, at one time probably, covered all of the country between the present White Bluffs and the bluffs along the western side of Cold Creek Valley. The bluffs along the eastern side of the Columbia show an exposure of more than 500 feet in thickness and the bottom of the deposit is not shown. The country between the Columbia River and the bluffs on the west side of Cold Creek Valley is covered largely with wind blown material, largely fine sand, and the formation on which this material rests is entirely concealed from view. It is possible, of course, that the deposits constituting the White Bluffs may be the material on which this aeolian deposit lies. The outlines of this formation, as given on the map, are only approximations as there is no sharp contacts shown between this formation and the wind blown material, which covers a large part of the Pasco and Prosser quadrangles. In all probability, the Ringold formation covers a larger area than simply surface exposures would show. This formation lies on the basalt and not interbedded with it, as is the case with the Ellensburg formation.

Lithologic character. The Ringold formation consists largely of layers of sand somewhat consolidated, gray limestone, sandy clays, volcanic ash, and more or less calcareous material mixed through these materials. Samples were collected by the writer from near the Ringold School and have been studied in the laboratory.

These samples vary more or less in color, but most of them are either light gray or light yellow. In texture, they vary somewhat, but in the main, they are fine grained. The sandy appearing layers are made up partly of quartz sand and partly of volcanic glass. Some of the layers when pulverized and mixed with water are slightly plastic indicating the presence of a considerable amount of clay material, while the material composing other layers has practically no plasticity and is almost all quartz sand and volcanic glass.

Structure. The Ringold formation has a thickness, where exposed in the White Bluffs, of at least 500 feet and as the bottom of the deposit is not exposed, it is not possible to say how much more. The surface of this formation, as it extends to the eastward is very smooth and even being cut in but few places by drainage channels. The very small amount of precipitation is, of course, responsible to a great extent for this lack of stream or drainage courses. Merriam and Buwalda[1] say that the

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[1]Merriam, J. C., and Buwalda, J. P., Age of Strata Referred to the Ellensburg Formation in the White Bluffs of the Columbia River: Univ. Cal. Pub., Bull. of the Dept. of Geol., Vol. 10, pp. 262-263.

"evenness and approximate horizontality of this surface as viewed from the summit of the bluffs, and the apparent absence of hills upon it, suggest immediately that it is a surface of aggradation rather than one of erosion or of river planation. Its striking parallelism, so far as the unaided eye may judge, with the strata in the Ringold in the face of the White Bluffs strengthens this idea."

<u>Conditions at time of deposition.</u> The conditions that existed at the time the material composing the Ringold formation was deposited have not been very thoroughly worked out. The material composing the deposits where examined is very fine grained, but at the same time, most of it settles and drops to the bottom in still water very quickly, which would indicate that there must have been more or less movement of the water.

Merriam and Buwalda[1] give the following with

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[1]Ibid, p. 263.

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reference to the mode of deposition of this material:

"The available data indicate that the Ringold formation was deposited in a basin, the walls of which were essentially the Yakima Range on the west, the Saddle Mountains on the north, and the lava plateaus on the east and south. It is probable that the flat area extending east from the White Bluffs and lying about five hundred feet above the Columbia is to be regarded as an undissected remnant of the aggradational surface developed at the close of the period of deposition, and indicates the elevation to which the basin was filled.

"The Columbia cuts through high ranges like the Saddle Mountains instead of flowing around them, and is an antecedent stream in this part of its course; in pre-Ringold time, its channel therefore lay across the area now occupied by these sediments. The presence of the Columbia in this region at the time the sediments were laid down, and the similarity of the sediments to those transported by the stream at the present day, make it probable that the Columbia deposited this formation. Whether the strata were laid down in a lake formed in the course of the stream, or as flood plained deposits, is not certain, as the limited time spent in the area did not permit an examination of the peripheral areas to determine the presence or absence of such evidence as beaches, bars, and other lacustral features. The muddiness of the Ringold sandstones and the sandiness of the clays are, however, to be contrasted with the cleaner strata usually produced by the efficient classifying agencies of lacustral waters. The apparent scarcity or absence of freshwater molluscan remains, usually quite common in lacustral beds, and the presence at different localities of scattered bones of land mammals, also favor the belief that the deposits are largely of flood-plain origin."

GEOLOGIC STRUCTURE.

General Character of Deformation.

The sheets of lava that cover such a large area in southeastern Washington and extend far to the south and east flowed out as practically horizontal layers. On top of these layers of basalt, in places at least, in south central Washington, were deposited in practically horizontal layers sediments that have been designated the Ellensburg formation. Since the deposition of the sediments, geological forces have produced profound changes in the whole series of rocks so that now they constitute prominent ridges that are separated by wide and comparatively flat valleys. These ridges and valleys, in most cases, have a general east and west direction.

The region under discussion contains two of these high ridges with the Yakima River between them. One of these prominent ridges begins in the northeast corner of the Prosser quadrangle, extends almost east to a little past the center of the quadrangle and then turns almost due southeast and continues in that general direction until it reaches the Columbia River just a little north and east of the southeast corner of the Pasco quadrangle. The more prominent part of the ridge is in its western part and is known as Rattlesnake Hills. The other one of these ridges, the Horse Heaven Hills, begins on the western side of the Prosser quadrangle about ten miles north of its southern border, extends east and a little north, almost to the eastern edge of the quadrangle where it turns almost due southeast and continues until about the eastern edge of the Pasco quadrangle, where it unites with the eastern end of the Rattlesnake Hills.

Character of Folds.

Among the early geologists to study and describe the geology and structure of central Washington was I.C.Russell. He had made several trips through southeastern Oregon, which is a part of the same great basaltic area and where the rocks have been broken and tilted to form great block like ridges having one steep slope and one gentle slope. His work in central Washington was in the nature of a reconnaissance, and from what he saw and his knowledge of the structure of the formations of southeastern Oregon, he considered the ridges of central Washington to have been produced very largely, at least, by faulting and tilting of great earth blocks.[1]

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[1]Russell, I. C. A Reconnaissance in Central Washington; U. S. Geol. Survey, Bull. 108, pp. 28, 38-40.

A detailed study of the Ellensburg quadrangle by George Otis Smith led him, however, to conclude that the structure so common in south central Washington has been produced by folding rather than by faulting.[2]

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[2]Smith, George Otis, U. S. Geol. Survey Geol. Atlas Ellensburg Folio No. 86, p. 4, 1903.

From the statements given, it is evident that two quite different views have been advanced to account for the structural features of central Washington. In many places, the Yakima River has cut across the prominent east and west ridges and in some of these cuts the structure may be observed.

Rattlesnake Hills. The Ahtanum Ridge is a very prominent ridge across which the Yakima River has cut a deep gorge and exposed the structure of the ridge at this point.

Smith[1] makes the following statement with reference to the structure of Ahtanum Ridge:

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[1]Smith, George Otis, U. S. Geol. Survey, Geol. Atlas Ellensburg Folio, No. 86, p. 5, 1903.

"The crest of the ridge is narrow and presents a regular sky line with slight eastward slope. Structurally, Ahtanum Ridge closely resembles the ridges to the north and the broad arch in the basalt is well exposed at Union Gap a mile east of the edge of the quadrangle, where the Yakima has made a steep sided cut a mile in length and 800 feet in depth across the ridge. Five miles farther east, the arch pitches down, so that the basalt disappears beneath the sandstone in a low pass not over 100 feet above Moxee Valley to the north. . . . On the north side of this anticline, near the eastern edge of the quadrangle, the dips are steep and the strata are even over-turned for short distances."

In a number of other places in this same report, Smith speaks of these prominent east and west ridges, so common through the area, as anticlines, leaving no doubt in the mind of the reader as to what he considers their structure.

Rattlesnake Hills are the eastward extension of Ahtanum Ridge and represent the part of this east and west ridge with which we are concerned here. In general appearance, the two parts of this ridge are very similar. The north and northeastern slopes of these hills are steep while the opposite slopes are not so steep. The slopes of these hills are largely covered with soil and only in a few places are the basalt layers exposed.

