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OIL AND GAS POSSIBILITIES

OF

Western Whatcom County

BY

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INTRODUCTION

This investigation was made to secure information on the geology of a part of western Whatcom County, with particular reference to the possible occurrence of oil and gas. A study was made of the gas that has already been developed, and field work was done to determine favorable locations for further gas tests. The work was commenced early in 1934, when a field party gathered data on the Pleistocene deposits covering much of the area and also began the study of the underlying formations. The investigation was continued later in the season by a detailed survey of the rocks occurring in the area.

Many of those who have been largely responsible for bringing the development of gas in this region to its present stage assisted in supplying the information on early drilling. They also gave logs of more recent exploration and details that were very useful in the study being made.

The writer wishes to acknowledge the helpful cooperation of Mr. H. O. Griffin of the Whatcom Natural Gas Company, Mr. C. F. Livermore, well driller, Mr. William Newton, Mr. John Pierce, Mr. Cecil A. Morse, Mr. Charles Larrabee, Mr. E. H. Miller, Mr. H. D. McEldowney, and the many others who contributed time and information.

W. G. Bennett, of the Division of Geology, was in charge of the earlier studies and assisted in the first part of the later work. His interest and cooperation were greatly appreciated.

The writer was assisted throughout the field work by S. N. Twiss, of the Division of Geology, who gave very efficient help in searching for outcrops and collecting data on their field relations.

AREA INVESTIGATED

A preliminary reconnaissance of western Whatcom County showed that the initial studies as to its oil and gas possibilities might well be confined to the area west of the high hills of Sumas (Nooksack) and Anderson mountains. The northern and western boundaries are, of course, fixed; the southern boundary is marked by the discontinuity in that direction of rocks which could be a source of oil or gas. The eastern boundary was arbitrarily chosen. If production should be found in the more favorable areas to the west, it may be advisable to continue the study for some distance to the east; but it is not thought that the possibilities there warrant additional work until more definite stratigraphic data have been gained in the area outlined.

PREVIOUS STUDIES

The occurrence of coal in western Whatcom County, together with a good grade of building sandstone, has led to a considerable amount of geologic investigation of the region. Most of this work was confined to specific resources and to small areas, but some was broader in scope.

The most complete account of the general geology has been given by Jenkins[1] as a result of his study of the coal of the region. Much of the information given in that report has a direct bearing on the conditions related to oil and gas occurrence. The present work leaves his structural interpretations essentially unchanged; but it has been possible to acquire more detail on structure and delineate some features more definitely by study of added exposures.

The Pleistocene formation overlying the coal measures are mentioned by Bretz,[2] who gives some details on the Glacial history of the region in connection with an investigation of the Puget Sound region. Other mention has been made of the area as a whole or of specific parts, and a partial bibliography is given by Jenkins in the report just cited. Attention should be directed to Landes'[3] report on the coal deposits; Shedd's[4] report on the Chuckanut Bay sandstone; McLellan's[5] brief account of the rocks of the region and their occurrence on Lummi Island in which he applies the name "Chuckanut" to the formation as a whole; and Crickmay's[6] study of lithology and structure of the northeastern part of the area.

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[1]Jenkins, Olaf P., Geological investigation of the coal fields of western Whatcom County Washington: Wash. Div. Geol. Bull. 28, 1923.

[2]Bretz, J H., Glaciation of the Puget Sound region: Wash. Geol. Survey, Bull. 8, 1913.

[3]Landes, Henry, The coal deposits of Washington: Wash. Geol. Survey Ann. Rept. for 1901, Vol. 1, pp. 263-65.

[4]Shedd, Solon, Building and ornamental stones of Washington: Wash. Geol. Survey Ann. Rept. for 1902, Vol. 2, pp. 62-65.

[5]McLellan, R. D., Geology of the San Juan Islands: University of Washington publications in geology, Vol. 2, 1917.

[6]Crickmay, C. H., The structural connection between the Coast Range of British Columbia and the Cascade Range of Washington: The Geological Magazine, Vol. LXVII, pp. 482-491, 1930.

TOPOGRAPHY AND GEOGRAPHY

This area has a most diverse topography. A person unfamiliar with it may best understand what is involved by a study of the Samish Lake, Blaine, and Sumas topographic sheets of the United States Geological Survey.

The southeastern third of the region has the high relief given by mountain masses extending into Skagit County. Chuckanut Mountain lies south of Bellingham and rises abruptly from Samish and Chuckanut bays to 2,385 feet a mile south of the county line. The valleys of Samish Lake and Chuckanut Creek separate this mountain from the still higher Lookout Mountain to the northeast, where an elevation of 2,715 feet is reached. Lake Whatcom, 12 miles long and about a mile wide, lies northeast of Lookout Mountain and separates it from the higher massive Anderson Mountain, which extends along the lower east side of the area. The valley of Nooksack River lies between Anderson and Sumas (Nooksack) Mountain, the latter continuing northward almost to the international boundary.

Squalicum Mountain, an outlier of Anderson Mountain, lying a few miles northeast of Bellingham, is a rounded, more or less circular mass, rising 1,525 feet above sea level. King Mountain is a 521-foot hill just north of Bellingham.

The mountains are rugged and are deeply incised on their flanks by small swift streams along which resistant strata cause precipitous cliffs. Virgin timber and a tangled mass of second growth and windfalls cover the ground, while devil's club, alder, vine maple, and salmonberry bushes make travel very slow and laborious. Search for outcrops presents a real problem, as there are practically no roads or trails throughout most of this part.

The separating valleys and lake shores are less than 550 feet above sea level. Good roads follow these around the mountains, excavations along them aiding greatly in geologic study.

A totally different topography marks the north and northwest two-thirds of the area. It is a region of generally low relief with rolling hills and broad flats over which Nooksack River meanders. Two small areas, one southeast of Birch Bay and another east of Blaine have greater relief, rising to elevations of 354 and 452 feet, respectively. The low region is very fertile and has been extensively cultivated. This northwest part has been an important farming district for years and supports many small towns. Excellent roads make it possible to reach almost any part of this region.

Bellingham is centrally located in the area covered by this report. It is the fourth largest city in Washington, having a population of 30,823. The population of Whatcom County is given in the 1930 census as 59,128. Of this number, probably 95 per cent live in the area under discussion.

The climate of western Whatcom County is mild, the mean temperatures ranging from 61.6° in summer to 38.9° in winter. The annual precipitation is about 31 inches, chiefly in the winter months.

DESCRIPTIVE GEOLOGY

STRATIGRAPHY

Clays, sands, and gravels, with unassorted glacial tills make up most of the surface deposits in the area. They are mainly Pleistocene, although Recent alluvial deposits cover the earlier materials in some places. Underlying the Pleistocene beds, and cropping out in areas of greater relief are shales, sandstones, and conglomerates which comprise the great thickness of early Tertiary (Eocene) rocks of the region. These last have been economically important for many years on account of the coal, building stone, and ceramic materials occurring in them. They, in turn, rest unconformably on a great series of schistose rocks that outcrop in places where erosion has been very active.

PRE-TERTIARY ROCKS

The oldest rocks exposed in this region are the schists immediately underlying the coal series. They outcrop for long distances south of the area in Skagit County and may be seen along the coast in road cuts bordering Chuckanut Drive of the Pacific Highway. Other exposures are on the Samish Lake Highway near the southeast shore of that lake, and in the vicinity of Sumas in the northeast part of the area.

They are metamorphic rocks which include chlorite, talc, and graphite schists and also some basic igneous rocks which have been altered to greenstone and serpentine. The predominant rock is chlorite schist, a pearly to dark gray contorted, crumpled, splintery fracturing mass cut by innumerable veinlets of white quartz. Where the schist is graphitic it is almost black. The quartz veinlets are characteristic of this formation and occur as pinching and swelling lenses between the schist folia and also in fractures at various angles to the schistosity planes.

These schists are the highly altered equivalent of a sedimentary series of unknown extent. They are probably continuations of the schists occurring east of this area in Vedder Mountain, Sumas Mountain, the south part of Anderson Mountain, and on the upper reaches of the several forks of Nooksack River. Some of these occurrences have been studied by Crickmay[1] and assigned by him to Triassic and to undivided Mesozoic age.

Near the north and along the northeast side of Lummi Island the older rocks are also exposed unconformably underlying the Chuckanut formation. Here they are described by McLellan[2] as altered dikes of porphyrite-basalt and basic andesite correlated with the Leach River group of Vancouver Island.

The limestones of the Kendall vicinity, probably of Carboniferous age, do not occur and have no counterpart in this area, although the series in which they occur may be in fault contact at one place[3] with the eastern extension of the Chuckanut formation.

CHUCKANUT FORMATION

The Chuckanut formation is made up of a great thickness of conglomerates, sandstones, and shales which unconformably overlie the schists of the region. The actual contact is exposed in several places, for example, on Samish Lake Highway just west of the east line of sec. 26, T. 37 N., R. 2 E.; on Saar Creek above the old Denny-Renton clay mine near the center of the S. ½ sec. 12, T. 40 N., R. 4 E.; near the north end of Lummi Island, as mentioned above; and, the best exposure seen, in the ravine of an unmapped creek about one-half mile west of Reed Lake in the SE. ¼ SE. ¼, sec. 30, T. 37 N., R. 4 E.

The schists are eroded more easily than the resistant sandstones of the overlying formation; hence the approximate position of the contact can usually be determined from the topography, where the actual contact cannot be seen. The old schist surface was not only very uneven but probably had considerable relief. This accounts for the variation in angle between the planes of the bedding of the Chuckanut rocks and of the contact, and it may account, in part, for the different thicknesses of the Chuckanut shown in stratigraphic sections measured in different places.

[1]Crickmay, C. H., op. cit., pp. 489-490 and accompanying geological map.
[2]McLellan, R. D., op. cit., p. 99.
[3]Crickmay, C. H., op. cit., Pl. to face p. 488.

Basal Conglomerate and Associated Beds.—The contact exposure west of Reed Lake shows the characteristics of the basal Chuckanut formation in the south part of the area. Here, a foliated, highly contorted chlorite schist, with abundant quartz veinlets, is overlain by 3 feet of moderately fine, soft greenish-gray sandstone made up of schist fragments. This sandstone is probably a local member formed by the cementation and induration of fine material of the old land surface. It is overlain by a foot of conglomerate made up of an irregular mixture of blocks and large angular slabs of schist in a ground mass of similar material. Above the coarse conglomerate lies 72 feet of the usual basal conglomerate composed almost entirely of angular and subangular fragments of quartz, an inch or so across, in a finer aggregate of quartz and schist grains. Finer sandy phases occur as lenses and layers in this rock, and these contain abundant carbonized fragments of leaves and grasses.

This thick member has a strikingly white color, from the great amount of quartz. It is very well cemented and forms a resistant bed over which the creek cascades. Sandstones, sandy shales, and some soft, unctuous clay shales lie above the conglomerate and make up an alternating sequence to the top of the mountain.

The basal conglomerate exposed on Saar Creek has a thickness of 80 feet and is a mixture of igneous and metamorphic pebbles with some composed of quartz. They average from 1 to 2 inches in diameter, although boulders up to 18 inches in diameter occur at the contact with the underlying slaty schist. The overlying beds at this place are more shaly than is usual, and the character of the shales is markedly different from that seen elsewhere in the formation. This is probably due to a local difference in the types of rocks whose erosion produced these beds. Some of these shales are valuable for making firebrick, buff-burning face brick, and various ceramic products, and they were mined and used by the old Denny-Renton Clay Company of Seattle.

Conglomerate.—The occurrence of basal conglomerate has been noted above. Other conglomerates occur in the upper part of the Chuckanut formation. The most accessible outcrop, as well as one of the most interesting, is exposed in a large cut on the highway west of Lake Whatcom at Lake Louise. The base of this member is concealed, but a stratigraphic thickness of 80 feet is exposed. It is made up of grit, pebbles, and cobbles in an arkosic sand matrix. The average diameter of the pebbles is one to two inches. They are well rounded, show no particular orientation within the bedding, and are composed of various types of igneous and metamorphic rocks of a generally dark color. The cementation is not strong and is probably ferruginous, as the fresh material is a bluish gray and the weathered portions slightly brownish yellow. Very irregular, contorted sandstone masses occur in the conglomerate as well as a few beds that are evenly bedded.

A similar conglomerate, probably the same member, is exposed on Lookout Mountain in the SW. ¼ sec. 12, near the center of the W. ½ sec. 12, and in the SE. ¼ sec. 11, T. 37 N., R. 3 E. Other occurrences are on Chuckanut Drive near old Wildcat Cove Station, on Chuckanut Mountain near the center of the east line, sec. 31, T. 37 N., R. 2 E., and a possible occurrence is near the center of sec. 23, T. 37 N., R. 3 E., above Samish Lake.

A monotonous repetition of similar beds marks the whole Chuckanut formation, but this Lake Louise conglomerate member seems to have no counterpart elsewhere in the series, and probably can be used as a horizon marker in the formation.

Other, generally fine, conglomerates outcrop in the vicinity of Manley's Camp, in street cuts in Bellingham, on Squalicum Mountain, on King Mountain, and at many other places. They are interbedded with sandstone and may grade laterally into grit and coarse sandstone. Cross-bedding is common but usually on a rather small scale. The pebbles are generally rounded, under an inch in diameter, and are of igneous and metamorphic rocks. They are only moderately well cemented, so the rock breaks down rather easily, yet it and the conglomeratic sandstone are somewhat more resistant than the associated rocks, and so form prominent outcrops.

Sandstone.—Sandstone forms the major part of the Chuckanut formation, as may be seen in the measured sections, (pp. 15 to 23). It shows all gradations from very fine grain to very coarse. It may be so massive that no bedding planes can be distinguished in members 25 feet or more thick; or it may be so platy and thin bedded that slabs of one-quarter inch thickness can be separated from one another. Cross-bedding is very pronounced in some of the exposures but is hardly a large-scale feature throughout. It occurs on a small scale for distances of one to a few feet in individual beds in most outcrops. Lateral variations in texture occur along the strike of some beds that are exposed for several hundred feet. In one such instance a gradual change takes place from medium-grained sandstone to sandy shale, and in another, the change is from sandstone to coarse grit or fine conglomerate.

Many beds are very argillaceous; others are rather free from clay; and it is common to find irregular pieces, lenses, and thin layers of coaly matter in what would be otherwise a clean sandstone. The grains are a mixture of quartz and fragments of igneous and metamorphic rocks, and some members are distinctly arkosic.