These basalt layers on the northeastern side of these hills where they occur in Tps. 10 and 11, N., Rs. 25 and 26 E., slope gently to the northeast, while those on the southwest side slope gently to the southwest. Cold Creek Valley, which is parallel with these hills on the northeast, has an altitude above sea level of from about 500 to 560 feet. The summit of these hills is about five and a half miles from this valley and almost parallel with it. The rise from the valley toward the hills is quite uniform for about four miles to an altitude ofabout 1200 feet, after which the rise is much more abrupt to about the 2,000 foot contour, after which the slope becomes very precipitous and continues to the summit at an elevation of from 3500 to 3566 feet. The steep southeastern slope of these hills is so completely covered with decomposed rock material, mostly soil and sand, that it is almost impossible to find any outcrops of the basalt layers. The drainage on this side of the hills is into Cold Creek Valley and is practically at right angles to the crest of the ridge.

The southwest side of Rattlesnake Hills in this locality is much longer than the other and the slope much less steep. The slope on this side conforms to the dip of the layers of basalt. Due north from Prosser, the beds are almost horizontal, the elevation increasong very gradually from about 660 feet at Prosser to 1650 feet eight miles north or at an average of about 124 feet per mile. From this point, the slope is steeper, the rise being about 1100 feet for the next six and a half miles or about 170 feet per mile. From here on the slope is much more abrupt, the rise being about 200 feet in one-half mile or at the rate of 400 feet per mile.

The gulches and drainage channels come cown almost at right angles to the crest of the ridge on the western part of the Prosser quadrangle, but on the eastern side, they are almost parallel with it. The amount of precipitation over this part of Washington is very small and hence there are no permanent streams flowing down either slope of these hills. There are, however, some quite prominent gulches especially on the western side, and in these streams do flow at certain times of the year. In places where these gulches are deep, the basalt layers are exposed to a considerable depth and it is possible to gain some idea of the position of these beds. The crest of the hills is formed of a layer of basalt that does not weather readily and hence the summit is being lowered but slowly.

Russell[1] says that "a little way down the

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[1] Russell, I. C., A Geological Reconnaissance in Central Washington: U. S. Geol. Survey, Bull, 108, p. 41, 1893.

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southwest slope sedimentary beds occur, in which there is at least one interstratified sheet of basalt, having a thickness of from 50 to 75 feet. This interstratified sheet marks a secondary crest on the southwest side of the main crest, owing to the unequal waste of hard and soft beds; but it is not conspicuous for the reason that the disintigrated rock is not removed as fast as it is formed, and hence the character of the rocks beneath is obscured."

Russell's examination of these hills was confined more especially to that part west of the area being discussed here. Careful examinations were made to locate outcrops of sedimentary deposits along the southwestern side of the Rattle Snake Hill, but the only ones found are the ones already mentioned and these are all far down the slope, in fact down in the valley. No evidence whatever was found of any sedimentary deposits near the summit of the ridge. It is barely possible, nevertheless, that sedimentary deposits may occur near the top of the ridge on this side, as there is such a covering of sand and soil on this slope that the underlying formations are concealed, and but few outcrops are found.

On account of the very few exposures of the basalt layers composing the Rattlesnake Hills, it is very difficult to determine positively what the structure is in the southeastern hills. On the northeastern slope the lower beds dip gently to the northeast, and the basalt layers on the southwest side on the lower part of the slope dip gently to the southwest. This would indicate that these beds here may be in the form of an arch or an anticlinal fold. The upper part of the hills on the northeast side are very steep and if this ridge is formed by an anticlinal fold either the two limbs near the crest must have very different dips, the northeast one being very steep while the southwest one is much less steep, or else the northeast slope represents a steep erosion cliff.

Again as has already been said, this steep southeastern slope may represent a fault scarp. After a very careful study in the field of the conditions, in so far as they could be determined, and taking into consideration the work of other geologists who have studied the conditions more or less in this part of Washington, I am inclined to the view that the part of the Rattlesnake hills considered here represent an anticlinal ridge. This conclusion is reached not because of any very large amount of direct evidence as far as the eastern end is concerned, but partly on account of the fact that Ahtanum Ridge, which is the western extension of Rattlesnake Hills, is without doubt anticlinal in structure, the lava sheets dipping very steeply on the north side, while on the south side the dip of the layers is much less abrupt.

Horse Heaven Hills. The Horse Heaven Hills constitute another very prominent east and west ridge on the area under discussion. Like the Rattlesnake Hills, there has been more or less discussion in regard to the structure of this ridge. Its northern slope is very precipitous and the bluff rises abruptly from the Yakima Valley, while the southern slope is a comparatively gentle one. Beginning at the southern edge of the Prosser quadrangle on the section line that passes through the town of Prosser, the altitude is 650 feet above sea level and 12 miles north it is 1527 feet or 877 feet higher. The increase in altitude is fairly uniform for this distance or about 70 feet to the mile. From this point on to the crest of the ridge, a distance of about a mile, the increase is much more rapid, the highest peak of the ridge having an altitude of about 2,000 feet. These hills, like the Rattlesnake Hills, are largely covered with soil and sand and in but few places do the basalt layers outcrop on the surface.

The Horse Heaven Hills, when viewed from the north, appear like a great mountain wall rising precipitously to an altitude of from 1200 to 1500 feet above the valley. The crest line is gently undulating, but on account of the arid climate, it is but slightly notched by stream channels. The surface of the Horse Heaven Plateau, as the southern slope of these hills has been designated, tends to conform to the dip of the basalt layers of which the hills are composed. The surface, however, is almost entirely covered with a layer of what has been designated as Ritzville loam and Ritzville very fine sand[1], varying in thickness from

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[1]Kocher, A.E., and Strahorn, A. T., Soil Survey of Benton County, Washington: U. S. Bureau of Soils, Field Operations (map) 1916.

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a foot or two to as much as 100 feet. The northern slope of the Horse Heaven Hills, especially on the western part of the Prosser quadrangle, is covered largely with the Ritzville loam and sand. The scarcity of outcrops of basalt and the peculiar topographic features of this slope of these hills has been attributed by Russell[2] to landslides.

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[2]Russell, I. C., Geological Reconnaissances in Central Washington: U. S. Geol. Survey, Bull. 108, p. 43, 1893.

"The rocks forming it (Horse Heaven escarpment), like the beds on the precipitous face of Rattlesnake Mountain, are mainly Columbia lava, but the outcrops are largely concealed by landslides. The slides have formed many small, undrained basins on the face of the steep slope, and also irregular lines simulating terraces. A very large portion of the details in this, as well as many other fault scarps formed of broken strata of Columbia lava, are thus accounted for."

The reason why landslides have been so numerous on the steep slopes of Columbia lava, whether formed as fault scarp or as precipices due to the undercutting of streams, is because the strata are in layers, separated in some instances by thin sheets of lapilli or of clay and sand, which weather out and allow large slices of the dense rock resting on them to break off.

The crest line of the Horse Heaven Hills has a layer of basalt which outcrops along a considerable part of the distance across the Prosser quadrangle. This layer dips quite abruptly to the south to begin with and then gradually flattens out and becomes almost horizontal.

Russell[1] in describing the Horse Heaven Plateau says that the northern border "is formed by a great

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[1]Russell, I. C., A Geological Reconnaissance in Central Washington: U. S. Geol. Survey, Bull. 108, p. 43, 1893.

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displacement, having two branches which meet near the town of Kiona, a station on the Northern Pacific Railroad. The shorter of the two fault lines runs southeast from Kiona and dies out at a distance of eight or ten miles; but the longer arm can be traced by its great scarp for over 50 miles toward the southwest. Near Kiona, where the two faults unite, the escarpment is 1600 feet high. The southeastern arm decreases gradually in elevation and finally merges into the plain, but the larger northwestern arm maintains a remarkably straight course, rising toward its western terminus and traversing a region of general elevation bordering the Yakima hydrographic basin on the west."

Later studies of the geology of central Washington have led to the belief that the Horse Heaven Hills are not the result of faulting, but that they represent an anticlinal fold and are similar to many if not all of the east and west ridges in that part of Washington.

Waring[1] makes the following statement

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[1] Waring, Gerald A., Geology and Water Resources of a Portion of South Central Washington: U. S. Geol. Survey, Water-Supply Paper, No. 316, p. 24, 1913.

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on this point:

"The Horse Heaven Plateau, which lies south of the Yakima River, between the Columbia and Yakima, and extends westward to the Cascade Mountains, has the characteristics of a great unsymmetrical anticline, with gentle south and steep northern slope. Along its northern border, its edge is slightly upturned, like the edge of a saucer, and in its northwestern part, the bluffs on its north face are so steep as to suggest faulting. However, although no reliable northward dips were seen, owing largely perhaps to the covering of soil and talus, the structure as a whole appears to be due to sharp folding rather than to faulting. Still in hard, much fractured rock like the basalt of this region, it is often difficult to distinguish between these two types of deformation, and it may be that actual breaking and slipping has taken place along the steeper portion of the scarp in the vicinity of Prosser."

From the above statement, it is plain that while Mr. Waring favors the view that the Horse Heaven Hills represent an unsymmetrical anticlinal fold, yet he admits that they may be the result of faulting. The Horse Heaven Plateau, as already stated, is covered with a fine soil and sand and much of this has been shifted by the wind and finally deposited on the north steep slope of the Horse Heaven Hills, so that the basalt layers on this side of the hills are almost completely concealed from view. This is especially true as far as the area under consideration is concerned.

In beginning the study of the area, it was realized fully, I think, that one of the very important questions to be solved is the one of structure, and this was kept in mind constantly and a careful search made for any evidence that might help in solving this question. Nothing was found, however, that would justify a positive statement on this point as far as the area under consideration is concerned. Farther west, these ridges are known to be a result of folding of the basalt layers of which they are composed, and on account of this, it is rather natural to suppose that these same ridges and depressions where they occur on the area under discussion, have much the same structure.

PHYSIOGRAPHY

Relation of Surface Features to Structure.

The surface features of south central Washington are very closely related to the structure in some cases conforming to it and in others they are independent of it. One of the very striking features is the broad east-west ridges, broad, flat east-west valleys and plains. In the valleys and beneath the plains the layers of basalt tend to be in almost horizontal positions and to conform to the present surface. In some cases, the steep slopes also are determined very largely by the attitude of the beds composing them. In the valleys, the slopes have been made smoother than they originally were by the accumulation and deposition of alluvium. This material has had a tendency to fill up the depressions and make the surface of the floor of the valley comparatively level.

One of the very striking physiographic features in this part of the state is the way the streams cut across the high east and west ridges so common in this part of Washington. One of the most pronounced and best examples of this is the Yakima River, where it cuts through Ahtanum Ridge at Union Gap. Here the stream flows across this ridge in a very narrow steep sided gorge that is about 900 feet deep. North of Union Gap, the stream cuts across other ridges in a similar way. The most prominent of these ridges are Selah and Umpitanum ridges. The above examples are all north and west of the area under discussion here but are of importance in explaining the physiographic features of the Pasco and Prosser quadrangles.

The Columbia River has also cut across several of these east and west ridges in much the same way as the Yakima River. One of the most pronounced of these is where the Columbia cuts the uplift known as Saddle Mountains. At Sentinal Bluffs, where the Columbia cuts across this ridge, it has an altitude of about 2300 feet and the river has an altitude of a little less than 500 feet, which gives a depth for the canyon of a little more than 1800 feet. These mountains, like a number of the other ridges in central Washington, have a very steep northern slope, while the southern one is much more gentle. Another one of these uplifts and the one nearest the area under discussion is where the Columbia River cuts across the extreme eastern end of the Horse Heaven Plateau just a little east of the southeastern corner of the Pasco quadrangle. The stream here flows across an area that has an altitude of about 1450 feet, while the river is about 300 feet above sea level and the canyon about 1150 feet deep. The bluffs here are very precipitous, and the canyon very narrow until an altitude of about 1000 feet or 700 feet above the river is reached, after which the bluffs on the west side are much less precipitous. On the east side, however, they continue to rise very abruptly until an altitude of 1250 feet is reached and then the slope is more gradual.

The Yakima and Columbia Rivers had their courses determined before these transverse ridges existed and as the elevation began, the streams were able to cut into these ridges as fast as they rose and in this way, the streams continued in the same channels and finally cut deep gorges across these ridges. Had the elevation taken place faster than the streams could deepen their channels, then the ridges would have acted as dams across the streams and caused the ponding of the water back of them. The water would gradually rise until finally it would flow over at the lowest point in the ridge which might or might not be the old channel of the stream. In the case of some of these ridges, the streams have not cut across them at the lowest places. This is especially true with reference to Ahtanum Ridge, there being a pass across the ridge about five miles east of Union Gap where the crest is more than 600 feet lower than it is at Union Gap, where the Yakima River cuts across it. In certain cases, the main drainage lines also cross the larger topographic depressions, which is not what is naturally expected.

The above discussion deals very largely with the conditions around the Pasco and Prosser quadrangles, but the same agencies have affected this area also, but some of the results are not so plainly shown here as in other places.

Work of the Streams.

One of the very important functions of a stream consists in removing from the land surface loosened rock material and finally depositing this material to be consolidated into rock again. The material is loosened by various agents such as changes in temperature, frost, wind, and percolating water. This loosened material finally works into the stream and is carried along in suspension or rolled along on the bed of the stream and with this material the stream continues to deepen its gorge until a base level, either permanent or temporary, is reached. The valleys occupied by many streams have been formed by this process and are known as valleys of erosion. Other features that are often developed along a stream, but less prominent than the cutting of the gorge, are those that result from the stream depositing material. The flood plains and terraces so common along some streams are the results of this action.

In many cases, however, streams occupy valleys that have been formed by the folding and warping of the earth's crust in such a way that ridges and depressions are formed and the main streams occupy these depressions and the lateral streams flow down the sides of the ridges. These depressions are known as structural valleys but as time goes on, erosion valleys may be developed.

Relation of stream course to structure. The only streams of importance that affect the region under discussion are the Columbia and Yakima rivers. Each of these streams cuts across ridges and valleys and does not conform to the surface features as they are now. The Yakima River occupies a structural valley in crossing the Prosser quadrangle, but farther west it cuts across structural valleys, leaving parts of them on either side of the stream. That part of the Columbia Valley considered here is the result largely of gradational processes and the stream is largely responsible for its valley. A few small intermittent streams occur and help to drain this area and these practically all occupy erosion channels. Waring[1], in discussing the Horse Heaven

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[1] Waring, G. A., Geology and Water Resources of a Portion of South-Central Washington: U. S. Geol. Survey, Water-Supply Paper, No. 316, p. 24, 1913.

Plateau, says: "There are several minor folds, of which perhaps the most important in the shallow syncline that probably determined the course of Glade Creek, a wide coulee-like drainage channel that is dry during the summer throughout most of its length." Even though the course of this stream may have been determined by a synclinal fold, the gorge along which it flows at present is mainly the work of erosion.

Wind Work.

The area being discussed here has an arid climate and as a result of this the amount of erosion by water at the present time is very small. These conditions, however, have changed more or less from time, and in times past, water may have been more important than it is now. The winds that blow over this area mainly from the south and southwest, are, at least frequently, strong, and are able to transport considerable quantities of fairly coarse material. The soil in the main is dry and but poorly compacted and the surface but poorly protected by a scanty growth of vegetation. On account of the above conditions, the wind has been able to transport much material and be an important factor in modifying the surface of the area.

<u>Sand Dunes</u>. Dune sand, as described by the U. S. Department of Agriculture, Bureau of Soils, [1] "consists

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[1]Kocher, A. E. and Strahorn, A. T., Soil Survey of Benton County, Washington: U. S. Dept. of Agriculture, Field Operations, Bureau of Soils, 1916, p. 66

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of a gray or grayish-brown sand of fine to medium texture extending to depths of many feet without material change." In a number of places over the region under discussion, typical sand dune areas occur. These areas in general are not large and occur mainly along the Columbia River. The sand has been largely blown from the Columbia River and may be piled up into dunes that are from 15 to 40 feet high. These dunes are many of them more or less crescent shaped and have steep north and northeast slopes while the south and southwest slopes are longer and less steep. In some cases, the dunes are connected and form long ridges. These dune sands are shifting more or less all the time and as a result of this, they contain very little growing vegetation. In some cases, considerable depression in the form of basins or troughs occur between the dunes.