Their color on unweathered surfaces is most often bluish to greenish-gray which becomes gray and very light gray to buff and light-brown where weathering has affected them. Certain strata are loosely cemented and quickly disintegrate from erosion, while others are well cemented and have been quarried and used extensively for building purposes. Shedd[1] gives the physical characteristics of the rock taken from the old Chuckanut quarry, mentioning that the porosity is 10.91 per cent. He gives the following chemical analysis:

Analysis of Chuckanut sandstone

Silica (SiO_2)	90.19
Iron (Fe_2O_3)	3.50
Alumina (Al_2O_3)	1.92
Lime (CaO)	0.59
Magnesia (MgO)	1.78
Loss on ignition	2.32
	100.30

Shale.—The shales exhibit all gradations from very unctuous clay types, free from grit, to those so sandy as to verge on sandstones. Their color, when unweathered, is usually gray and dark-gray; although greenish shades have been seen, and variations from light-blue to deep-red occur in isolated exposures near the borders of the area. Where carbonaceous, as many of them are, the color darkens with increase in carbon content until they become black. Some are soft and easily weathered, others are hard and compact, while a few exceptional occurrences are so dense and indurated as to resemble slate.

Many shale beds, and particularly those that are carbona-

[1]Shedd, Solon, Building and ornamental stones of Washington: Wash. Geol. Survey Ann. Rept. for 1902, Vol. 2, pp. 62-65.

ceous, bear abundant imprints of leaves, stems, and plant fragments, while in some beds beautifully preserved imprints of palm fronds occur. These may be seen most advantageously in the sandy carbonaceous shales and at shale-sandstone contacts along Chuckanut Drive. Such fossils are common to the whole formation, with the possible exception that the palm imprints occur mainly in the beds nearer the base of the series.

The percentage of shale in the series is low. It varies greatly from place to place and becomes much greater if rocks on the border between shale and sandstone, which would be described better as shaly sandstones, are included in the figures. The 9,000-foot section measured along Chuckanut Drive shows 10 per cent shale which may represent fairly the amount in the southern part of the district. The relative percentage is higher to the northwest, where conditions of deposition apparently favored the accumulation of the finer sediments. Well logs and diamond drill records indicate that the percentage of shale in at least the upper part of the formation is around 30 per cent.

Coal.—Coal, in fragments, thin layers, and lenses, is distributed irregularly throughout the whole thickness of the Chuckanut formation; while beds of appreciable thickness, some of which are commercially important and have been mined for many years, occur at several places. The coal occurs in the upper part of the series with the exception of one bed which is just above the basal conglomerate.

The thickest bed so far discovered is in the syncline underlying the city of Bellingham and at present is being mined near the northwest city limits by the Bellingham Coal Mines Company. This bed is 14 feet thick. It has partings of carbonaceous shale which are thicker in the lower part of the bed than in the upper, so only the top seven or eight feet of coal is mined. The coal is black, and has a cubic fracture, and is of subbituminous grade. Jenkins[1] gives the following analysis:

Proximate analyses of coal from the Bellingham beds

SAMPLE	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	B. t. u.
1. As received	4.26	36.67	40.78	19.29	1.01	10,872
Moisture free	....	37.26	42.59	20.15	....	11,356
2. As received	4.16	34.62	44.67	16.55	0.68	11,467
Moisture free	....	36.12	46.61	17.27	....	11,965
3. As received	4.70	35.11	47.73	12.46	0.94	11,657
Moisture free	....	36.84	50.01	13.15	....	12,232

[1]Jenkins, O. P., Geological investigation of the coal fields of western Whatcom County, Washington: Wash. Div. Geol. Bull. 28, 1923.

These analyses are rather characteristic of the coals of the Chuckanut formation in this part of western Whatcom County; although, due to movement and pressure, the coal just overlying the schist and formerly mined at Blue Canyon, has less volatile matter and a higher content of fixed carbon.

The Blue Canyon coal is said to have varied greatly in thickness from place to place in the old workings, but an average was about seven feet. Other coal beds below the Bellingham seam have been worked at different times. These had thicknesses from 2 to 6 feet. The total number of beds is not known; for structural changes could make one bed outcrop at widely separated places, while different conditions of deposition could account for differences of thickness and quality. It is not thought, however, that the original basins in which the coal was laid down extended for any great distance, hence the resultant coal beds are considered to be discontinuous rather than persistent members of the formation.

All of the coals opened so far have been very gassy. Closed lights have to be used in the mines unless there is very good ventilation, and even then the condition of the air must be tested often and carefully. This is no more than would be expected in coal which contains so much volatile matter and which lies in highly folded rocks.

Limestone.—No limestone is known to occur in the Chuckanut formation. It is not to be expected, due to the character of the sediments and the conditions that existed while the materials were laid down. Limestone has been reported, so far without verification, in one or two well logs (see Chamber of Commerce well No. 5), and limy sediments have been reported in other drillings. The latter could have formed as impure marl by the precipitation of calcium carbonate in warm, shallow, fresh-water lakes through the agency of aquatic plants.

An impure marl-like material was encountered interbedded with shale and sandstone in the Hunter No. 2 well in the SW. ¼ sec. 27, T. 39 N., R. 2 E. It was soft, chalky material which showed no shell fragments under the microscope. It contained very fine quartz sand and powdery calcite in about equal amounts, with smaller amounts of altered and unaltered feldspars, hornblende, pyrite, epidote and apatite. A little less than one-half of the material, as sampled, was soluble in hydrochloric acid. This occurrence is of interest, for such a bed may prove to be a horizon marker. It may represent strictly local deposition, but should be looked for in future drilling.

Type sections.—Chuckanut Drive has been cut in the cliffs and steep west slopes of Chuckanut Mountain, along the shore of Samish Bay. Bedrock is exposed for a long distance, and it is possible to measure a section totalling over 9,000 feet in stratigraphic thickness. The base of the section is in the southwest corner of sec. 9, T. 36 N., R. 3 E.; while the actual contact with the schist is concealed, the position is known to within a few feet, since schist outcrops a short distance south of the lowest exposure of sandstone. The upper part of the section is not exposed continuously, and the thickness is obtained from the attitude of the beds that are exposed. The top of the section is just north of the old Wildcat Cove Station, near the center of the east line of sec. 25, T. 37 N., R. 2 E. Above this exposure the beds dip the opposite way and are repeated.

Section along the east shore of Samish Bay

Top of Section.	Thickness. Feet.
Sandstones, interbedded shaly sandstones, and sandy shales. Mostly concealed	1,750
Conglomerate, coarse, rounded pebbles and cobbles, with grit and sandstone interbeds. Base and top concealed	25
Sandstones with interbedded shaly sandstone and sandy shales. Mostly concealed	2,550
Concealed	180
Sandstone, coarse, cross-bedded	25
Concealed	240
Sandstone, massive	60
Concealed	130
Sandstone and shale	15
Sandstone, cross-bedded	12
Shale, sandy	80
Sandstone, massive, jointed	125
Sandstone, interbedded shale	4
Sandstone, coarse. Leaf horizon at top	40
Shale, sandy	4
Sandstone, cross-bedded	8
Concealed	135
Sandstone, coarse	60
Sandstone, shaly	85
Shale, sandy	20
Sandstone, well-bedded	20
Shale, carbonaceous	1
Sandstone	8
Shale, carbonaceous	1

Section along the east shore of Samish Bay—Continued

Top of Section.	Thickness. Feet.
Sandstone, thin-bedded	4
Sandstone, massive, thin layer carbonaceous shale	20
Shale	5
Sandstone	6
Sandstone, shaly	3
Sandstone	5
Concealed	85
Sandstone, massive. Some shale interbeds	105
Sandstone, massive, and shale containing leaves	105
Shale. Fossil leaves	6
Sandstone, massive	25
Sandstone and interbedded shale	50
Concealed	60
Sandstone, cross-bedded	30
Sandstone. Small amount shale, partly concealed	75
Sandstone, interbedded carbonaceous shale	60
Sandstone, massive. Tree trunk imprints	86
Shale, carbonaceous	6
Sandstone, massive and cross-bedded	25
Shale, carbonaceous	2
Sandstone	2
Shale, carbonaceous	5
Sandstone, with some shale	105
Shale, carbonaceous. Some interbedded massive sandstone	65
Sandstone, cross-bedded	15
Shale, carbonaceous, with sandstone lenses	34
Sandstone, cross-bedded, with interbedded shale. Palm horizon at top	43
Sandstone, shaly partings. Contains tree imprints	50
Shale, coaly	1
Sandstone	1
Shale, coaly	0.5
Sandstone	4
Shale, carbonaceous, with sandstone lenses containing carbonized stump. Palm horizon	20
Sandstone, massive, pebbly at base	43
Sandstone, massive. Thin shale layer at top	10
Sandstone, massive, with shale showing mud cracks	6
Sandstone, cross-bedded. Some sandy shale	8
Sandstone, massive	20
Concealed	175
Sandstone, poorly exposed	50
Concealed	50
Sandstone, massive	30
Sandstone, shaly, and carbonaceous shale	12
Sandstone, massive	20
Sandstone, poorly bedded. Contains leaf imprints and probable ripple marks	20

Section along the east shore of Samish Bay—Continued

Top of Section.	Thickness. Feet.
Sandstone, irregularly bedded. Shale parting	50
Shale. Palm horizon	2
Sandstone, cross-bedded	8
Shale	2
Sandstone, massive	6
Shale, partly carbonaceous	6
Sandstone, cross-bedded. Shale parting	14
Shale and bony coal	5
Sandstone, cross-bedded	15
Shale and bony coal	2
Sandstone with pebble layers. Numerous tree trunk impressions	55
Shale, massive, irregularly shaped lens	4
Sandstone, shaly parting	6
Shale, leaf imprints	1
Sandstone, cross-bedded	3
Sandstone, thin-bedded, shaly. Palm horizon at base and leaf imprints at top	10
Sandstone, massive	2
Shale, carbonaceous, and thin-bedded sandstone	5
Sandstone	5
Shale	1
Sandstone	5
Sandstone, shaly, thin-bedded	10
Sandstone, cross-bedded. Leaf imprints at top	10
Sandstone, very irregular bedding	6
Sandstone, shale, and bony coal, interbedded	35
Sandstone with shaly partings. Coaly layer at top	8
Shale, sandstone and coaly shale. Palm horizon at top	12
Sandstone, cross-bedded	6
Shale, carbonaceous, with bony coal	7
Sandstone, cross-bedded, shaly partings	12
Shale, carbonaceous. Palm horizon	4
Sandstone, massive	6
Sandstone and interbedded massive shale	15
Coal, bony. Palm horizon	2
Sandstone, cross-bedded, very lenticular	6
Shale with carbonaceous layers	4
Sandstone, cross-bedded. Shaly parting	11
Shale, coaly. Palm horizon	0.3
Sandstone	2
Coaly seam	0.2
Shale, massive	3
Coaly seam	0.5
Sandstone, cross-bedded. Tree imprints	47
Shale and bony coal	2
Sandstone, cross-bedded	5

Section along the east shore of Samish Bay—Continued

Top of Section.	Thickness. Feet.
Shale	1
Sandstone, cross-bedded	5
Sandstone and shale. Leaf horizon at top	6
Sandstone	8
Shale with coaly seam and sandstone lens	8
Shale and interbedded sandstone	10
Concealed	115
Shale	5
Sandstone, well-defined cross-bedding	12
Concealed	10
Shale and shaly sandstone	7
Shale, sandy	10
Sandstone, shaly, concretionary	8
Sandstone, shaly, compact. Conchoidal fracture. Coaly seam at top	12
Sandstone, massive, cross-bedded	12
Coal, bony	2
Shale and interbedded sandstone	10
Shale and coaly layer	12
Sandstone, fine-grained, cross-bedded	8
Sandstone, shaly	6
Concealed	10
Sandstone, massive	5
Shale. Palm horizon at top	7
Sandstone, shaly partings	8
Shale, sandy	5
Sandstone, massive, slightly faulted	60
Sandstone and interbedded coaly seams	110
Shale, very carbonaceous, interbedded with sandstone	25
Shale and fine-grained sandstone	25
Sandstone, massive, cross-bedded	30
Conglomerate, pebbles up to 2 inches in diameter, composed of subangular quartz and schist	15
Concealed	290
Sandstone, massive	110
Concealed	75
Sandstone, massive, poorly exposed	20
Concealed	90
Sandstone	10
Concealed	140
Sandstone, massive	10
Shale, sandy, carbonaceous at top	40
Sandstone, massive, medium-grained. Contains some intraformational conglomerate or clay pebbles. Numerous imprints of wood at several horizons	115
Shale, carbonaceous, and shaly sandstone	2
Sandstone	4

Section along the east shore of Samish Bay—Continued

Top of Section.	Thickness. Feet.
Sandstone, shaly	6
Sandstone, massive and cross-bedded	12
Shale, carbonaceous. Good leaf imprints	2
Sandstone. Contains imprints of wood	3
Shale	0.5
Sandstone, massive, medium-grained	30
Shale, carbonaceous. Contains well-defined leaves and thin coaly layers	4
Shale, sandy with interbedded fine-grained sandstone	10
Sandstone, cross-bedded	1
Shale, sandy, thin-bedded, with some shaly sandstone	4
Shale, fine-grained, compact, conchoidal fracture	3
Sandstone, fine-grained, much cross-bedded	15
Shale, thin-bedded. Contains distinct imprints of palms and leaves	1
Sandstone, coarse, with pebble layers and lens of sandy shale. Irregular bedding	10
Shale, bluish-gray. Interbedded sandy shale	4
Concealed. Probably mostly shale	100
Sandstone, massive, buff-colored	8
Shale, sandy, with ferns and stem imprints	6
Shale, carbonaceous	0.3
Sandstone, shaly, gray	4
Sandstone, massive, buff-colored	6
Shale, well-bedded. Fragments of carbonized wood	2
Shale, sandy, compact, conchoidal fracture	12
Sandstone, shaly. Contains fossil leaves	7
Shale, sandy	4
Sandstone, massive	12
Concealed	200
	9,484
Unconformity	
Schist	

The highway along the west side of Lake Whatcom exposes over 6,000 feet of the lower part of the Chuckanut formation. The highest exposed members, stratigraphically, are those at Lake Louise, near the center of the west line of sec. 8, T. 27 N., R. 4 E. Exposures are very scarce beyond these and are probably involved in a fold. The bottom 1,950 feet of the section is concealed, and that thickness and the position of the schist contact is estimated from topographic features and structural data obtained near the actual contact to the west of the measured section. The lowest exposure is on the highway above the northwest shore of South Bay of Lake Whatcom.

Section from South Bay to Lake Louise, along Lake Whatcom

Top of Section.	Thickness. Feet.
Sandstone, weathered, buff, medium-grained	50
Conglomerate, massive. Pebbles 1 to 2 inches in diameter, well-rounded, igneous and metamorphic. Arkosic groundmass. Few layers and irregular masses of interbedded sandstone.	80
Concealed. Chiefly coarse weathered sandstone, some fine conglomerate	820
Sandstone with shaly phases, some pebble lenses and intraformational conglomerate. Greatly weathered	230
Concealed	170
Sandstone, shaly, thin-bedded, with gray laminated sandy shale, carbonaceous layers, arkosic in part	227
Sandstone, fine to medium-grained, well-cemented, platy	50
Shale, fissile, sandy, dark-gray, carbonaceous	10
Sandstone, fine-grained, generally massive. Some coaly fragments and shale	222
Concealed, mostly shaly sandstone	80
Concealed	80
Sandstone, very shaly, thin-bedded. Leaf imprints	115
Concealed, mostly shaly sandstone	30
Sandstone, weathered, buff, massive, well-cemented	108
Sandstone, shaly, fine-grained, weathered	11
Shale, dark-gray, carbonaceous	2
Sandstone, fine-grained	8
Shale, sandy, carbonaceous, dark-gray	1
Sandstone, fine-grained, shaly	9
Shale, very sandy, dark-gray, carbonaceous	9
Sandstone, thin-bedded, fine-grained	10
Shale, sandy, fissile, carbonaceous, dark-gray	7
Sandstone, fine-grained, some shale	11
Shale, sandy, dark-gray	9
Sandstone, shaly	45
Shale, sandy, weathered	5
Sandstone, shaly, weathered	25
Sandstone, massive, medium-grained	15
Concealed	50
Sandstone, fairly well cemented, medium to coarse-grained, cross-bedded. Planes in part contorted	69
Sandstone, shaly, soft, thin-bedded	84
Sandstone, soft, thinly foliated. Slight small-scale cross-bedding. Weathered buff	43
Shale, very sandy, thin-bedded	18
Concealed	42
Sandstone, massive, coarse. Small-scale cross-bedding	40
Concealed	18
Sandstone, massive, coarse	25
Concealed	4
Shale, sandy	5

Section from South Bay to Lake Louise, along Lake Whatcom—Continued

Top of Section.	Thickness. Feet.
Sandstone, massive, fine-grained, hard	9
Shale, sandy, fine-grained, bluish-gray	10
Sandstone, fine-grained, bluish-gray, thin-bedded to massive	17
Sandstone and shale, thin-bedded	10
Shale, sandy, dark-gray, carbonaceous	3
Sandstone, fine-grained, wavy bedding	4
Shale, sandy, dark-gray, carbonaceous. Contains leaves	5
Sandstone, medium-grained, massive, well-cemented	46
Shale, carbonaceous. Excellent leaf imprints	1
Sandstone, wavy bedding planes	5
Shale, sandy, dark-gray	2
Sandstone, medium-grained, massive	4
Shale, dark-gray to black. Contains leaves	10
Sandstone, thin-bedded, banded	10
Shale, sandy, carbonaceous, dark-gray	8
Sandstone, soft, shaly	5
Concealed	140
Sandstone, coarse, banded, weathered light-buff	20
Sandstone, thin-bedded, platy	18
Sandstone, massive, coarse, well-cemented, hard	23
Sandstone, thin-bedded, soft, fine-grained, wavy	40
Shale, fine. Contains coaly matter	1
Sandstone, soft, gray	2
Shale, sandy, fine. Contorted bedding	4
Sandstone, fine-grained, shaly, thin-bedded. Contorted bedding planes	104
Concealed	205
Sandstone, fine-grained to coarse, gray, arkosic. Includes 2 feet hard shale with leaves	55
Concealed	100
Sandstone, generally coarse, arkosic. Some fine-grained and shaly. Coaly layers near middle	220
Concealed	50
Sandstone, coarse, arkosic	12
Concealed	90
Sandstone, rather coarse, bluish-gray, arkosic	110
Concealed	136
Sandstone, in part thin-bedded and shaly. Gray to dark bluish-gray. Generally fine and slightly crossed-bedded	75
Shale, fissile, very carbonaceous	1
Sandstone, in part shaly	41
Shale, thin-bedded, sandy, dark-gray	4
Sandstone, very shaly, gray	5
Shale, sandy, dark-blue, carbonaceous	17
Sandstone, fine-grained, thin-bedded	7
Shale, sandy, dark bluish-gray, carbonaceous	9
Concealed	100

Section from South Bay to Lake Louise, along Lake Whatcom—Continued

Top of Section.	Thickness. Feet.
Sandstone, medium-grained, bluish-gray, well-cemented. Top is thin-bedded and platy	59
Sandstone, generally very shaly, dark bluish-gray	95
Sandstone, fine-grained; in part shaly	95
Concealed	230
Sandstone, shaly, in part very thin-bedded. Contains carbonaceous layers	155
Sandstone, massive, bluish-gray	30
Sandstone, shaly, thin-bedded; in part platy, buff	45
Sandstone, massive, medium-grained, bluish-gray	70
Sandstone, shaly, alternating with sandy shale; gray to dark-gray, thin-bedded	165
Sandy shale and shaly sandstone. Abundant leaves and palm fronds. Gray to dark-gray	93
Sandstone, medium-grained, gray, massive	14
Shale, sandy, carbonaceous. Contains stems and leaves	10
Sandstone, medium-grained, massive	7
Shale, sandy, dark-blue	10
Sandstone, fine-grained	6
Shale, sandy, dark-gray	6
Sandstone, fine-grained, bluish-gray	13
Shale, sandy with shaly sandstone. Dark-gray	9
Sandstone, thin-bedded, fine-grained	20
Shale, sandy, partly concealed	20
Sandstone, medium-grained, hard, massive	55
Sandstone, partly concealed	25
Sandstone, thin-bedded. Partly shaly	55
Shale, dark-gray, carbonaceous. Some sandstone	12
Sandstone, medium-grained, massive	14
Shale, very sandy, dark-gray	12
Sandstone, fine-grained, thin-bedded	20
Sandstone, shaly. Partly concealed	25
Sandstone, fine-grained, bluish-gray. Contorted bedding	24
Shale, sandy, dark-blue, carbonaceous	8
Sandstone, massive, fine-grained	7
Sandstone, shaly; and sandy shale, partly carbonaceous	49
Sandstone, medium-grained, gray, fairly hard	30
Sandstone, well-cemented, softer toward top	24
Sandstone, very shaly, dark bluish-gray	3
Sandstone, gray, medium-grained	8
Sandstone, dark bluish-gray. Partly very shaly	29
Sandstone, medium to coarse, bluish-gray	14
Shale, sandy and sandstone, shaly, gray, carbonaceous	35
Concealed	52
Sandstone, massive, coarse, gray	28
Concealed	46
Sandstone, bluish-gray, medium to coarse-grained. Contains lenses of fine conglomerate and fragmental coal	67

Section from South Bay to Lake Louise, along Lake Whatcom—Continued

Top of Section.	Thickness. Feet.
Concealed. Partly soft coarse-grained sandstone	70
Sandstone, shaly, fine-grained. Partly thin-bedded	32
Sandstone, shaly, thin-bedded, dark-gray, carbonaceous	7
Sandstone, medium-grained	13
Concealed	24
Sandstone, shaly, bluish-gray	7
Sandstone, massive, coarse	27
Concealed	21
Sandstone, coarse, massive, bluish-gray	30
Sandstone, coarse. Contains irregularly placed coaly fragments	3
Sandstone with quartz pebbles	2
Sandstone, massive, gray, medium to coarse-grained	12
Sandstone, massive, fine-grained, gray	12
Sandstone and thin-bedded sandy shale, alternating	14
Sandstone, thin-bedded, cross-bedded, fine-grained	9
Shale, sandy, dark-gray. Contorted bedding	5
Sandstone, massive, medium-grained, buff	8
Sandstone, shaly, thin-bedded, platy	3
Sandstone, fine-grained, gray	3
Shale, bluish-gray, sandy	1
Sandstone, fine-grained, thin-bedded	4
Sandstone, shaly, very thin-bedded, dark-gray	9
Sandstone, thin-bedded, fine-grained	4
Shale, sandy, dark-blue	4
Sandstone, gray, medium-grained, massive	7
Shale, blue, sandy	6
Sandstone, fine-grained, thin-bedded	6
Shale, sandy, dark-gray, carbonaceous	4
Sandstone, medium-grained	8
Shale, sandy, carbonaceous. Contains leaf imprints	5
Sandstone, massive, fine-grained, well-cemented	38
Sandstone, shaly, thin-bedded	4
Concealed	1,950
Unconformity	8,719
Schist	

Thickness.—Strata totalling 8,669 feet were measured from the basal conglomerate of the Chuckanut to the top of the massive conglomerate exposed at Lake Louise. To this may be added 1,750 feet lying above that conglomerate and measured in the vicinity of Wildcat Cove. Above this are the strata containing the Bellingham Coal bed and the other beds encountered in drill holes and opened in mines north of the mountainous region, and probably some 1,550 feet lying above the main Bellingham coal.

Jenkins,[1] on structural data and an assumed correlation of certain coal beds, estimated the thickness to be about 12,000 feet. The strata are too involved in folding and cross-folding to permit obtaining accurate information above the measured sections; while the discontinuity of beds along the strike makes long-distance correlation very uncertain, particularly on beds as variable as the coals in this area. There is a known thickness of over 10,000 feet; and it is thought, on the basis of such inferences as may be drawn from field and drill-hole evidence, that the probable total thickness is in excess of 16,000 feet.

Age.—No fossils of the animal life of the time have been found in the Chuckanut formation, so the age of these rocks must be determined on the evidence of fossil leaves and other plant forms found so abundantly in the series. Earlier writers have worked on this material and typical collections have been made. Knowlton studied collections submitted by Henry Landes, of the University of Washington, and placed the beds in the Eocene Period of the Tertiary and correlated them tentatively with the coal-bearing Eocene beds of King County.

PLEISTOCENE DEPOSITS

Unconformably overlying the Eocene rocks are horizontally-bedded unconsolidated gravels, bouldery and pebbly clays, soft clays, and sand. These are directly or indirectly of glacial origin.

The pebbly clay or "till" is a heterogeneous mixture of clay and sand with pebbles and boulders, that is sometimes called "hard pan" or boulder-clay. It is the unassorted burden that is transported by ice and laid down without particular change when the glacial ice melts. The other sediments are water-assorted and occur, usually, as well-stratified beds of various thickness with well-marked junctures between the several textural types.

The sands are usually rather free from clay and are composed mainly of quartz grains with lesser amounts of other minerals and rock fragments. These beds carry ground water, if not enclosed in clay, and are the members sought in drilling for water in the Bellingham area. The assorted gravel beds also carry water as a rule.

The clays that occur interbedded with the assorted sands and gravels are dark bluish-gray in color when damp and un-

[1]Jenkins, O. P., op. cit., pp. 47-49.

weathered. They may contain various amounts of sand but generally are rather free from any gritty material except very fine silt. The less sandy phases are soft and very plastic or unctuous when damp. They contain considerable iron oxide and so weather to various shades of yellow. Such clays are impervious to water, and, as far as they extend, confine ground water to the sandy or gravelly beds that may be above or below them.

All of these glacial or aqueo-glacial sediments change greatly along the strike of the beds, and usually they are decidedly lenticular. A bed of sand may become increasingly clayey until that characteristic predominates, or well-assorted gravel may verge through a transitional stage into well-assorted sand. Any of these materials may become thinner until the particular bed tapers off, and in such a case the bed may be completely surrounded by sediment of a different kind with sharp boundaries between them.

Marine fossils are unknown in the underlying Chuckanut formation, but these upper unconsolidated sediments were partly, if not wholly, laid down in marine water and contain, in places, abundant shells and shell fragments.

Because of the great changes of conditions during the period of deposition, changes that were local in character, it is not possible to make any but the most general correlation of beds from place to place. This is illustrated by the following three sections taken from exposures in the bluff along the shore of Bellingham Bay at locations approximately a quarter of a mile apart.

Section from bluff northwest of Bellingham in the NW. ¼ sec. 23, T. 38 N., R. 2 E.

Elevation	Thickness	MATERIAL	Structure	Condition of Deposition	Age
Feet	Feet				
87	....	Soil			
....	10	Mixed and irregular beds of gravel and sand	Roughly stratified	Outwash	Post-glacial
77	40	Succession of sand and clay beds of variable thickness	Stratified	As sediments in marine water	Inter-glacial
37	3	Clay, yellow and blue	do.	do.	Do.
34	6	Sand	do.	do.	Do.
28	1	Clay, with sand interbeds	do.	do.	Do.
27	5	Sand	do.	do.	Do.
22	1	Clay	do.	do.	Do.
21	18	Sand	do.	do.	Do.
3	3	Bluish-gray pebbly plastic clay containing Pectens and other shells in upper one foot. In 100 feet laterally toward the southeast this bed thickens to 30 feet	Unstratified	By ice as a till in marine water	First Glacial advance (Admiralty)
....	Base concealed				
Sea Level					

Section from bluff northwest of Bellingham in the NE. ¼ sec. 22, T. 38 N., R. 2 E.

Elevation	Thickness	MATERIAL	Structure	Condition of Deposition	Age
Feet 102	Feet 35+	Bluish-gray, pebbly plastic clay containing abundant marine shells near base. Sandy at top.	Unstratified	Deposited by ice	Last Glacial epoch (Vashon)
67	20	Clay, silt, sand, grit, and gravel. Clay and grit predominate. A grit member from 1 to 2 feet thick near base contains numerous shells (Leda, Pecten, and Cardium).	Stratified	Deposited in marine water	Inter-glacial
47	12	Sand with clay balls	Well-bedded	do.	Do.
35	10	Cross-bedded and contorted sand containing clay masses that have been squeezed by overlying sediments or ice. Some aligned pebbles.	Stratified	As sediments in marine water. Possibly over-ridden by ice in later advance	Do.
25	5	Sand, fine	Well-bedded	Marine	Do.
20 Sea Level	20	Sand, brown	Well-bedded	do.	Do.

Section from bluff northwest of Bellingham in the SE. ¼ sec. 15, T. 38 N., R. 2 E.