The largest sand dune areas on the Pasco and Prosser quadrangles are in sec. 12, T. 9 N., R. 28 E., secs. 5, 6, and 7, T. 9 N., R. 29 E., and T. 11 N., R. 27 E. In addition to the above, there are a number of areas where the surface is covered with sand and in some cases, the topography resembles very closely that of sand dunes. In these cases, however, as a general thing, there is more growing vegetation and the sands are not so readily shifted. There is also more soil mixed with the sand and this also has a tendency to prevent shifting.

ECONOMIC GEOLOGY

GENERAL STATEMENT.

Within the Pasco and Prosser quadrangles no deposits of metaliferous ores have been found and many of the non-metallic substances of economic importance are either absent entirely or but poorly represented.

Building Stone.

The principal stone found over this area is the Yakima basalt. This has been used in a few cases as a material with which to construct buildings. This is widespread over the area, is easy of access, and may be quarried easily. It does not have the property, however, of splitting readily in certain direction and hence, is not so readily worked into definite shaped blocks as some other stone. The Yakima basalt is very dark, almost black in color, and on account of this, it does not present a very pleasing appearance when used in large masses. It is, nevertheless, a very satisfactory material for foundations for buildings and uses of this kind.

In a few places on these quadrangles the Ellensburg formation is known to occur. This material, as a general thing, is so poorly consolidated that it is of no value for building purposes. In one place on the Prosser quadrangle, this stone has been quarried and used in one building in Prosser. The material is volcanic ash, light gray in color, fine-grained, and poorly consolidated. It is not a good grade of building material and if used in anything but an arid climate, it would undoubtedly disintegrate rapidly.

Clay.

Most localities contain deposits of clay from which the common clay wares may be manufactured. The character of the clay will depend very largely upon the kind of rock in the locality. Over most of the area under discussion, the rock as, already stated, is basalt and when this decomposes, it has a tendency to form a very fat plastic clay. Over this area, however, so much foreign material of various kinds is mixed with what little clay there is that it has no value for even the very common grades of clay wares. In fact, very little, if any, clay of commercial value is found on the area.

Road Material.

Sand and Gravel. Deposits of sand and gravel are quite common in various parts of the area under discussion. These occur, not only along the present streams channels, but in many cases considerable distances from them. The sands in some cases are light colored quartz sands, while in others they are black basaltic sands. These sands vary much in texture and grades well suited for road building purposes may be found in many places.

Two fairly distinct classes of gravel occur over the area. In one of these, the pebbles are almost all quartzite and belong to what has been designated the Satsop gravels, while the other is made up largely of basaltic pebbles. The basaltic gravels occur along the present stream courses while the quartzite gravels are distributed promiscuously over the area. In some cases, these latter are found well above the present streams in places at least as much as 1,000 feet. These quartzite gravels have been used in some places for road material and have proven fairly satisfactory. The pebbles vary much in size and the deposits must be screened and only the fine material is used.

The value of a deposit of gravel for road building purposes will depend very largely upon (1) the percentage of pebbles that makes up the mass; (2) the value as road material of the rock fragments composing the pebbles, and (3) the value as a cementing material, under various weather conditions, of the finer material composing the binder or filler.[1]

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[1]Moorefield, Charles H., Earth, Sand-Clay, and Gravel Roads; U. S. Dept. of Agriculture, Bull. No. 463, p. 47, 1917.

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The principal qualities that determine the value of a stone of any kind for road building purposes, are hardness, toughness, and its ability to resist wear. The pebbles, composing these quartzite gravel deposits, are in the main very hard but are not especially tough. These deposits are made up almost entirely of quartzite pebbles, which is a point in their favor as a road material. They are poorly cemented together, however, in the original deposits and do not cement readily in the road. This is due, very largely, to the absence of lime and iron.

Basalt. Basalt is a basic igneous rock, with high specific gravity, and dark gray to black color. It varies more or less in texture but is usually fine grained, the crystals being so small they cannot be seen with the naked eye. The general tendency is for it to break with concholdal fracture into angular pieces with sharp edges and corners. In some cases, the rock is very porous on account of there having been a large amount of steam in the molten mass and this formed bubbles around which the rock solidified. In some cases, it cooled very quickly and took a glassy form and is very brittle. When fine grained and compact basalt is not readily decomposed by the various weathering agencies.

Basalt is usually considered a very good road metal. For this purpose, however, it should be selected with great care and as a general rule only the fine grained varieties are to be recommended. It should be of medium toughness and unweathered. In case the road is for very heavy traffic, the harder tougher varieties may be used, but for ordinary traffic these may not furnish sufficient dust to cause the larger particles to be cemented and bound together so firmly enough so as to prevent the roadway from breaking up.

In many places on the Pasco and Prosser quadrangles the basalt has the properties necessary to make it a good road building material. In the valleys, much of the basalt is covered with a considerable thickness of soil or sand and gravel, which would have to be removed before this rock would be available, and as a result of this, other materials have been used to a considerable extent.

Soil.

Soils are largely the products of rock decay and on account of this fact, have a tendency to differ in different localities, due to variation in kinds of rock. All rocks, when exposed to the atmospheric agencies, tend to undergo changes that finally will break them to pieces. These changes may be either mechanical or chemical, and the products of these changes are the soils. Soils are residual if they remain where formed, and transported if removed from the place where decomposition occurred and deposited in another.

The U. S. Department of Agriculture, Bureau of Soils has mapped and made a study of the soils of Benton and Franklin counties, Washington. Most of the area discussed here lies within these counties. The following discussion of these soils is largely taken from these reports.

According to this study, these soils, based on origin and processes by which the soil materials have been accumulated, are as follows:[1]

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[1]Kocher, A. E. and Strahorn, A. T., Soil Survey of Benton County, Washington: U. S. Dept. of Agriculture, Field Operations of the Bureau of Soils, 1916, p. 20, 1919.

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"(1) Soils derived from loessial or wind-blown material; (2) soils derived from eolian or wind-blown material;

(3) soils derived from old valley-filling material, mainly lake-laid; (4) and soils derived from stream-laid material. The stream-laid soils may be subdivided into soils derived from (a) glacial outwash or river-terrace material, (b) river-flood-plain material, and (c) alluvial-fan material."

Soils derived from loessial material. The loessial or wind borne material is made up of very fine material and is thought, by some at least, to have been derived from a wide range of rocks and minerals and to have been carried aloft by the winds and finally settled down as dust deposits. These soils contain a high silt content and are of uniform structure and texture. In color, they are light-brown to grayish-brown. The amount of weathering of this material after deposition has probably been very small on account of the arid climate. This soil does not have the characteristics of material that has been transported by being blown or rolled along the surface by wind and on this account, it is classed as loess. It shows no signs of lamination and there is no gradation through partially decomposed rock to the unaltered rock beneath, as there would be if this soil had been formed in place by the weathering of the basalt.

The types derived from this loessial deposit occupy the high rolling plateau areas of these quadrangles and are by far the most extensive and important soils from the standpoint of agriculture.

Soils derived from eolian material. This group of soils is much less extensive on these quadrangles than the loessial soils. This type covers a considerable area along the western side of the Columbia River in the northern part of the area under discussion, and another in the southern part of Franklin County around Pasco and to the northeast. These soils have a more or less irregular surface, such as is characteristic of wind blown sand. The ridges and undulating surface is very common.

These soils have come largely from material along the Columbia River and have been transported by being rolled along the surface or by winds blowing across sandy surfaces. It is much less homogenious in character than the material composing the preceding group and sometimes shows evidences of wind stratification. These soils are brown, light-brown, dark-brown, and dark-gray in color.

Soils derived from old sedimentary valley-filling material. Soils of this group are found in various places over the Pasco and Prosser quadrangles.
In general, they are found bordering the lower edge of the loessial soils and consist of light-colored sands and silts laid down in horizontal layers. They accumulated in the main

in bodies of water that existed through this part of Washington in times past.

The surface of these deposits is level or gently sloping and the material has a firm compact structure. The soils of this group are light-brown to grayish-brown with light grayish brown to gray subsoil. These soils are confined to areas that do not have an altitude of more than about 1200 to 1300 feet and are, generally, deepest on the lowest parts of the area and gradually thin out as the elevation increases. In some places, these soils are underlain by a deposit of hard, almost white, calcareous material, usually spoken of as hardpan.

Soils derived from stream-laid material. The soils of this group have a fairly wide distribution over the area under discussion. They occur along the courses of present or former streams. The largest areas of these soils are found along the Columbia and Yakima rivers.

The glacial outwash soils of this group are found mainly in the northwestern part of the Pasco quadrangle with small areas in the northern part of the Prosser quadrangle. These lie at a considerable altitude above the present streams, 100 to 350 feet, and are thought to be of glacial origin, though they might be considered as old river flood-plains occupying high terraces as contrasted with the present low terraces and present flood-plains. These soils consist of basaltic and crystalline rock material that has probably been transported for long distances by glacial streams, the coarse material being well rounded before it was deposited.

The river flood-plains soils of the stream-laid group are confined to the bottom and lower terraces along the Columbia and Yakima rivers and the valleys of the larger intermittent streams, especially Cold Creek. The soils of this group are light-brown to light-yellowish brown or grayish-brown in color, and are found resting on a substratum of either gravel or basalt rock. Crystalline rocks predominate in the gravels underlying these soils but the soils have been formed from a variety of materials.

The alluvial fan deposits of this group of soils are not of wide distribution, as they are a result of the deposition of material carried by the intermittent streams that come from canyons and loose their waters soon after reaching the sandy arid desert plains of the region. The soils are light brown in color with frequently a reddish or rusty brown tint. This series consists very largely of material that is imperfectly assorted and that has been derived from basaltic rocks.

The belief is very general that at least the fine textured soils of central Washington consist very largely of volcanic ash. To obtain evidences on this point, a number of samples of the type having the greatest resemblance to volcanic ash were collected in connection with the soil survey of Benton County by the U. S. Bureau of Soils and studied in the laboratory of the Bureau with the following results:[1]

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[1]Kocher, A. E., Strahorn, A. T., Soil Survey of Benton County, Washington: U. S. Dept. of Agriculture, Field Operations of the Bureau of Soils, 1916, p. 25, 1919.

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"Isotropic material with low refractive index and conchoidal fracture was found in very small quantities in each of the seven samples examined. The general appearance of this material, as well as its inclusions, strongly indicates that it is volcanic glass, but the conclusion that all the soil or any considerable proportion of it is volcanic ash cannot be drawn. The results of the analyses simply indicate that these soils do contain small quantities of volcanic ejectments."

A mineralogical examination was made of samples from four soil types, in connection with the soil survey of Franklin County. These samples represent Ritzville silt loam of the loessial group; the Burke and Sagmore very fine sandy loam of the current laid group; and the Beverly very fine sandy loam of the current-laid group. The results of the examination are shown in the following table:

Mineralogical constituents of four extensive soils.[1]

Ritzville silt loam	Burke very sandy loam	Sagemoor very sandy loam	Beverly very fine sandy loam
Sample No. 551113. Orthoclase, quartz, biotite, hornblende plagioclases, etc., and traces of isotropic material of low refractive index.	Sample No. 551170 Very similar, mineralogically, to the foregoing; the grains, however appear larger. The isotropic material is present only in traces	Sample No. 551195 Similar to the foregoing samples; isotropic material in traces.	Sample No. 5511134. Similar to the foregoing samples; isotropic material slightly more abundant; few spicules present.

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[1]Van Duyne, Cornelius, Agee, J. H., and Ashton, Fred W., Soil Survey of Franklin County, Washington: U. S. Department of Agriculture, Field Operations of the Bureau of Soils, p. 43, 1914.

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Water Resources.

The water supply of any locality consists of the surface water, which occurs in the form of streams, lakes, ponds, and pools, and the underground water or the water that is present in the soil and rocks below the surface. The source of all water in any region is precipitation in the form of either rain or snow. A part of this precipitation, if it is in the form of rain, flows directly down the slopes and back into the ocean and a part of it sinks into the earth's crust and constitutes the ground water. This part that sinks below the surface eventually reaches a depth below which the pores in the rocks and soil are filled with water. This depth, however, varies much in different localities and in the same locality at different times. The upper surface of this zone of saturation, known as the water-table, tends to conform to the surface topography of the area. It is lower in the vicinity of streams than it is on the uplands or divides between the streams. Character of material may also affect the altitude, the surface being higher, where the material is not readily permeable, than it is where the material is very porous.

The amount of precipitation in any region varies more or less and as the position of the water-table depends largely on this, it will vary also. There is a general tendency for the upper part of the ground water to be constantly moving laterally and downward toward the permanent streams. The underground water is being gradually returned to the surface in various ways, and as a result of this, during the dry seasons of the year, when it is not being replenished by rain, the water-table is gradually lowered. The drawing off of this underground supply may continue until the water-table sinks below the beds of streams or bottoms of wells when they become dry. Such streams are known as intermittent streams.

The character of the rock is also an important factor in determing the depth below the surface at which the water table will occur. Fine grained compact material affords but little more space for the water, and therefore much less favorable conditions for the circulation of the water than do the open porous rocks and soils. On account of this the water table, generally, will be much nearer the surface in the more impervious material, as clay or fine grained rocks, than in the more porous beds of sand and gravel. Other things that affect the height of the water-table are vegetation, evaporation, and temperature.

Streams. The only source of surface waters as far as this area is concerned, is the streams and there are only two of these, the Columbia and Yakima, that are of any importance. These are both large streams that rise outside of the area but enter and flow across it. Each has a large flow of water and the Yakima especially furnishes water for irrigating large areas throughout central Washington.

Springs. In many places underground water comes to the surface, either seeping out in small quantities, or in some cases flowing out in large quantities. In case this outflow of underground water is concentrated and takes place through a natural opening in sufficient quantity to cause a distinct current, it constitutes a spring. The concentration of underground water may be brought about by various causes and the amount of this concentration may determine the size and character of the spring. One of the very common causes of springs is for the ground water, as it sinks into the earth, to come in contact with impermeable layers of material, such as clay, and follow this until it comes to the surface. Joint planes and bedding planes in rocks often serve as the guiding paths of large enough quantities of underground water to cause the formation of springs.

Springs are quite common along both the northern and southern slopes of the Rattlesnake Hills. Some of the better known of these springs are Campbell Spring and Bennett Spring on the south slope of these hills. There are a number of other springs along this slope of the Rattlesnake Hills, especially on the western side of the Prosser quadrangle. Most of these springs are between 1,500 and 2,500 feet above sea level. On the northern slope the springs occur more widely distributed than on the southern side as they are found at intervals from east to west across the quadrangle. Most of these springs supply only a small amount of water and flow only during the wet season of the year. The slopes of the Rattlesnake Hills are the only places on these quadrangles where springs of much importance occur.

Wells. Wells are openings in the earth that extend below the water table. The underground water gradually seeps into the opening and rises to the level of the water table. In the case of shallow wells the water table, during the dry season, may sink below the bottom of the well and the well goes dry. The depth to which wells must be sunk in different localities varies on account of a number of things such as climate, topography, and character of rock. In some cases, an impervious subsoil or rock floor may occur only a short distance below the surface and this may prevent the water from sinking very far below the surface and in this case it may be returned to the air by the action of capillarity or through the agency of plants.

The source of the water supply for the rural population is largely underground water and on account of this fact, it becomes of very great importance. This part of Washington has an arid climate. The amount of precipitation will vary somewhat, being slightly greater on the higher altitudes. The records of the U. S. Weather Bureau show a mean annual precipitation at Kennewick of 6.34 inches, with a minimum of 3.58, while the greatest rainfall recorded for any one year was 9.92 inches. The amount of precipitation varies slightly in different parts of the area, being slightly more on the Rattlesnake Hills and Horse Heaven Plateau while in the low interior valleys, it is a little less. Practically all of the precipitation occurs during the winter months.