Elevation	Thickness	MATERIAL	Structure	Condition of Deposition	Age
Feet 65	Feet 1	Soil			
64	6	Clay, sandy, jointed, yellow, containing fine sand partings	Stratified	Quiet water	
58	16	Sand, fine and coarse. Includes clay lenses up to 4 feet thick	do.	By streams in fairly shallow water. Changing currents	Alluvium
42	1.5	Clay, blue, plastic	do.	do.	
40.5	1	Sand, 1-inch clay partings	do.	do.	Inter-glacial
39.5	8	Sand, fine, horizontally bedded. Contains balls of clay	Lower surface uneven	Influenced by changing currents	Do.
31.5	15	Clay, smooth, unctuous. Sandy partings on bedding planes	Stratified	Marine	Do.
16.5	1.5	Clayey sand		do.	Do.
15 Sea Level	15	Sand, gray, medium-grain	Evenly stratified	do.	Do.

RECENT DEPOSITS

Recent deposits of silty clay, sand, and some fine gravel have been laid down on the Pleistocene sediments. They are flood-plain deposits of Nooksack River and make up the wide flats that border that stream and extend westward into the vicinity of Birch Bay.

On these river flats are isolated, rounded and elongated knobs or hills, rising 20 to 60 feet above the level of the surrounding plains, and forming marked breaks in the general topography. They are composed of poorly to well-assorted sands, usually stained to some shade of yellow, and contain lenses and layers of fine gravel. They represent older terrace and possibly some beach deposits that have been mostly removed by erosion which has left these as remnants.

THICKNESS OF PLEISTOCENE AND RECENT SEDIMENTS

The continental ice sheet overrode the whole area, overtopping the highest hills, and left a cover of ground moraine on the older rocks. The bedrock surface was very uneven, so the original depressions had thick accumulations, and areas of greater elevation had only a thin cover or none at all. Later erosion has modified and removed much of this till, so large areas are devoid of any Pleistocene materials except in protected places. To add to the variety of the surface covering, recessional moraines were piled up in several places by the retreating glacier, and it is in such places that the bedrock is most deeply covered.

The Recent alluvium and terrace deposits occupy areas where some of the Pleistocene sediments have been removed by river erosion; so, by taking the place of the older sediments, they do not add to the total thickness of surface materials.

Bedrock outcrops in very few places in the northern part of the area, although in part of this region the cover is known to be relatively thin. This information is based on drill-hole records, and it is at times very difficult to decide from these logs just where the bottom of the Pleistocene deposits lies. Thicknesses of 325 feet, 390 feet, 280 feet, and 200 feet have been logged with apparent accurracy in different holes between Bellingham and Ferndale.

Northwest of Ferndale the cover is much thicker, and as much as 595 and 615 feet is recorded. In the vicinity of Birch Bay the overburden probably is not over 200 feet thick. The cover for several miles west of Goshen is known to be thin, since bedrock outcrops at several widely separated places. Conditions are unknown in the northern and northeastern part of the area, but it is not thought that Pleistocene and Recent deposits extend to more than 100 or 150 feet below sea level.

IGNEOUS ROCKS

No igneous rocks are known to occur in the area, although a few isolated outcrops are found on the borders of the region investigated. These are basic types on the order of andesite with some dioritic phases. It is thought that more detailed study would show even these to be associated with the underlying formations and so of earlier age than the Chuckanut.

STRUCTURE

A great structural upwarp extends across the Cascade Range, through eastern Snohomish County, western Skagit County, the San Juan Islands, and into Vancouver Island. It has been mentioned by Willis[1] and Weaver[2] as being a feature incidental to the Cascade Mountain uplift and as being the origin of the Entiat Range as well as those lower but very pronounced topographic forms found to the northwest. As a result of this regional upwarping, the Eocene rocks and underlying schists of western Whatcom County have been raised and folded. Prolonged erosion has removed the later sediments from the main axis of the upwarp, exposing the metamorphic rocks over large areas, and has cut deeply into these lower rocks. The Chuckanut formation in the area covered by this investigation lies on the northeast flank of this main uplift and shows the results of the general elevation and folding.

The principal folds trend in a general northwest direction. This effect, however, is complicated by transverse folding, and the main axes are curved and bent in various directions. As might be expected, particularly in the south part of the area, the structures plunge to the northwest.

The inclination, or dip, of the folded strata is rather steep throughout. Angles as low as 10° were noted but most of the

[1]Willis, Bailey, Physiography and deformation of the Wenatchee-Chelan district Cascade Range: U. S. Geol. Survey, Prof. Paper 19, p. 90, 1903.

[2]Weaver, Chas. E., The Tertiary formations of Western Washington: Wash. Geol. Survey, Bull. 13, p. 245, 1916.

readings, taken on scores of outcrops, ranged from 20° to 60°. In a few places, as near the schist contact in the south part of the area, very close minor folding occurs, with angles of dip up to 90°. Slight overturning of the steep beds shows in three places: along Chuckanut Drive in the SE. ¼ sec. 36, T. 37 N., R. 2 E.; in Samish Lake vicinity, near the west center sec. 23; and near the north center sec. 25, T. 37 N., R. 3 E. The sharpness of some of the folding is well shown above Reed Lake, near the north center sec. 30, T. 37 N., R. 4 E., where, in a space of a few feet, the beds with a strike of N. 40° W., 85° SW. are bent over to N. 24° E., 24° NW.

The structural features are given on the accompanying map (Pl. I). The names applied to the anticlines and synclines are, with some modification, those used by Jenkins[1] in his study of the coals of the region, but some changes have been made in the position and trend of the folds. The symbols representing the strike and dip of the strata are put on the map for two purposes. They show the steepness of the dipping beds and the general attitude upon which the position of the axes is based, and they also give the geographic position of outcrops where data have been obtained and where further studies may be made.

FOLDS

Chuckanut anticline follows a sinuous line from South Bellingham toward Samish Lake, while a south branch trends along Chuckanut Mountain to the schist contact. It is bordered on the west by Chuckanut syncline, and a short syncline lies between the north and south branches. The dip of the beds is very steep and their converging strike indicates a general plunge of the structure to the northwest.

Lake Padden anticline lies north of Lake Padden and is separated from Chuckanut anticline by a sharp syncline running beneath the lake. This anticline extends for about four miles from a merging of two synclines to the southeast to a similar merging to the northwest. The beds dip rather steeply, but not as much so as in some of the other structures. Except for one place where 60° was recorded, all dips are under 30°, some as low as 5°.

Lookout Mountain anticline is the principal structural feature of the area. It extends the whole length of the mountain, a distance of eight miles or so, and continues to the north for

[1]Jenkins, O. P., op. cit., Pl. I.

three miles more, where it joins the King Mountain anticline. The crest is broad with many minor transverse folds, and the whole structure plunges rather steeply to the northwest. An excellent view may be had of the exposed south end of the anticline from Reed Lake. Here, eroded strata of sandstone and sandy shales, over 2,500 feet thick, crop out, layer upon layer, to the top of the mountain. The section measured from South Bay to Lake Louise was obtained from the steeply dipping beds of this fold.

Northeast of Lookout Mountain anticline is Lake Whatcom syncline, which trends many miles to the north and there cuts between King and Squalicum Mountain anticlines. To the east of this syncline are the sharply folded strata of Anderson Mountain, where details of structure have not been worked out due to the complexity of folding, the inaccessible nature of the region, and the fact that it has but little possibility of oil or gas.

King Mountain anticline is a structure that is well defined in part by outcrops. Just north of the west end of the axis, in King Mountain, the strata have dips of about 50°, with one exposure showing as much as 72°; elsewhere the dips are more moderate and range between 10° and 55°. The axis is shown to trend about 4 miles from the enveloping branching syncline at the north end of Lake Whatcom to King Mountain; it may be projected to the northwest into the vicinity of Ferndale, but there is no evidence available at this time as to such continuation. Well-kept drill records should show whether the structure continues, turns to some other course, or flattens out beyond King Mountain.

Bellingham basin is a broad, shallow synclinal trough which lies in a curve of the Lookout Mountain-King Mountain anticlines. It underlies the city of Bellingham and contains the principal coal bed of the area, that mined by the Bellingham Coal Mines Company. In general, the strata forming the basin have moderate dips of 10° to 20°, but they steepen to as much as 62° in some places. The basin trends to the southwest and has a gentle plunge in that direction.

Squalicum anticline trends through Squalicum Mountain and into Anderson Mountain just north of Olsen Creek. It has a component, called Anderson Creek anticline, which extends to the north between the two mountains and curves to the east up Anderson Creek. The crest is broad and more dome-like than some of the structures, although the subsurface shape must be very irregular. The dips, for the most part, are moderate; they generally range between 4° and 20° with considerable steepening at the north and west ends of the structure.

The Goshen anticline is the northernmost structure of which there is any evidence. The few exposures available through the concealing Pleistocene mantle indicate a broad dome-like anticline whose longer axis trends northerly for four miles or so. The strata dip at low angles from 3° to 8°. One exposure to the northeast, possibly a mile and one-half from the axis, has a dip of 22°.

The structure under the Pleistocene sediments to the north and northwest in the area is entirely unknown. As there is a general northwest trend for most of the principal folding, it may be assumed that strata there will also maintain that trend. Where the axes lie or what transverse folding may occur cannot be predicted at this time. The amount of folding and the inclination of the beds is also unknown; but, on the very uncertain premises of distance from the major folding and the dips of the farthest west and north exposures, it is believed that broader structural forms and more moderate dips will prevail. In this connection it would be well to mention that the prominent hills west of Ferndale and those just south of the international boundary, together with those lying along the coast, are strictly features of the Pleistocene overburden and appear to bear no relation to the structure of the deeply buried Chuckanut formation. This same situation holds true for all other mounds, knobs, and hills north of Bellingham and west of the outcrops of King Mountain and Goshen anticlines.

FAULTS

Faulting is apparently not a pronounced feature of the structural conditions here. A few faults were seen but none of these showed a displacement of over a few feet. The examples most easily seen occur in the outcrops along the beach of Lummi Island. A certain amount of slipping and faulting has taken place near the schist contact, particularly in regions of steep folding.

GEOLOGIC HISTORY

Rocks of Paleozoic and Mesozoic age of many kinds, both sedimentary and igneous, had come into existence in western Whatcom County and adjacent areas before Tertiary time. By the beginning of Eocene time, the first period of the Tertiary era, these rocks had been metamorphosed to schists, slates, quartzites and greenstones and had undergone prolonged erosion. At that time most of the Pacific Coast region was of very low relief, but it was still a land area. To account for the type of sedimentation of the following period, greater relief must be assumed for the northern part, but the present Cascade Mountains were not in existence.

During Eocene time the land was lowered slightly and extensive bodies of shallow fresh water formed over this and adjacent areas. These lakes and swampy regions extended far to the east and may have been more or less continuous with similar bodies of water over what is now part of eastern Washington. They were not connected with the sea and were probably separated from the embayments then occupying a large part of western and southwestern Washington.

Streams brought into these lakes a great amount of gravel and rock fragments from the higher regions on their borders and thus built up the great thickness of basal conglomerate that is exposed in many places today. The lakes were filled and became swampy, and in these accumulated the remains of the vegetation growing there. That the climate was tropical or at least subtropical is shown by different leaf forms and by the palm fronds now preserved as fossils from the life of that time. These early swamps are represented by the coal found now at Blue Canyon and in the Glacier coal field to the east.

For a long period of time following this the land was slowly depressed and the lakes deepened. The erosion of the land was slower, due, probably, to the more broken and softer surface having been already stripped off to make up the basal gravel beds. So finer sediments, consisting of sands and sandy clays, accumulated; and, when the depressive action temporarily stopped, the lakes began to fill and again became swampy, and at such times deposits of swamp vegetation again formed.

The lateral variation of sediments along the strike of the same bed, together with the cross-bedding and occasional poor assorting, all point toward shallow-water deposits and locally different conditions of deposition. Some of the beds contain very coarse sand and fine conglomerate, and these were probably formed, in part, as subaerial deposits built up and distributed by torrential streams in piedmont areas.

This process continued intermittently until over 16,000 feet of sediments now making up the Chuckanut formation had accumulated, including many thick beds of plant remains. The only notable break in the sequence was after some 8,000 feet of beds had formed, when an uplifted bordering land surface furnished the coarse gravel that was carried by streams and spread over the finer sediments already present. This gravel is now the Lake Louise conglomerate.

By the close of Eocene time the lakes and swamps had filled with sediments or were drained. Apparently for the rest of Tertiary time the area remained land; no traces of other deposits have been found. It was during this time that Eocene sediments were being consolidated by pressure and the infiltration of cementing materials and possibly were being moderately folded.

At the close of the Tertiary time, or a little earlier, great diastrophic movements took place that resulted in the uplifting of the present Cascade Range and the forming of the northwest-extending upwarp that lies just south of Whatcom County. Coincident with this, the sediments were folded and tilted to their present attitude.

A long period of erosion followed, during which time the rocks of the Chuckanut formation were deeply eroded and the present topographic forms were outlined. This sculpturing was more or less directed by the folds the rocks had assumed, but the differential hardness of the various strata determined the general shapes the hills and valleys now have. The area of greatest uplift to the south suffered the greatest erosion, resulting in the Chuckanut formation being stripped entirely off large areas with consequent deep dissection of the underlying rocks.

In common with northern United States, this region shared in the changing climate which became steadily colder during late Tertiary time, reaching a maximum in the Pleistocene. Although it may not have been very much colder than now, conditions permitted the accumulation of vast quantities of snow. This resulted in the formation of a continental ice sheet, a tongue of which flowed over western Whatcom County to occupy a considerable part of the Puget Sound depression. The ice aided in carving and modifying the topography, and on its retreat left a deposit of glacial drift made up of mixed gravel, sand, and clay over the bedrock.

After the ice began to melt back, much of the area was depressed, and a marine embayment was formed to the northwest.

This is shown by shells of various marine invertebrates in the upper part of the lower glacial till. The streams from the melting ice sorted and transported much of the glacial drift and deposited it in the marine water as beds of clay and sand with occasional beds of gravel. In this way a thickness of well over 100 feet was built up. Shells of a marine fauna similar to that of the present day accumulated in these strata. In some places they are abundant, but in general conditions for sea life were probably none too favorable.

After a long interval, a second ice sheet spread over the region and the glaciation was repeated. This resulted in a new layer of till on top of the interglacial sediments. Some temporary advances of the ice sheet, or a certain amount of water-sorting of the later till during deposition, accounts for roughly stratified sediments occurring within the upper till sheet.