The area being considered here has to depend on wells almost entirely for its domestic water supply. On account of the arid condition of the district the amount of underground water is not especially large and many of the wells that have been dug or drilled on the Horse Heaven Plateau and the southern slope of the Rattlesnake Hills have furnished only a small amount of water. In many cases the settlers haul water as much as twelve or fifteen miles, tank wagons holding 500 or 600 gallons being used for this purpose. On some of the farms, cisterns have been constructed in which rain and snow are collected during the winter and stored for use during the summer. In case a farmer does not have a well and has no storage facilities such as a cistern or reservoir, he must either buy water from a neighbor who has a well or cistern or go to the river for it.

Over the Horse Heaven Plateau, a considerable number of wells have been drilled and in most cases, more or less water obtained. These wells are usually about six inches in diameter and range in depth from 110 to 1,100 feet. In a number of places very shallow openings, 15 to 35 feet, have been made and small amounts of water obtained. In most cases of this kind, these openings are located in canyons and are where seeps occurred. These openings have simply developed the seeps and formed places in which to collect the water.

The information given here was obtained from the people living on the farms where the wells are located and in many cases they were renters, and were not present when the wells were drilled. Hence, the information, in some cases at least, is not as reliable as it should be.

In sec. 8, T. 8 N., R. 26 E. is what is known as the Hayden well. This has a depth of 485 feet and supplies a very large volume of water. During the summer this well supplies water to a number of the surrounding settlers, as much as 25,000 gallons a day being pumped from it. The well is six inches in diameter and the main supply of water was found near the bottom of the well and is said to have risen 200 feet above where it was first struck. The drill penetrated 50 feet of soil and loose rock, then 250 feet of very hard compact basalt, the balance a softer less compact basalt. The layer in which the water occurs is said to be a porous basalt.

What is known as the County well is due southeast about one and a half miles in sec. 16, T. 8 N., R. 26 E. This well was drilled at the joint expense of the State of Washington and Yakima County before Benton County was formed. The depth of this well was given to me as 835 feet. The drill is said to have passed through twenty or thirty feet of sediment, then 400 feet of basalt, after which a layer of sand was encountered; but the man on the place did not know how thick this is or what the formation is below it. The water stands about 300 feet from the surface. This well furnishes a good supply of water, an average of about 5,000 gallons daily having been pumped from it during the summer.

Another well of considerable importance is the one at Horse Heaven postoffice, sec. 14, T. 7 N., R. 26 E. This well is 350 feet deep and is in basalt the entire distance. The amount of water is not especially large but has been sufficient to supply the farm demand with some to spare. The main flow occurred at a depth of 335 feet.

In sec. 25, T. 7 N., R. 24 E., is a well 400 feet deep, all the way in basalt and has but very little water. Another well has been drilled about six and one-half miles west in sec. 26, T. 7 N., R. 23 E. At this place, about seven feet of soil occurs on the surface and the balance of the distance, 210 feet, is in basalt. This well furnished a good supply of water. North of this well about four miles in sec. 2, T. 7 N., R. 23 E., another well has been drilled to a depth of 480 feet. The entire distance is in basalt. This well is said to furnish a good supply of water. A wind mill is used for pumping.

A number of other wells have been drilled over the Horse Heaven Plateau and so far as studied, conditions appear to be about the same as in those given above. In some cases, a large supply of water is obtained, while in others, practically no water or only a small amount is obtained. There does not appear to be anything so far as the surface is concerned that would indicate the presence or absence of water below the surface.

The area between the Yakima Valley proper and the Rattlesnake Hills has been settled and dry farming is carried on over a considerable part of it. As already stated, springs are quite common along the slopes of the Rattlesnake Hills. These, however, are not sufficient to supply but a small part of the water needed by the settlers, and as a result of this, wells have been drilled on a number of the farms and in some cases, a large amount of water has been obtained.

In section 32, T. 11 N., R. 25 E., is a well 430 feet deep which is said to furnish a large amount of water. The log of the well as given to me is, as follows: Thin layer of soil on top, then about 410 feet of basalt, then 20 feet of clay, and below this a layer of sand. The water rose in the well about 40 feet when the sand layer was struck.

From the information I was able to obtain, it would appear that water may be obtained quite generally over this area, but on account of the character of the rock, it is expensive to drill wells to any great depth and as a result of this, many of the farms in the region are without wells and water is hauled for domestic use.

Water Power. Washington is so situated that it receives a large amount of precipitation in the form of rain or snow, and as a result of this, the state is well supplied with streams, many of which are capable of furnishing a large amount of power. The area under discussion, however, has only two streams of any importance and very little power has been developed along either of these streams. In 1894, a hydraulic power plant was installed at Prosser, mainly for pumping water for irrigation. The power was developed by means of a low dam across the stream at the head of Prosser Falls. Later the lands to be irrigated were furnished water by gravity through the Prosser siphon and the pumping machinery was abandoned, but the plant was continued, the current developed being used for other purposes.

The only other water power developments in this area have been in connection with irrigation, the power developed being used for pumping water. In a number of cases along some of the canals used to carry water for irrigation, the gradient is such that it has been necessary to break it by traps and the power developed in connection with these traps has been used for pumping water on to land that could not be watered by gravity.

Possibilities of Gas and Oil.

Since early in 1913, it has been known that some natural gas occurs on the northeastern slope of the Rattlesnake Hills on the Prosser quadrangle. The Conservative Land Company owned or controlled a considerable tract of land in the above mentioned locality and began early in 1913 to drill a well from which it was hoped to obtain artesian water. This well is in SE¼, SE¼ of section 20, T. 11 N., R. 26 E., and has a depth of 1234 feet. Gas was encountered at a depth of about 700 feet beneath a layer of shale or clay. As drilling continued, three layers of porous basalt, containing some gas, are said to have been penetrated. These layers ranged in thickness from 8 to 21 feet. This well is reported to have 80 feet of 8¼ inch casing and 710 feet of 6½ inch casing. The flow of gas from this well has been variously estimated as being from 70,000 to as high as 500,000 cubic feet a day.

The following has been given as the log of this well:

LOG OF WELL NO. I

Sec. 20, T. 11 N., R. 26 E.

From	To	Thickness	Material.
0	16	16	Surface.
16	126	110	Basalt.
126	166	40	Sandstone, yellow, soft.
166	506	340	Basalt.
506	628	122	Basalt, gray.
628	699	71	Shale or clay, greenish blue
699	719	20	Basalt, porous; and gas.
719	744	25	Basalt, porous; pressure 5½ lbs. volume 500,000 cu. ft. per day, from 3" well; cased off and drilling continued.
744	814	70	Basalt, hard.
814	827	13	Basalt, porous; more gas.
827	840	13	Basalt, hard.
840	848	8	Basalt, porous; more gas.
848	894	46	Basalt, hard.
894	915	21	Basalt, porous; more gas; now altogether 16700 cu. ft. daily.
915	1234	319	Basalt, alternating hard and soft; no further gas.

The second well drilled in this district is in the $NW\frac{1}{4}$, $SW\frac{1}{4}$ of sec. 21, T. 11 N., R. 21 E., and has a total depth of 800 feet. The drilling of this well began in 1917 and gas was struck at a depth of 700 feet in January, 1918. This was formerly known as the C. T. Wrightsman well, but is now known as No. 2 of the Walla Walla Oil, Gas and Pipe Line Companies' wells. The flow of gas from this well is said to be much larger than that from Well No. 1, and has been variously stated, based on measurements, at from 2,600,000 to 3,000,000 cubic feet a day. The gas from this well has been used as fuel for drilling other wells in this locality.

The following, given as the log of this well is thought to be fairly reliable, except as regards the ten feet of granite, which is thought to have reference to arkosic material:

LOG OF WELL NO. II.

Sec. 21, T. 11 N., R. 26 E.

From	To	Thickness	Material
0	16	16	Surface.
16	55	39	Gravel and boulders.
55	100	45	Basalt.
100	128	28	Sand, loose, white.
128	168	40	Basalt,
168	285	117	Basalt, blue.
285	310	25	Broken formation.
310	390	80	Basalt, blue.
390	420	30	Broken formation, water.
420	520	100	Basalt, blue.
520	530	10	Granite.
530	610	80	Basalt.
610	700	90	Slate, green.
700	730	30	Basalt, gas.
730	800	70	Basalt, hard, gray. Bottom.

A sample of the gas was taken from this well during the field work in the summer of 1924, and sent to the U. S. Bureau of Mines for analysis and the following results were obtained:

ANALYSIS OF GAS FROM WELL NO. 2
BENTON COUNTY, WASHINGTON, GAS FIELD.

Carbon dioxide	0.48%
Oxygen	5.35
Methane	71.12
Ethane	0.00
Nitrogen	23.05

S. C. Lind, Chief Chemist
U. S. Bureau of Mines.

In the SE¼, SE¼ of sec. 20, T. 11 N., R. 26 E., due southeast of Well No. 1, is gas well No. 5. This was drilled for the Walla Walla Oil, Gas and Pipe Line Company, and has a total depth of 780 feet. According to Mr. H. D. James, the first 12 feet consisted of volcanic ash and clay; then 125 feet of gravel and loose basaltic boulders, the balance of the distance being in basalt which varies more or less in texture and appearance. The open flow capacity is estimated at about 1,300,000 cubic feet per day.

Well No. 3, controlled by the Walla Walla Oil, Gas and Pipe Line Company, is in the NE¼, NE¼, Sec. 19, T. 11 N., R. 26 E. and has a total depth of 1507 feet. Conditions here, from available information, appear to be similar to those in the other wells in this immediate locality. Gas is said to have been encountered at a depth of 782 feet but the well was plugged in shooting. This is about 80 feet below where the gas is said to occur in the other gas wells and is probably an error in some of the measurements.

The Walla Walla Oil, Gas and Pipe Line Company drilled well No. 4 in the NE¼, NE¼ of sec. 21, T. 11 N., R. 26 E., and has a depth of 640 feet. According to Mr. James, clay was encountered at 640 feet and the well has not yet been drilled through it. Water is said to have been found at a depth of 300 feet. This well has not reached the gas horizon and no reason is given for discontinuing drilling.

In the SE¼, SE¼, sec. 20, T. 11 N., R. 26 E., the Walla Walla Oil, Gas and Pipe Line Company has drilled another well designated as No. 5. It is said that the materials passed through in drilling this well were, first 12 feet of volcanic ash and clay, then 125 feet of gravel and loose basaltic boulders, and below this, basalt. This well has a depth of 780 feet and is reported to have an open flow of 1,300,000 cubic feet of gas per day.

This same company has drilled another well, designated as No. 6 in the NE¼, SE¼, sec. 18, T. 11 N., R. 26 E. to a depth of 205 feet and then work was stopped. Mr. James states, however, that this well has not been abandoned but that it is the intention to drill it deeper.

In the summer of 1924, the Walla Walla Oil, Gas and Pipe Line Company was drilling well No. 6A, located in the NE¼ of sec. 29, T. 11 N., R. 26 E., and had reached a depth of about 300 feet.

The deepest well drilled in this district is the one drilled by the Seattle-Inland Oil Company and is located in the NW¼, NW¼, sec. 27, T. 11 N., R. 26 E. This is No. 8 on the accompanying map. This well was started late in 1920 and work was discontinued in May, 1921. The ordinary churn drill was used until a depth of about 295 feet had been reached and for the balance of the distance, a core drill was used. The total depth is reported as 2211 feet. Gas was encountered, as shown by the following log, which was furnished me by Mr. M. E. Hay, below a layer of what was designated as a blue volcanic ash shale at a depth of 699 feet. Between 699 and 916 feet in depth, three other layers containing gas were passed through. These layers are given as 11, 10 and 21 feet in thickness. The estimated capacity of this well was given as about 400,000 cubic feet per day. This well is No. 1 of the Seattle-Inland Oil Company and No. 7 as shown on Plate I.

LOG OF WELL NO. I
Seattle Inland Oil Company.
Sec. 27, T. 11 N., R. 26 E.

From	To	Thickness	Material
0	295		Churn drill hole.
295	299	4	Blue basalt hard and solid.
299	311	12	Blue basalt porous.
311	383	72	Blue basalt solid.
383	392	9	Blue basalt shattered.
392	394	2	Gray sand rock.
394	415	21	Blue basalt broken and porous.
415	528	113	Black basalt hard and shattered.
528	624	96	Gray basalt hard and solid.
624	628	4	Gray basalt broken no water return.
628	687	59	Shale or blue volcanic ash or blue mud.
687	690	3	White sand.
690	699	9	Blue volcanic ash shale.
699	720	21	Black porous basalt, puffs of gas 5½ lbs. pressure.
720	739	19	Black porous basalt hard stringer.

From	To	Thickness	Material
739	740	1	Cavity, higher gas pressure.
740	745	5	Black porous basalt.
745	753	8	Gray basalt solid.
753	757	4	Gray basalt broken.
757	793	36	Gray basalt solid.
793	794	1	Gray basalt broken.
794	806	12	Gray basalt solid.
806	808	2	Volcanic Ash or shale.
808	819	11	Black porous basalt, gas 2 lb. pressure.
819	824	5	Gray basalt solid.
824	828	4	Black porous basalt.
828	831	3	Gray basalt solid.
831	841	10	Gray basalt broken, 2 lb. pressure.
841	860	19	Gray porous basalt.
860	893	33	Gray basalt solid.
893	895	2	Volcanic ash.
895	916	21	Black porous basalt, $5\frac{1}{2}$ lbs. pressure.
916	1067	151	Gray basalt solid.
1067	1072	5	Black porous basalt with shale stringers.
1072	1090	18	Soft black porous basalt.
1090	1141	51	Soft gray basalt shale stringers.
1141	1162	21	Hard gray basalt solid.
1162	1172	10	Soft black porous basalt.
1172	1180	8	Gray porous basalt hard stringers.
1180	1215	35	Gray basalt hard and solid.
1215	1220	5	Red porous basalt soft.
1220	1224	4	Black porous basalt soft.
1224	1271	47	Hard gray basalt.
1271	1280	9	Black porous basalt.
1280	1335	55	Hard gray basalt.
1335	1360	18	Gray porous basalt.
1360	1407	47	Gray basalt.
1407	1440	23	Gray porous basalt.
1440	1516	76	Gray basalt.
1516	1582	66	Gray basalt slightly porous
1582	1625	47	Gray basalt.
1625	1629	4	Soft gray basalt and shale.
1629	1635	6	Black porous basalt.
1635	1647	12	Conglomerate, shale and porous shale.
1647	1764	117	Blue gray basalt.
1764	1768	4	Soft porous basalt.
1768	1780	12	Green shale.
1780	1796	16	Gray porous basalt.
1796	1856	60	Gray basalt.
1856	1867	11	Gumbo.
1867	1910	43	Gray porous basalt.
1910	1977	61	Gray basalt.
1977	2041	64	Gray porous basalt.
2041	2055	14	Gray basalt.
2055	2057	2	Black basalt.
2057	2077	20	Gray basalt.
2077	2084	7	Black basalt.

From	To	Thickness	Material
2084	2106	22	Gray basalt.
2106	2143	27	Black basalt.
2143	2165	22	Soft gray basalt.
2165	2212	47	Gray porous basalt.

Well No. 8, as shown on the map in sec. 27, T. 11 N., R. 26 E., was drilled by the Conservative Oil and Gas Company. The total depth of this well is reported to be 806. It is stated by the driller that clay was encountered at about 600 feet below the surface. A water bearing stratum was passed through at a depth of about 450 feet, the water rising to the surface, according to statements. It is said more water was encountered just below the layer of clay.

Well No. 9 in the NW¼, NW¼, secs. 28, T. 11 N., R. 26 E., was drilled for Anderson and North. Very little information was obtainable in regard to this well but it appears that work was stopped before any great depth had been reached.

The Colfax Oil and Gas Company had a well, No. 10 on the map, drilled in the SW¼, SW¼, sec. 16, T. 11 N., R. 26 E. to a depth of 720 feet. The well is reported to have been abandoned after this depth had been reached.

Well No. 11 in the SW¼, NW¼, sec. 5, T. 11 N., R. 25 E., was drilled for the Spokane-Benton Gas Company. Very little information could be obtained in regard to this well. It is reported, however, that it was drilled to at least 1000 feet.