The ice front retreated at a uniform rate except for short periods when it remained essentially stationary. During such periods the ground moraine took on the characteristics of a recessional moraine. The Ferndale hills and those along the boundary are instances of this. The last episode connected with glaciation was the deposition of a relatively small amount of outwash gravel on the present land surface by streams from the melting ice working through the upper drift.

The land was uplifted after the last glacial period and the streams eroded more actively. Nooksack River, probably with the aid of Frazer River, temporarily flowing through here, cut a wide valley in the Pleistocene deposits to its old outlets at Birch Bay and Drayton Harbor, and to its present outlets at Lummi and Bellingham bays. The latest subsidence of the land caused the river to build up a wide flood plain of silts and clays in these valleys.

There are some indications of a late marine flooding of the area in the building of isolated beach and dune-like deposits. If this occurred at all, it must have been of very short duration and have followed the formation of practically all of the present-day topographic features.

OIL AND GAS

GENERAL CONDITIONS FOR PRODUCTION

Certain conditions are almost invariably present if gas, and particularly oil, occur in commercial quantities. A source for these products must be present in sediments, usually clays or shales, in which are intombed the remains of the life of the time. The shales were originally the muds laid down in shallow seas and marine embayments and as delta deposits on the borders of such waters. The organic material in them may consist of animal remains ranging from those of the larger vertebrate types down through all the invertebrates, such as clams and snails, to the microscopic Formaninfera that swarm in such seas. Plant remains, such as seaweeds, algae, and diatoms, may be present as well as higher plant forms of the great coastal marshes.

As such forms die, the organic substance is buried in the ever-accumulating muds and by them is prevented from being oxidized and the decomposition products dissipated. In time these muds become the shales of sedimentary rock series. Chemical changes in the organic material take place with resulting formation of petroliferous compounds.

The oil and gas tend to migrate gradually to adjacent porous beds through the influence of ground water, the action of capillarity, and the squeezing and consolidating effects of earth pressure and movement.

Finally, oil and gas accumulations, which may be of commercial importance, must be concentrated in certain favorable portions of the porous "reservoir" rocks where they are confined by adjacent impervious strata. They are aided in this concentration by the movement of ground water and by the difference in specific gravity between the hydrocarbons and the associated water. Long slopes of reservoir rocks naturally lead to upward drainage of most of the oil and gas. The amount and pressure of ground water is an important factor as is also the permeability or percentage of connecting pore space in the rock itself. Favorable locations for concentration may be of many kinds but in most cases are inclined porous beds where the gas and oil may rise to high levels without escape. The oil will usually be concentrated just down the slope from the gas, and under it will be the water. Rocks that are so folded as to dip in all directions from a central area are called structural domes, and these make excellent traps for oil and gas. Anticlines, particularly those with portions of their crest higher than the general fold, are well suited to the accumulation of oil. Such forms have always been most important among oil structures. A marked change of dip in sloping strata, dipping porous beds cut and sealed by faulting, textural changes in the reservoir rocks, and many other circumstances and structural forms may play important parts in causing oil or gas to be concentrated in a given area.

CONDITIONS PREVAILING IN WESTERN WHATCOM COUNTY

When the criteria for commercial accumulations of oil and gas are applied to western Whatcom County, it is found that some features of the area are satisfactory and some are not. The porous sandstones and conglomerates are present in almost too prodigal amount. Some of these are eminently suitable for carrying and storing either oil or gas in their interstices. Interbedded with the sandstones are impervious shales which could confine the oil to the porous members. The strata have been arched and folded into very well defined anticlines, some of which are apparently well suited to hold any oil or gas that might be present; and a few of these folds have a large gathering area down the long slopes of the structures. Details of these structures are given under the heading of, "Areas favorable for testing."

A puzzling feature of the problem of the occurrence of oil and gas in western Whatcom County is a source for petroleum hydrocarbons. Marine or estuarine beds are lacking, and fossils representing a form of life almost universally associated with the source of oil and petroleum gas have not been found here. Such a fauna exists in neighboring areas, for instance at Sucia Island in the San Juan group; but there is no apparent connection between the Chuckanut formation and these other beds, and, besides, the latter in part were so metamorphosed prior to the deposition of the Chuckanut beds as to destroy any oil that they may have had.

Even though such sources are lacking, as seems to be the case, there is still the possibility that oil may have been derived from vegetal sources. Many coal seams from a few inches to 14 feet thick, as well as highly carbonaceous shales, are known. They represent a luxuriant subtropical vegetation which flourished for long periods and built up thick deposits of vegetal material. These were buried in the muds and clays of the time and later were carbonized. This process would produce gas as one product of the chemical change, but presumably it would be largely marsh gas and not necessarily connected with petroleum. Fresh water beds containing only vegetal remains are not known to have been the source of any commercially important oil accumulation, although they may have been partly instrumental in producing the petroleum of some fields.

Deep drilling here has invariably encountered salt water in some of the porous rocks. If this represents flooding by sea water after the strata were formed and folded, it would have no bearing on the problem of origin and might be considered as an unfavorable condition for accumulation. If it represents water that was present and trapped when the sediments were formed, it indicates that for a time, at least, marine conditions prevailed and that certain zones of deposits might conceivably be a real source for petroleum.

So far as gas alone is concerned, the situation is different. An immense amount of gas has been generated in forming the coals and carbonaceous shales and is still being generated, as is shown by the very gassy condition of the mines of the region. This gas, although not of petroleum origin is, nevertheless, a natural gas which can hardly be distinguished from some "dry" petroleum gases. It may have high-heating value and altogether be an important commercial product. The conditions under which commercial accumulations could occur have been described in the foregoing paragraphs, as they would in no way differ from those pertaining to petroleum gas.

OIL SEEPS

The presence of oil seeps in the area is not proof that commercial amounts of oil are present; but they are important in view of the predominance of fresh-water beds in the Chuckanut series, suggesting the presence of some deposits capable of producing oil. No natural seeps were seen by the writer, since they usually show during the rainy months when the ground water level is high; but reputable witnesses, who would not be misled by films of iron oxide and iridescent vegetal scums on stagnant pools, have reported many occurrences of escaping oil.

A seepage that has become quite notable occurs at times at Alabama and Orleans Streets in Bellingham, and oil, running probably into scores of gallons, has been taken from this place. It is an amber-colored light oil of paraffin base lying between kerosene and gasoline in specific gravity and has been strained and used directly as motor fuel. It was found in pits and ditches over a considerable arèa and was escaping through glacial drift. Mr. H. E. Culver, Supervisor, Division of Geology, has seen this seep when a large amount was being produced and has said that it was apparently not derived from any artificial source.[1]

The writer has noted faint shows of oil rising with gas and salt water from one old abandoned drill hole and has taken small masses of inspissated wax-like oil from drill cuttings brought up in the bailings from another well.

The buried remains of marine life in the Pleistocene sediments might have been the source of some of these rather high-gravity seepages. Such substances could produce oil and no doubt did, but the quantity would be small. Seeps known to come from fissures in the Chuckanut formation are more important and a few such have been reported. If these can be authenticated, they may be taken as a suggestion of larger amounts occurring in favorable locations; however, an alternative interpretation considers these seepages as the product of local distillation of resins and fossil hydrocarbons in the underlying coals.

GAS OCCURRENCES

Gas has been encountered in drilling for water and coal quite generally throughout the area. It finally resulted in rather extensive prospecting in the hope of establishing commercial gas fields, and this has met with considerable success. Five shallow wells, from 132 feet to 200 feet deep, have production from unconsolidated Pleistocene sands, and a few others showed gas to exist in the underlying Chuckanut formation in what are probably commercial quantities. Unfortunately, the latter wells, through trouble with tools, casing, and water, could not be placed in condition for production and had to be abandoned. Essential data pertaining to those having production is given here. Further details of these wells and logs of the formations encountered are given under the head of "Records of drilling."

[1] Oral communication.

Producing wells of the shallow gas field, six miles north of Bellingham

Name	LOCATION	Depth	Capacity; cubic feet per day	Pressure; pounds per cubic inch
Whatcom No. 1...	E. ¼ cor. sec. 28, T. 39 N., R. 2 E............	175	3,000,000 to 4,000,000	50
Chamber of Commerce No. 1.	NW. ¼ SW. ¼ NW. ¼, sec. 27, T. 39 N., R. 2 E.	171	900,000	27
Chamber of Commerce No. 2..	SW. ¼ SW. ¼ NW. ¼ sec. 27, T. 39 N., R. 2 E.	172	1,250,000	28
Chamber of Commerce No. 4..	SE. ¼ SW. ¼ NW. ¼ sec. 27, T. 39 N., R. 2 E.	166	750,000	52
Hunter No. 1.....	SW. cor. NE. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E.	193	5,000,000	70

No commercial use has been made of this gas up to the present time (November, 1934); although it has been burned for domestic purposes at nearby farms. However, a two-inch pipe line is completed now to the County Farm and the metered flow, figured against the maintained pressure, will allow some estimate to be made of the probable life of wells being drawn upon. This information is greatly needed since none of the wells has been allowed to blow for a long enough time to ascertain how the volume will stand up under use.

A tabulation of several gas analyses is included to give some idea of the nature of this gas and with these for comparison are given analyses of known petroleum, coal, and marsh gases from other places. Some of the samples of the gas from wells in this area were taken with care, and dependence can be placed in the analyses; others probably are not so dependable. The great variation in composition is the most striking feature. The high nitrogen content of most of the samples suggests atmospheric contamination, but since similarly high percentages of nitrogen have been found in samples from other localities where air contamination was unlikely, this interpretation in these instances is in doubt. The samples from Kilgard and Abbotsford, although across the boundary in Canada, are really from the north extension of this field, and the analyses are particularly dependable.

Analyses of gas from western Whatcom County and vicinity, with some from other fields for comparison

LOCATION	See text page	ANALYST	Methane (CH_4)	Olefines, etc. (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	Hydrogen (H_2)	Nitrogen (N_2)	Oxygen (O_2)	Hydrocarbons	Illuminants	Specific gravity	B. t. u.
Near Abbotsford, B. C...... 1	40	R. J. Offord, Dept. of Mines, Ottawa	96.65	....	1.15	....	1.08	....	1.12	none	....	....	0.571 to 0.574	....
Near Kilgard, B. C.......... 2	40	G. S. Eldridge & Co., Vancouver, B. C.......	95.1	none	1.5	none	0.2	....	2.8	0.4	....	....	....	950 to 1,000
Anderson farm (Birch Bay) 3	68	Unknown	59.0	....	....	....	0.1	....	40.2	0.6	....	0.1	....	598
Do. 4	68	do.	52.2	....	....	0.8	0.6	6.4	37.3	2.0	....	0.7	0.706	594
Green farm 5	66	Bogardus, Seattle	69.75	....	....	0.70	0.10	5.15	23.90	0.15	0.25	....	....	745.5
Do. 6	66	C. A. Newhall Co., Seattle ...	68.50	....	....	0.60	0.15	5.68	24.62	0.05	0.40	....	....	....
Holman farm 7	61	Unknown	19.0	....	....	2.4	1.0	3.1	70.0	4.4	....	....	....	....
Jepsom farm 8	61	do.	64.0	....	....	1.7	0.9	15.6	14.0	2.8	....	1.0	0.578	759
Lange farm (Well No. 2)... 9	50	Kansas City Testing Lab.	93.4	0.0	2.7	....	0.96	....	2.53	0.41	....	....	....	982
Do. 10	50	W. Alexander, Seattle Gas Co.	53.2	....	0.1	0.6	0.0	0.2	44.5	0.8	....	0.0	0.741	534
Lingbloom farm, Chamber of Commerce No. 1........11	53	K. C. Test. Lab..	36.2	0.2	15.0	....	0.0	....	48.4	0.2	....	....	0.835	630
Do. 12	53	W. Alexander, Seattle Gas Co.	69.1	....	0.4	0.5	0.0	2.2	27.0	0.8	....	0.0	0.663	701
Chamb. of Com. No. 2......13	54	do.	65.7	....	0.7	0.55	0.0	0.55	32.0	0.4	....	0.1	0.691	630
Chamb. of Com. No. 4......14	54	do.	60.5	....	1.6	0.5	0.0	2.7	33.4	1.2	....	0.0	0.695	640
Whatcom No. 1..............15	52	do.	63.5	....	0.4	1.4	0.2	0.7	33.5	0.1	....	0.2	0.700	648
Petroleum gas; Pittsb'g, Pa..	40	①	92.0	....	3.0	....	....	3.0	2.0	....	....	....	....	978
Natural gas; mid-cont. field..	40	①	96.0	....	....	....	0.8	....	3.2	....	....	....	....	967
Coal gas; Scranton, Pa......	40	②	94.20	0.39	....	1.3	1.06	....	3.31	0.92	....	....	....	....
Marsh gas; Western Oregon..	40	③	93.9	....	....	....	2.4	....	3.7	....	....	....	....	....

① Bagley, W. S., Non-metallic mineral products, p. 68, 1930.
② Ries, H., Economic geology, p. 78, 1930.
③ Average of five analyses from Washburne, C. W., Reconnaissance of the geology and oil prospects of northwestern Oregon. U. S. Geological Survey, Bulletin 590, p. 108, 1914.

The available evidence leads to the conclusion that the gas of this area was derived from at least three sources: first, from the gaseous products of decomposition of buried vegetal matter in the Eocene lakes and swamps of the region; second, from the progressive carbonization of plant accumulations to lignite and subbituminous coal; and third, from the distillation of marine organic remains in the Pleistocene clays of the area. That these substances are present and that these processes have gone on, cannot be doubted; that other materials are present and that there may have been another source for the gas is speculative and not subject to proof on present data.

Very little is known about the structure of the Pleistocene beds in which the shallow gas is found to the north of Bellingham. Information must be based entirely on drill records; some of these were very carefully kept, but others are only fragmentary. By using such information as is directly available and adding to it the results of general observations over the whole area, some conclusions are possible.

More or less tilted Eocene shales and sandstones underlie the shallow gas field. Their truncated edges are covered in some places by till, and this may be thick or thin, depending upon original deposition and subsequent erosion. In other places the till was entirely eroded; there the bedrock is covered by the sands and clays of the thick interglacial series. These unconsolidated sediments are stratified and essentially horizontal, but they vary laterally in texture and are generally lenticular. For instance, a bed of sand may increase in thickness from a few inches to many feet and then pinch out altogether. Such changes may happen within a few score of feet or the bed may change abruptly after extending long distances without variation.