Well No. 12, drilled for the Prosser-Grandview Gas Company is in the SW¼, NW¼, sec. 5, T. 11 N., R. 26 E., and is on the southwestern slope of the Rattlesnake Hills, while those described above are on the northeastern. This well, according to the available information, was first begun in 1912 in search of water. It was drilled to a depth of 482 feet with the ordinary churn drill, after which a diamond drill was used and the well continued to a depth of 825 feet.

The following is the log of this well as given by Lynch Brothers, who drilled the well from 482 feet to the bottom:

Log of Well near Prosser, Washington.

Sec. 32, T. 10 N., R. 25 E.

From	To	Thickness	Material
0	482	482	Old well drilled with casing in.
482	554	72	Basalt, gray.
554	558	4	Burned shale (Vol. Ash).
558	560	2	Basalt, gray mixed with burned shale.
560	572	12	Conglomerate (burned shale gray, red and yellow.)
572	624	52	Lime shale or conglomerate (Vol. ash)
624	629	5	Lime shale, very sticky.
629	638	9	Lime shale, sandy.
638	641	3	Sand (soft).
641	642	1	Shale, brown (Where shale is used,
642	644	2	Shale, green. (really means Volcanic (ash in gumbo form).
644	647	3	Basalt, porous.
647	658	11	Basalt, porous.
658	661	3	Semi-porous basalt.
661	736	75	Basalt, gray.
736	746	10	Basalt, porous.
746	748	2	Cavity.
748	754	6	Basalt, porous, gray.
754	756	2	Black Vol. ash.
756	780	24	Basalt, slightly porous.
780	804	24	Basalt, solid gray.
804	814	10	Basalt, solid gray.
814	817	3	Shale, black, crumbly (vol. ash)
817	825	8	Basalt, gray, porous.

Lynch Brothers considered the cavity encountered at a depth of 748 feet the same as the cavity on the east side of the Rattlesnake Hills where the gas is encountered. No gas was found in this cavity, however.

In the case of all the productive gas wells in this district, the gas is encountered at a depth of from 700 to 800 feet. In these wells, and in others drilled near them, the material just above the layer in which the gas occurs is given as shale, slate, volcanic ash, or clay. This material is said to very more or less in color, blue or greenish blue predominating. The thickness of this overlying material is usually about 70 to 1000 feet.

__Gas Pressure__. The pressure of natural gas in various gas fields is very different as is also the pressure in the different wells in the same field. This variation, and in fact, the cause of pressure is not very well understood. The pressure in many wells is as much as 700 to 800 pounds per square inch, while in some cases it reaches a pressure of from 1400 to 1800 pounds to the square inch. In most cases, there appears to be a relation between pressure and depth, the pressure increasing as the depth increases. In wells where the gas occurs at a depth of from 600 to 1,000 feet, the initial pressure is usually from 300 to 400 pounds per square inch. In some few cases, the gas from much deeper wells is known to to have had much lower initial pressure. A well was drilled at Cleveland, Ohio, to a depth of 4,577 feet and a small flow of gas obtained. The highest initial gas pressure observed in this well was 37 pounds per square inch.[1]

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[1] Van Horn, F. R., Reservoir Gas and Oil in the Vicinity of Cleveland, Ohio; Transactions, Am. Inst. of Mining Engineers, vol. 56, p. 839, 1917.

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The gas from all the gas wells in Benton County has a very low pressure. Measurements of the pressure have been made from time to time and the results have varied more or less but in no case so far as I could learn, has the closed pressure been given at more than 5½ pounds per square inch, while in many cases, it has been reported, as just a little above three pounds per square inch. This of course is very low and is one of the striking things about the occurrence of this gas.

<u>Gas associated with oil</u>. One of the very important questions that has been raised in connection with the occurrence of this gas has been the possibility of its being associated with petroleum. In case a gas contains ethane (C_2H_6), propane (C_3H_8), or butane (C_4H_{10}), it is generally considered as a favorable indication that it is associated with petroleum on account of the fact that these substances are found in many gases that are known to be associated with oil. The presence of these substances, however, does not prove conclusively that

the gas is associated with oil. Cases are on record where gases have been analysed and found to contain one or more of the hydrocarbon gases heavier than methane (CH_4) and yet no oil is present. On the other hand, cases are known where a certain part of a field yields both gas and oil from the same sand, and when analyzed, the gas showed the presence of no hydrocarbon except methane (CH_4).

The following table gives the composition of a few of the natural gases from well known oil fields. These gases, with the exception of number 2 each contains a considerable amount of the heavy hydrocarbon ethane (C_2H_6) and this simply shows that in most cases where the gas is associated with petroleum, it contains more or less of the heavy hydrocarbons. Number 2, however, is also from a producing oil field and from a sand in close proximity to a sand producing oil, yet it contains only methane (CH_4) as the combustible constituent:

Analysis of Samples of Natural Gas.
From U. S. Bureau of Mines, Bull. 88, pages 21-22.

	1	2	3	4	5	6
Carbon Dioxide (CO_2)	.0	1.1	2.4	.0	.0	.1
Oxygen (O_2)	.0	.0	.0	.0	.0	.0
Methane (CH_4)	80.5	94.3	64.1	6.6	80.4	50.6
Nitrogen (N_2)	1.7	4.6	1.8	2.3	1.5	38.4
Ethane (C_2H_6)	17.8	.0	31.7	91.1	18.1	10.9

1. Clarion County, Pa., near Mill Creek.
2. Osage County, Okla., North end 8f Hogshooter field.
3. Creek County, Okla., near Kiefer.
4. Crawford County, Pa., near Titusville.
5. Franklin County, Ohio, near Columbus.
6. Dallas County, Texas, near Dallas.

<u>Conclusion</u>. After a thorough study of the field conditions and considering all the data available, I cannot help but conclude that there is little to warrant the expectation of developing any large quantity of natural gas on either the Pasco or Prosser quadrangles. By natural gas I mean gas formed by the decomposition of plant and animal remains. Gas was first discovered on the northern slope of the Rattlesnake Hills in 1913. More or less drilling has been going on there ever since, and 14 wells in all have been drilled. Some of these are very shallow and have not reached the layer in which the gas usually occurs, while others have gone much below this layer. One of these wells was drilled to a depth of 2212 feet and was not through the basalt. No additional gas was obtained below 916 feet.

Oil seeps are reported to occur in this locality but I failed to find any surface indications of either gas or oil. The analysis of this gas given on a preceding page shows only methane (CH_4), none of the heavier hydrocarbons being present. Methane is marsh gas, and, as already stated, while it does not prove anything definitely, it is an indication that this gas is probably not associated with petroleum.

The extremely low pressure which this gas has is another discouraging thing about it. In all the important gas fields, so far as I have been able to determine, the initial pressure has been much greater than it is in these wells. The general tendency is for gas pressure to increase as depth below the surface, at which the gas occurs, increases.

This, however, is not a fixed rule and there are exceptions to it. Even in the case of very shallow wells, the pressure is much more than it is in these wells.

The structure of the Rattlesnake Hills, while not positively known, is apparently favorable for the occurrence of gas. The beds seem to have a slight dip in opposite directions from about the crest of the ridge. This gives the effect of an anticlinal fold which would favor the accumulation of gas.

The geology in this field is not favorable for gas or oil. In no case so far has a gas or oil field of importance been developed in igneous formations. The Rattlesnake Hills are composed of layers of basalt with perhaps occasional thin deposits of other materials occurring between them. The basalt varies more or less in texture, in some places having a large amount of pore space, while in others, it is very compact. The thickness of the basalt in the region is not known as the deepest well has not passed through it. Southeast, about 35 miles from the wells on Rattlesnake Hills, at Attalia, a well has been drilled to a depth of about 3,200 feet and is said to be through the basalt. If this report is true, it gives the thickness of the basalt in that locality. The indications are that the basalt rests on igneous or metamorphic rocks so that the conditions are not very favorable for gas or oil, so far as the character of the rock is concerned, even below the basalt. All the gas found in this field occurs in layers of basalt that have an open porous structure.