Gas escaping slowly from the beveled edges of beds of carbonaceous shale or in considerable volume from tilted sandstone, reservoir rocks may be trapped in overlying beds of sand if the latter are covered by clay. Over long periods of time an immense volume of gas could accumulate in such favorable locations. It is essential that the gas could not escape elsewhere along the strike of the sandstone member; such conditions for retention probably occur in certain structures in this district.

Some such process and conditions are probably responsible for the gas of this field. A well that happened to tap such a sand would get production, while a nearby well might miss the

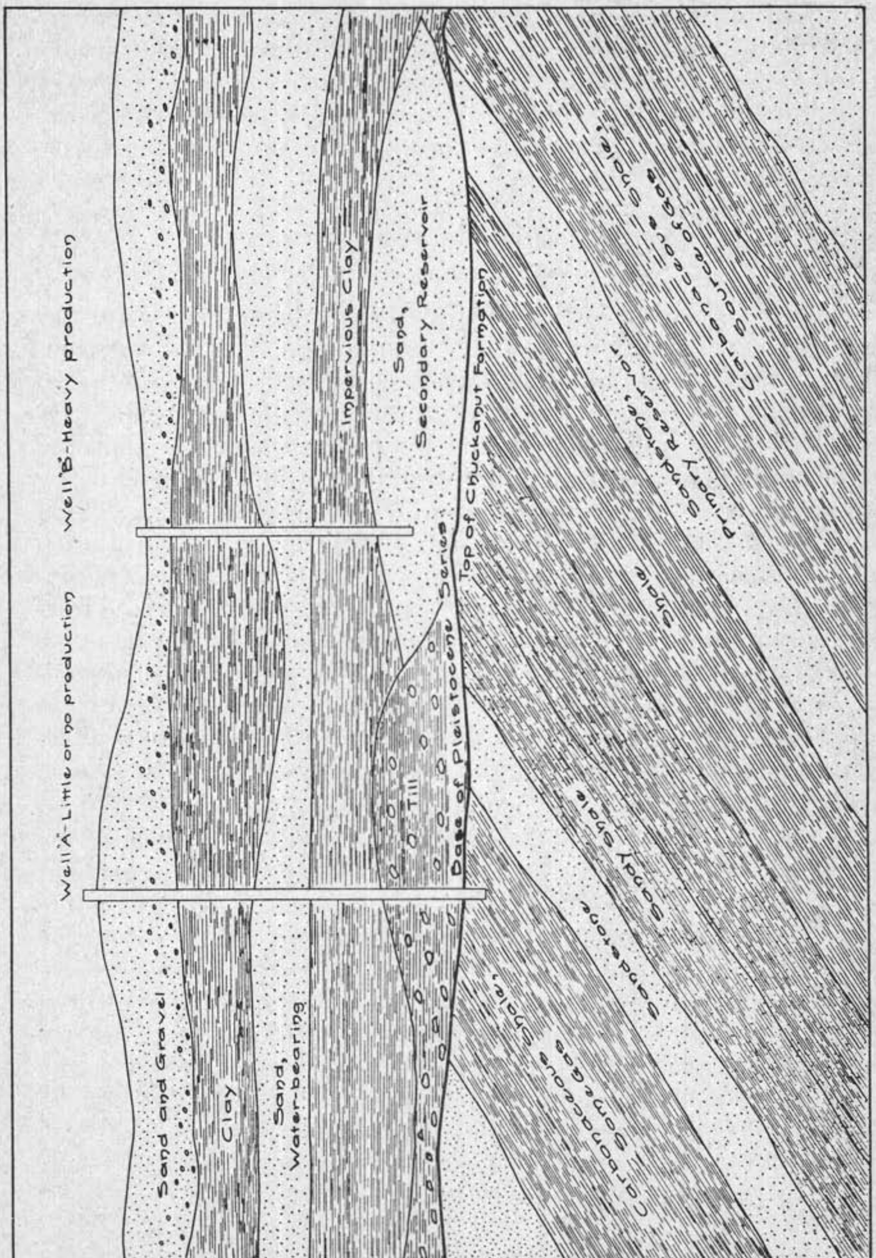

FIG. 1. Diagram showing hypothetical conditions for gas accumulation in Pleistocene sediments.

sand. There would be no way to predict what might be encountered until the outline of such a body, possibly very irregular in shape, was determined by much drilling. A better idea of the hypothetical conditions outlined above may be gained by inspection of Fig. 1. Many variations in these conditions are not only possible but are necessary to account for known occurrences of gas in this field.

AREAS FAVORABLE FOR TESTING

SHALLOW TESTS

Very little can be said as to favorable places to test for the shallow gas occurring in the Pleistocene sands. The occurrences are unique, surface indications are lacking, and results obtained in nearby holes are only roughly indicative of the possibilities of the area. A favorable ground for testing might be expected in the vicinity of a line from Ferndale to just south of King Mountain (near the center of sec. 7, T. 38 N., R. 3 E.). This would be on the probable extension of the King Mountain anticline; and the present gas production indicates that the accumulation was influenced by some such underlying structure. However, many nonproductive holes also have been drilled here, so the bedrock attitude, whatever it may be, is not the only governing factor. It is probably essential that the drill penetrate sealed beds of sand in contact with certain productive underlying strata if gas is to be obtained from the Pleistocene beds.

Test holes will usually range between 150 and 250 feet in depth, so, fortunately, the drilling will be relatively cheap. Care should be used to keep water shut off, for the drilling should be dry to properly test any possible gas occurrence. In some places no water will be struck, in others there may be four or even more water sands. It is possible to carry 6¼-inch casing down through all of the water sands, using temporary shut-offs, pulling the casing and dropping it deeper as successive water-bearing beds are found. Drilling should stop at bedrock, the top of the Chuckanut formation; for there is no indication of what the structure may be under the concealing overburden, and to drill without such information is unwarranted.

DEEP TESTS

No tests have yet been made of the very favorable structures present in the Chuckanut formation. There is a good probability of gas occurring in these and if oil should be present, it will be found under the same conditions. Such tests should be started with a hole large enough to allow for all possible contingencies and reach as great a depth as is possible to carry drilling. A thickness of strata that may reach 10,000 feet or more is involved, and favorable horizons may occur anywhere above the bottom of the series. The rocks are consolidated enough to stand well and yet soft enough for easy drilling. Some squeezing shales may be found but otherwise only water shut-offs need interrupt drilling. As these tests would be initial prospecting, the greatest care should be used to keep the drilling dry in order to make the most of every possible occurrence of either gas or oil; and accurate logs and samples should be kept so that the subsurface material can be studied, and so that there will be a guide for future drilling in these places.

The map (Plate I) gives the location of the various anticlines, and other information will be found under the heading of "Structure" in the body of this bulletin. Additional details on the most favorable structures follow.

Goshen anticline.—This structure is in the east part of T. 39 N., R. 3 E., and lies immediately west of the Bellingham Northern Railroad. Four or five widely separated and isolated outcrops give the indication of the structure and show something of the extent of the fold. They may be seen in secs. 22, 11, and 12, T. 39 N., R. 3 E., and in secs. 18 and 19, T. 39 N., R. 4 E. As the mantle of Pleistocene material is thin, other outcrops may exist in the heavy brush cover of the fields.

The outcrop in sec. 18 forms low cliffs along the railroad right-of-way; the rock is a coarse sandstone grading into grit and fine conglomerate which shows cross-bedding and lensing. A strike of N. 10° W., 22° NE. was obtained on the north end of a slightly overhanging ledge and is thought to hold in general for the outcrop, but data based on this poorly assorted and stratified material are indefinite at best.

The indications of a broad dome-like anticline of low dip and probably large gathering area from the west warrant further and more detailed study. If other outcrops cannot be found, it would be advisable to secure more information, particularly on the south and to the northeast, by means of test pits carried two or three feet into bedrock. Such pits can be contracted to depths of 50 feet and more at around $2.00 per foot. If bedrock could be reached at a reasonable depth, it should be possible to obtain the strike and dip of the rock where no outcrops are available, thus giving a check on present data and probably helping to locate the center, or best drilling site, of the anticline. The structure appears to be very attractive and deserves further investigation to be followed by a very deep test if the present indications are borne out.

King Mountain anticline.—The structure of which the steeply dipping sandstones and fine conglomerates of King Mountain form north flank exposures, extends from near the NW. cor. sec. 7 to about the center of sec. 27, T. 38 N., R. 3 E. and lies just north of the city limits of Bellingham. It is well defined at the west end in spite of the thick mantle rock of the region. The dips there are from 16° to 72°, showing an assymetrical fold, the axis of which lies close to the base of King Mountain. The east end is also fairly well defined by numerous outcrops. Both ends plunge, making a high point on the axis in the N. ½ sec. 16. Unfortunately there are no outcrops in that section, so the determination of structure must be based on data from the two ends.

The north end of Lookout Mountain anticline probably merges with the King Mountain fold in the NW. ¼ sec. 16, although a saddle is likely to occur in the SW. ¼ sec. 16, where the Lookout Mountain axis may be crossed by extensions of the Bellingham basin and Lake Whatcom synclines.

A test of this structure is warranted. The fold is long and narrow so the position of the well is very important in order to be as close to the axial plane as possible, not only at the surface but also at depth. If the indicated assymetrical nature of the anticline continues to sec. 16, the hole should be started south of the axis on the surface in order to be on the axis of beds at a depth of 2,000 feet or so. Exact information is not available, but a favorable position is indicated near the center of the NW. ¼ sec. 16.

Squalicum Mountain anticline.—This is an irregular structure whose main axis trends from the top of Squalicum Mountain, or from just south of this, across the valley lying east of the mountain to about the center of sec. 20, T. 38 N., R. 4 E. north of Olsen Creek. The fold is broad, particularly where it is crossed by Carpenter Creek, and has an extension trending to the north which becomes the Anderson Creek anticline. The strata have dips ranging between 10° and 20°, which is low for this region. Outcrops are abundant except between the two high hills where the center or highest place on the fold is located. The west end of the main anticline is wide and plunges to the northwest; the east end is narrow with moderately steep inclination of its beds; while the north end of the Anderson Creek extension exhibits close folding and steep dips.

A test of the structure is warranted. The exact location of the well is not as important as in the King Mountain or Lake Padden anticlines, but it should be within the N. ½ of sec. 19 or SE. ¼ sec. 18, T. 38 N., R. 4 E.

Lake Padden anticline.—This anticline extends for 3½ miles northeast of Lake Padden. A mile or less to the southwest is the well-defined Lake Padden syncline, while about one-half mile to the northeast is the very poorly defined Samish Lake syncline. These two synclines merge in sec. 31, T. 38 N., R. 2 E. and in sec. 15, T. 37 N., R. 3 E., thus forming the closure, at those places, of the anticline.

It is not thought that this structure has the merit of some of the others, but it does appear to have complete closure and contains considerable acreage. The fold is probably more or less symmetrical although it must be sharp, resulting in a gathering area of no great size. An attempt should be made to secure more detailed information so as to locate the exact position of the axis and the high points thereon. Present information suggests the most favorable drill site lies near the south line of the SW. ¼ sec. 5, T. 37 N., R. 2 E.

Other anticlines.—The anticlines mentioned above are considered the most favorable, and tests of any others should wait on discoveries made in previous drilling. Most of the other structures lack closure in some direction, although a few places on the various axes might be satisfactory, such as at the north end on the north branch of the Chuckanut anticline, and on the north end of Lookout Mountain anticline. However, they should not be considered until more favorable structures have been tested.

RECORDS OF DRILLING

EARLY DRILLING AND GAS DISCOVERY

Drilling has been carried on extensively in western Whatcom County for water and coal, and, during late years, for oil and gas. Information of value in any study of the region may be obtained from the records of such work; and since there are no outcrops of bedrock throughout many townships, these logs constitute the only source of information on lithology and stratigraphy. Some such records were handled very well indeed, but unfortunately in many cases they were not kept as carefully as they might have been. It is at times difficult to understand just what formations are being described. At times, too, one must depend on verbal reports for details where original logs are lost or were not kept at all. It is thought advisable to record all available information and incorporate here everything that has a bearing on underground conditions from whatever source obtained. In so doing, an historical record is also made of the gas development in this region.

Gas has been encountered very commonly in water wells here. The first notice of such an occurrence seems to have been in a well which in 1893 a man by the name of Clark was digging in the SE. ¼ sec. 7, T. 37 N., R. 3 E., in what is now South Bellingham. Clark, who is said to have worn a full beard, was working at between 20 and 30 feet in this well, when he started to light his pipe; there was an explosion of gas and the beard was burned off. A stock company is said to have tried to develop this gas in 1901 by drilling nearby to a depth of about four hundred feet. This old hole, one of the earliest drilled in Washington for gas or oil, did not meet with success, although, as it now stands with casing pulled and caved, there is still some slight gassing.

WELLS IN THE VICINITY OF FERNDALE

The Enterprise oil test was probably the next venture. It was drilled in 1914 a quarter of a mile east of the station of Enterprise on the Great Northern Railway (SE. ¼ SE. ¼ sec. 19, T. 39 N., R. 2 E.). As a matter of fact, there were two Enterprise wells, the first one being discontinued at over a thousand-foot depth on account of a crooked hole. The rig was skidded 15 feet and the second well was drilled with cable tools to a depth of 2,411 feet by the National Oil and Gas Co. of Vancouver, B. C. After that, it was continued to 3,500 feet by diamond drill for the Canadian Oil and Venture Co. by Stone Bros. of Spokane. Some of the cores from this last work have been saved; those seen by the writer were of sandstone and very shaly sandstone, containing leaf fragments and coaly matter and differing in no degree from characteristic Chuckanut rock.

Log of Enterprise well

	Thickness. Feet.	Depth. Feet.
Quicksand	30	30
Sand, blue	70	100
Quicksand and gravel	95	195
Clay, blue	390	585
Sand, water	30	615
Shale, rotten; and clay (a)	225	840
Sand, coarse; flour sand	295	1,135
Conglomerate	20	1,155
Sand, gray	15	1,170
Clay, blue	30	1,200
Sand, fine gray (b)	20	1,220
Coal	5	1,225
Sand, gray	5	1,230
Clay, blue	10	1,240
Shale	30	1,270
Clay	65	1,335
Shale, brown	30	1,365
Sand, sharp white	15	1,380
Shale, rotten brown (c)	20	1,400
Shale, rotten	80	1,480
Shale, sandy (d)	10	1,490
Shale with gas, brown	60	1,550
Shale, light sandy	95	1,645
Shale, rotten brown	50	1,695
Shale, light sandy	5	1,700
Shale, brown	65	1,765
Shale with gas	1	1,766
Clay, blue	49	1,815
Sand, dark-gray	5	1,820
Clay, blue	40	1,860
Sand, sharp white	20	1,880
Clay, blue	12	1,892
Coal	3	1,895
Sand, gray	2	1,897
Clay, blue	18	1,915
Sand, sharp gray	43	1,958
Coal	2	1,960
Clay, blue	25	1,985
Sand, sharp gray and small streaks of clay	55	2,040
Shale; gas	2	2,042
Clay, blue	50	2,092
Shale, brown; gas	48	2,140
Limestone	5	2,145
Shale, hard; sandstone overlying	5	2,150
Coal with yellow clay caving badly	15	2,165
Shale, hard (e)	5	2,170
Shell, blue	65	2,235

Log of Enterprise well—Continued

	Thickness. Feet.	Depth. Feet.
Sand, fine	10	2,245
Shell, limestone	2	2,247
Shale	3	2,250
Sandstone, fine	15	2,265
Sandstone	2	2,267
Coal, some gas	10	2,277
Shale, dark-blue	5	2,282
Shale, black	8	2,290
Sand, fine; some gas	10	2,300
Sandstone, hard	3	2,303
Sandstone, fine; light gas	50	2,353
Shale, blue and black, carrying heavy gas	58	2,411
Drilled with standard rig to 2,411 feet; continued with 1½-inch diamond drill. Oil showing at 2,500 feet	1,204	3,615

(a) Probably at bottom of Pleistocene formation.
(b) End of 8-inch casing.
(c) Shot and broke off casing.
(d) Hard shale overlying.
(e) Salt water.

The greatest impetus was given to exploration in this region by the gas which W. T. Lange encountered in 1920 while drilling for coal with a portable horse-powered rig on his farm in the SE. ¼ NE. ¼ sec. 28, T. 39 N., R. 2 E. A small casing was used in which was a pipe, probably of 2-inch diameter. At 168 feet a heavy pressure of gas was struck which threw the small pipe out of the hole and up the hillside. This gas came in with a flow of brackish water and was lighted and burned for several days until shut off by driving the casing deeper. Then in 1930 another well, now known as the Lange No. 1, was drilled about 50 feet from the first Lange well in an effort to exploit the gas. Ten-inch casing was used, and at the very shallow depth of 63 feet gas was struck which threw mud and water to the top of the rig. More gas was struck between 100 and 110 feet, while at 168 feet the heavy flow corresponding to that of the earlier well was tapped. There was no water shut-off, so the well was standing full of water at the time, and all of this was blown out of the hole by the gas. Another group took over this operation then, and the hole was deepened to 500 or 600 feet where it was lost through drilling misfortunes.

The third Lange well, which is now known as the Lange No. 2, was started in 1931 fourteen feet east of the original hole and carried to a depth of 2,008 feet. This also encountered the heavy gas flow at 168 feet; and again, since there was no water shut-off, the column of mud and water was blown out of the hole by gas flowing at the estimated rate of 250,000 cubic feet per day. A careful check of what information is now available makes it possible to record certain features of Lange No. 2. (The third well drilled here.)

Log of Lange No. 2 well

	Thickness. Feet.	Depth. Feet.
Clay, "heaving sand," and gravel	150	150
Conglomerate (till?) (a)	4	154
Sandstone (set 8-inch casing)	205	359
Sandstone and shale, alternating. Shale estimated 75%, upper more of a gray color, lower dark to black	1,569	1,928
Shale, greenish-blue	80	2,008

(a) Probably the approximate base of the Pleistocene series.

There had been no water shut-off, so the position of water-bearing beds is in doubt. During the earlier drilling the water had been brackish, but at 585 feet salt water flowed over the top of the casing. This flow may have been due to increased gas pressure, but there was a notable increase in the salinity of the water at this point indicating a new source. At 728 feet there was more gas, while between 1,345 and 1,365 feet the largest flow was struck; this raised the 6-inch column of water 20 feet over the casing. In the attempt to make this well a commercial producer, great difficulties were met with: the casing parted while being lifted, dropped and wedged in the hole, and then the fishing tools were lost. The drilling was down to 4½ inches in size, and more than 956 feet was uncased. Due to these troubles and the small size of rig and hole, it was finally decided to abandon the work after two years of effort. With casing and tools still lodged in the hole and with a flow of 800 barrels of salt water per day, the gas on a two-month metered test was said to have averaged 50,000 cubic feet per day. An unusually high pressure has been recorded; it is said that the gauge showed 470 pounds day after day, although now, due probably to bridging and partial shut-off, the pressure has dropped to 350 pounds.

Following the Lange drilling, a number of shallow wells were completed in this immediate vicinity. Some were producers; some were unsuccessful. Wells were drilled in other districts, in general, without getting commercial gas. All these results, whatever they may have been, are of value, and logs and data pertaining to them, from as reliable sources as possible, are presented for the bearing they have on the study of the field.

Whatcom No. 1, of Whatcom Natural Gas Co. is located at the E. ¼ cor. sec. 28, T. 39 N., R. 2 E. This well is reported to have a capacity of from three to four million cubic feet per day. The pressure is 50 pounds. The gas on open flow through a two-inch pipe issues with a deafening roar and when ignited burns with a flame which is almost colorless in daylight, showing yellow at 30 to 40 feet from the opening.

Log of Whatcom No. 1 well

	Thickness. Feet.	Depth. Feet.
Sand and gravel, loose	90	90
Clay, blue	10	100
Sand and gravel	30	130
Clay, blue, limy, stiff and very tough	30	160
Sand, water-bearing, fine, also some loose gravel	11	171
Clay, gray, very hard and dense	0.5	171.5
Sand, loose, fine, bluish-gray, carrying heavy flow of gas	4+	175.5+

Whatcom Natural Gas Company's well No. 2, 650 feet west of Whatcom No. 1, was drilled to a depth of 216 feet, almost entirely in an unconsolidated fine water-bearing sand, which, due to its characteristic of surging up the hole behind the drill, is known as "heaving sand." No gas was found and the hole was abandoned.

Livermore No. 1 is located approximately 300 feet south of Lange No. 1, near center of the SE. ¼ NE. ¼ sec. 28, T. 39 N., R. 2 E. No gas was found and the hole was abandoned.

Log of Livermore No. 1 well

	Thickness. Feet.	Depth. Feet.
Sand, silty, some water	76	76
Clay, tough, few pebbles	12	88
Sand, muddy, clay streaks	72	160
Clay, with considerable gravel	54	214
Sand, fine, water-bearing	11	225

Cowden No. 1 well is located about 75 feet southeast of Livermore No. 1 and logs of these two tests are similar. It was drilled to 390 feet and at the bottom was reported to have had an oil-saturated sand. It was abandoned because of inability to drive the casing any deeper to shut out the water.

Cowden No. 2 well is located 200 feet north of Whatcom No. 1. Blue clay was encountered to 200 feet where boulders occurred, followed by soft sand to 205 feet. A peculiar feature was the absence of water. No gas was found and the test was abandoned.

Chamber of Commerce well No. 1 is located on the J. E. Lingbloom farm in the NW. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E. This well "blew in" for five feet after drilling stopped, as shown by 171-foot measurement by steel line. The capacity of the well is given as 900,000 cubic feet at 27 pounds pressure. (2.8 inches mercury in Pitot tube test.) The casing record follows: 99 feet 5 inches of 10-inch; 161 feet 1 inch of 8-inch; and 171 feet of 2-inch tubing. Packer set at 160 feet in 8-inch casing.

Log of Chamber of Commerce well No. 1

	Thickness. Feet.	Depth. Feet.
Soil	2	2
Sand, brown	10	12
Sand and gravel	30	42
Shale, blue, sandy, little water, not enough for drilling	34	76
Sand, gray	8	84
Shale, gray, sandy	10	94
Sand, blue, very soft, no water	5	99
Sand, blue-gray, fine	10	109
Sand, fine, gray, with boulders	30	139
Sand and conglomerate, coarse	6	145
Sand, limy, fine, gray, carrying a little gas	5	150
Sand, limy, coarse, dark	5	155
Conglomerate, limy, very hard	5	160
Sand, gray, carrying some gas	5	165
Sand, gray, carrying gas	6	171

Chamber of Commerce well No. 2 is located on the O. H. Lingbloom farm in the SW. ¼ SW. ¼ NW. ¼ sec. 27, T. 39 N., R. 2 E. The log of this well is not available, but those familiar with this drilling say that there is practically no difference between the logs of the Chamber of Commerce wells Nos. 1, 2, 3, and 4. Well No. 2 struck gas at 172 feet with a pressure of 28 pounds and a capacity of 1,250,000 cubic feet per day. A small pipe line carries this gas to the homes of O. H. and J. E. Lingbloom, where it is being used for domestic heating.

Chamber of Commerce well No. 3 is located on the J. E. Lingbloom farm, in the NE. ¼ SW. ¼ NW. ¼ sec. 27, T. 39 N., R. 2 E. This well was drilled to 212 feet and encountered no gas. It may have had more water than some in the vicinity, thus accounting for the "heaving" of the sand which was notable here.

Chamber of Commerce well No. 4 is located on the O. H. Lingbloom farm, in the SE. ¼ SW. ¼ NW. ¼ sec. 27, T. 39 N., R. 2 E. This well, drilled to a depth of 166 feet 3 inches, came into production out of a dry sand. The capacity is given at 750,000 cubic feet per day and the pressure at 52 pounds.

Chamber of Commerce well No. 5 is located on the F. E. Brown farm, in the SW. cor. sec. 27, T. 39 N., R. 2 E. This test was bottomed at 701 feet and abandoned because the gas showing was not of commercial size.

In the absence of samples the limestone mentioned in this log at 260, 354, 492 and 575 feet is a puzzling feature. A driller will often label a bed "lime" on account of the feel of the tools or because of some effervescence with acid even though it is not a true limestone. Mr. Snyder, driller of this well, is not likely to make this error for he is thoroughly familiar with limestone as encountered in eastern fields. Furthermore, fragments brought to the surface are reported to have been hard, white, and traversed by blue veinlets, and to have been entirely dissolved in hydrochloric acid. So far as can be learned this is the first report of limestone in the Chuckanut formation, none having been noted in other logs penetrating these beds, nor recorded from inspection of outcrops. Samples of such material from subsequent drilling will be of especial interest and should be preserved for study.

Log of Chamber of Commerce well No. 5

	Thickness. Feet.	Depth. Feet.
Soil	2	2
Sand	18	20
Gravel	3	23
Sand	25	48
Shale, sandy	10	58
Sand	47	105
Shale	20	125
Sand, fine	8	133
Sand, coarse	7	140

Log of Chamber of Commerce well No. 5—Continued

	Thickness. Feet.	Depth. Feet.
Shale	42	182
Sand, coarse	23	205
Shale	5	210
Sand	15	225
Shale	17	242
Shale	13	255
Shale	5	260
Lime rock	10	270
Sand	30	300
Shale	10	310
Sand	5	315
Shale	5	320
Sand	34	354
Limestone	3	357
Shale, dark	18	375
Shale, light	10	385
Shale, dark	5	390
Shale, gray, sandy	19	409
Sand and lime	4	413
Shale, light	37	450
Shale, dark	5	455
Coal	1	456
Shale, dark	14	470
Shale, gray	22	492
Limerock	5	497
Shale	18	515
Sand	12	527
Shale, gray	10	537
Coal	3	540
Shale, gray	15	555
Sand	20	575
Lime	5	580
Sand	17	597
Shale, brown	2	599
Sand	5	604
Shale, blue	16	620
Coal	2	622
Shale	3	625
Sand	19	644
Sand and shale	40	684
Sand containing salt water	12	696
A little gas		
Lime and sand	5	701

A well on the H. C. Beyers farm, near the SE. cor. NE. ¼ NW. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E. encountered no gas and was abandoned.

Log of well on H. C. Beyers farm

	Thickness. Feet.	Depth. Feet.
Soil	2	2
Sand and gravel	13	15
Sand, "heaving"	125	140
Shale	15	155
Sand, "heaving"	83	238

Hunter No. 1 well is located on the L. W. Harden farm, near the SW. cor. NE. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E. This was drilled through Pleistocene sands, gravels, and clays similar to other wells of the vicinity. At 193 feet it struck a heavy flow of gas estimated at over 5,000,000 cubic feet per day at a pressure of over 70 pounds. While "drilling itself in," the loose sand in which the gas occurred was blown out of the hole and scattered widely by the wind. After lying idle for several months, the well was opened by drilling out a cement plug and it was then found that water had invaded the gas sand and, it is reported, lowered the pressure and flow.

Hunter No. 2 well is located on the L. W. Harden farm in the NW. ¼ SE. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E. about 650 feet south of Hunter No. 1. After passing through materials not differing greatly from those of Hunter No. 1, the Pleistocene formation was bottomed at about 200 feet without having found gas in appreciable amount. Drilling was continued for 200 feet or so into the Chuckanut formation in the expectation of developing a deeper gas. Care was used to keep a tight water shut-off, and some gas was encountered at two horizons. The deeper of these built up considerable pressure, but not sufficient to make the well commercial, so the hole was abandoned.

Hunter No. 3 well, near the SE. cor. NW. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E., has been only recently completed, and but little information is available. It is reported to have encountered a commercial flow of dry gas at 330 feet in Pleistocene sediments.

The Abbotsford Oil and Gas Co. well is located on the C. C. King farm in the SE. ¼ SE. ¼ SW. ¼ sec. 27, T. 39 N., R 2 E. This drilling, the log for which is available to 342 feet, was later continued to 800 feet, where an encouraging amount of gas was encountered. It is expected that the test will be continued to 1,400 feet in the hope of getting the gas horizon of the Lange well.

Log of the Abbotsford Oil and Gas Co. well

	Thickness. Feet.	Depth. Feet.
Soil	3	3
Sand	55	58
Clay, soft	12	70
Clay, sandy	20	90
Clay, very soft	10	100
Sand, fine	10	110
Sand and gravel, coarse	15	125
Clay, sandy	28	153
Clay	5	158
Clay, sandy	15	173
Sand, coarse (a)	67	240
Shale, blue, tough	5	245
Sandstone	3	248
Shale, black	1	249
Shale, gray	6	255
Shale, sandy	7	262
Shale, brown	8	270
Shale, gray	15	285
Shale, fine, gray, with thin layers of hard sand	19	304
Sandstone	4	308
Shale, blue, sticky, thin sand layers	17	325
Shale, brown	17	342

(a) Bottom of Pleistocene occurs near this member, possibly in it; the exact position is in doubt.

The Van-Bell No. 1 well is located on the E. Bettsinger farm in the SE. ¼ NE. ¼ SW. ¼ sec. 27, T. 39 N., R. 2 E. At 603 feet the casing was pulled and the hole abandoned.

Log of the Van-Bell No. 1 well

	Thickness. Feet.	Depth. Feet.
Surface soil	4	4
Sand and gravel (first water at 10 feet)	20	24
Sand and light clay	1	25
Clay, blue, soft	5	30
Sand, hard, gray	2	32
"Hard-pan"	2	34
Clay, hard, sandy, dry	21	55
Sand, coarse, water-bearing	25	80
Clay, hard, sandy	25	105
Sand and gravel, tight	15	120
Clay	1	121
Sand and water-gravel (Water rose 74 feet in hole)	13	134
Clay	1	135
Sand and gravel	35	170

Log of the Van-Bell No. 1 well—Continued

	Thickness. Feet.	Depth. Feet.
Clay, sandy, with cemented gravel, dry. Bottom of 179 feet of 10-inch casing. Water shut-off	12	182
Clay, sandy, with pebbles and cemented gravel	42	224
Sand and gravel. 100-foot rise of water	24	248
Gravel, cemented, and 10 per cent clay (a)	7	255
Shale, dark-gray, sticky	50	305
Shale, hard gray, showing lime, firm	10	315
Sandstone, hard, gray, lime-streaked	21	336
Shale, brown. Oil show	1	337
Sandstone, limy	13	350
Bottom of 8-inch casing at 345 feet		
Shale, gray	20	370
Sandstone, gray	20	390
Shale, dark	8	398
Coal, bright, black (cave-in at bottom)	4	402
Shale, light, bony	3	405
Shale, gray	13	418
Set 418 feet of 6-inch casing		
Shale, gray with sandstone layers	12	430
Shale, dark, sticky	25	455
Sandstone, gray. Hole dry	5	460
Shale, gray, sandy and pebbly	35	495
Coal seams in layers of shale	5	500
First salt water. Rose immediately 175 feet in the hole.		
Sandstone, coal seams	15	515
Shale and sandstone in layers	10	525
Sandstone, hard, gray	15	540
Shale, hard, light-brown, gritty	8	548
Sandstone, gray	3	551
Shale, dark, sandy	6	557
Reduced to 4½ inches on account of caving from 500 feet. Set 550 feet of 4½-inch casing.		
Sandstone with shale layers	8	565
Shale, dark, sandy	2	567
Sandstone	2	569
Shale, dark	5	574
Sandstone	1	575
Shale	2	577
Sandstone, gray	7	584
Water, "salty as the sea," was struck at 580 feet; it rose 300 feet in the pipe. A slight amount of gas showed for a short time only with this water.		
Sandstone, coarse	8	592
Shale	1	593
Sandstone. Bottom of 4½-inch casing	8	601
Shale	2	603

(a) Probably bottom of Pleistocene sediments.

The Covey and Baus well No. 1, near the center of the N. ½ sec. 35, T. 39 N., R. 2 E. went through 25 feet of surface soil and clay and 78 feet of "heaving sand" to the depth of 103 feet. It was drilled deeper, but the lower part of the log is unknown. No gas was found and the hole was abandoned.

A well was drilled for water near the north line of the NW. ¼ sec. 33, T. 39 N., R. 2 E. This went through clay for 200 feet and then struck saline, sulphurous, artesian water in underlying sand. It is reported that this well stopped flowing when the Whatcom No. 1 gas well was brought in.

Artesian saline water was produced from a water well drilled in the NE. ¼ sec. 31, T. 39 N., R. 2 E.

In a water well drilled in the NE. ¼ sec. 30, T. 39 N., R. 2 E. a good flow of artesian water was struck at 235 feet. This was probably wholly in the Pleistocene sediments.

The Shale Oil and Gas Co.'s well is located in the SE. ¼ NW. ¼ NW. ¼ sec. 3, T. 38 N., R. 2 E. on the Harry Brown farm. Gas was expected at 230 feet but did not come in and the hole was abandoned.

Log of Shale Oil and Gas Co.'s well

	Thickness. Feet.	Depth. Feet.
Surface soil	2	2
Sand	3	5
Sand and soft clay	15	20
Boulders	4	24
Sand and gravel	26	50
Sand	4	54
Sand, water-bearing. Good showing of oil	3	57
Sand, loose	98	155
Sand, caving	8	163
Gravel, water-bearing	1	164
Sand	5	169
Clay	55	228
Sand and gravel, loose	2	230
Clay or shale	21	251

The water well of Greenacres Memorial Park is located near the SW. cor. SE. ¼ sec. 22, T. 39 N., R. 2 E. The casing record follows: 12-inch to 243 feet, 6-inch to between 350 feet and 450 feet, open hole to 775 feet.

Log of Greenacres Memorial Park well

	Thickness. Feet.	Depth. Feet.
Sand	22	22
Clay, blue	225	247
Sand and gravel, water-bearing	5	252
Sand, finely packed	69	321
Sandstone	17	338
Shale and sandstone	192	530
Shale, hard, carrying gas	245	775

The Acme Oil and Gas Co. of Bellingham have been drilling a test hole northwest of Ferndale, near the center of the S. ½ SE. ¼ sec. 13, T. 39 N., R. 1 E. This hole was started with a 10-inch casing; it is 1,241 feet deep, and probably will be continued. The Pleistocene sediments were not less than 425 feet thick and may have been as much as 595 feet. No coal beds were struck. It is reported that there were some showings of both gas and oil.

WELLS IN THE VICINITY OF MARIETTA

Near the E. ¼ cor. sec. 8, T. 38 N., R. 2 E., in a water test, a well was drilled through 18 feet of sand and then 182 feet of clay before being abandoned.

A water well drilled in the NW. ¼ sec. 8, T. 38 N., R. 2 E., went through 24 feet of river fill and sand and then through 450 feet of clay and was abandoned.

A water well drilled in the NW. ¼ SW. ¼ sec. 15, T. 38 N., R. 2 E. is said to have reached bedrock at a depth of 245 feet.

Another water well was drilled in the NE. ¼ sec. 7, T. 38 N., R. 2 E., and went through 36 feet of river silt carrying salt water and then through blue clay to a depth of 475 feet.

WELLS IN BELLINGHAM AND VICINITY

A water well drilled near the corner of Maple and H Streets is said to have struck bedrock at 170 feet, but sandstone and shale, carrying a little fresh water, is reported at 100 feet. These were probably Pleistocene sediments.

A water well near the corner of Chestnut and I Streets was drilled to 113 feet without reaching bedrock. Brackish water was encountered.

A water well drilled near a mill in the SW. ¼ sec. 33, T. 38 N., R. 3 E., went through 12 feet of soil, 32 feet of sandstone, and then 2 feet of coal.

A water well in the NW. ¼ sec. 33, T. 38 N., R. 3 E., went through 93 feet of blue clay.

Logs obtained in drilling for coal just north of Bellingham are given in Jenkins'[1] report and may be referred to there. They include the following:

Bore hole No. 1 (931 feet deep), in the SE. ¼ SW. ¼ sec. 18, T. 38 N., R. 3 E.
Bore hole No. 2 (600 feet deep), in the E. ½ SW. ¼ sec. 18, T. 38 N., R. 3 E.
Bore hole No. 4 (491 feet deep), in the E. ½ NW. ¼ sec. 19, T. 38 N., R. 3 E.
Bore hole No. 5 (675 feet deep), in the W. ½ NW. ¼ sec. 19, T. 38 N., R. 3 E.
Bore hole No. 6 (546 feet deep), in the center of S. ½ NE. ¼ sec. 24, T. 38 N., R. 2 E.
Bore hole No. 7 (380 feet deep), in the W. ½ NE. ¼ sec. 24, T. 38 N., R. 2 E.
Bore hole No. 8 (375 feet deep), in SE. ¼ sec. 13, T. 38 N., R. 2 E.
Bore hole No. 9 (438 feet deep), in the center E. line SW. ¼ SE. ¼, sec. 13, T. 38 N., R. 2 E.
Bore hole No. 10 (469 feet deep), in the NE. ¼ NW. ¼ sec. 24, T. 38 N., R. 2 E.

WELLS IN THE VICINITY OF VAN WYCK

Wells on the Holman place, near Van Wyck, at the SW. cor. of sec. 2, T. 38 N., R. 3 E. Two wells were drilled here for water about 20 years ago. One struck gas, which only lasted 24 hours or so, at 40 feet, then a heavier flow of gas was struck at 90 feet. This continued while the drilling went to 160 feet. The water obtained was of poor quality and carried gas in spite of attempts to case it off. The second well was drilled about 300 feet north of the first one, and this encountered gas at 75 feet and was also reported to have had a show of oil with the gas in the mud from the bailer. By casing off this gas they obtained good water in gravel at 127 feet.

A third well was drilled here 30 feet east of the first one, by Van-Bell Holding Co. in an attempt to develop the gas. They found sediments of a different type and no gas. This shows that a marked change may occur in the Pleistocene material in very short distances. No gas was found and the hole was abandoned.

Log of Holman No. 3 well. (Van-Bell)

	Thickness. Feet.	Depth. Feet.
Surface soil	3	3
Clay, yellow and boulders	12	15
Clay, blue, some boulders. Small amount of water and show of gas at 53 feet	114	129
Gravel, dry	22	151

The N. H. Jepsom well is located at the SW. cor. sec. 10, T. 38 N., R. 3 E. "The rock was greatly broken from 245 feet to 270 feet, where drilling stopped. At 210 feet saline water was struck which carried a considerable volume of gas. This gas has

[1]Jenkins, O. P., op. cit., pp. 69-80.

been used for domestic purposes at the Jepsom farm ever since it was discovered.''[1]

Log of N. H. Jepsom well

	Thickness. Feet.	Depth. Feet.
Soil and "hardpan"	10	10
Clay, to bottom of Pleistocene	80	90
Shale and shaly sandstone	180	270

A second well is said to have been drilled in an attempt to produce this gas. It was carried to a depth of 600 feet, but the results of the tests are not known, except for the report that, due to a misunderstanding, the gas horizon, when struck, was not properly developed.

A water well drilled in the NE. ¼ SE. ¼ sec. 9, T. 38 N., R. 3 E., went through 114 feet of Pleistocene sediments without reaching bedrock.

A water well drilled in the SW. ¼ sec. 10, T. 38 N., R. 3 E. struck bedrock at 104 feet and was continued through very hard sandstone and blue shale, to a depth of 175 feet.

A water well drilled near the west line, NW. ¼ sec. 31, T. 39 N., R. 3 E. had soil and hardpan for 10 feet, clay for 20 feet, and then dry gravel for 50 feet. At 74 feet this well struck an undecayed cedar log about two feet in diameter.

A water well in the NW. ¼ sec. 33, T. 39 N., R. 3 E. had clay with gravel for 50 feet, dry gravel for 120 feet, and then very fine sand carrying fresh water for 32 feet. This drilling stopped in clay at 202 feet.

Gas was carried with water struck at the very shallow depth of only 28 feet in a well in the Pleistocene sediments in the SW. ¼ SW. ¼ sec. 2, T. 38 N., R. 3 E. This was close to the Holman farm where gas also occurred.

A water well drilled in the SW. ¼ SE. ¼ sec. 2, T. 38 N., R. 3 E. after going through chiefly blue clay struck 9 feet of water-bearing gravel at 142 feet. This was underlain by blue clay.

A test to 1,625 feet was made for oil and gas on Alabama Ridge, approximately at the center of sec. 15, T. 38 N., R. 3 E., just west of Squalicum Mountain. Cable tools and a portable drilling rig were used. Casing record: 216 feet of 10-inch casing, 10-inch open hole to about 750 feet; then reduced open hole to 8 inches from 750 feet to 1,200; and again reduced open hole to 6 inches from 1,200 to 1,625 feet. There was no need to reduce

[1]Personal communication from C. F. Livermore.

casing except to ease the drilling engine. No water occurred below 216 feet during drilling, and the hole was dry when finished, yet, six months after this drilling was stopped the hole was found to be full of salt water through which gas was bubbling. These conditions obtain at the present time. A few thin colors which come up with the gas are noticeable. The log of this well follows:

Log of Alabama Ridge well

	Thickness Feet.	Depth. Feet.
Soil and brown clay	3	3
Conglomerate, very hard	17	20
Sandstone, gray	10	30
Clay, blue; some sand	30	60
Shale, sandy, gray; little gas	35	95
Shale, dark gray	77	172
Shale, dark gray, sandy	3	175
Shale, dark, and clay	15	190
Shale, dark brown, and dark sand	15	205
Shale, dark brown	45	250
Shale, dark gray, sandy	15	265
Shale, gray	70	335
Sandstone, light gray; little gas	30	365
Sandstone, dark gray	5	370
Sandstone, light, fine, very hard	5	375
Sandstone, dark-gray, very fine	15	390
Shale, dark sandy	5	395
Shale, very dark	55	450
Shale, dark-gray, sandy, and brown shale	10	460
Shale, gray sandy	15	475
Shale, gray sandy; mixed light sand	25	500
Sand, coarse mixed dark and light; some shale	18	518
Shale, gray sandy, and clay	22	540
Sandstone, gray, very hard	15	555
Shale, dark sandy; some brown shale	20	575
Lime, light-gray, sandy, clayey	25	600
Clay, gray; sandy, white pebbles	20	620
Shale, dark-blue, sandy	15	635
Sand, dark gray and white, very hard	10	645
Shale, dark, very hard; lime cap with mixed black and white sand showing some gas; then cap rock of compact sand carrying first gas (a)	40	685
Same formation as above, with coarser sand and some lime; some gas	20	705
Sand, gray, white and black; brown shale, clay and lime. Gas burns at the top of the 10-inch pipe, explodes, then continues burning with very blue flame down the pipe	30	735

(a) Probably only gas encountered.

Log of Alabama Ridge well—Continued

	Thickness. Feet.	Depth. Feet.
Shale, sandy, dark-gray to dark-blue to brown; little gas	20	755
Shale, gray, sandy with thin streaks of dark gray sand, shells	20	775
Shale, black to brown, slaty, with small rounded pebbles, bituminous	20	795
Shale and small rounded loose pebbles; some sand	5	800
Sand rock, soft, light gray	60	860
Shale, sandy, blue to black	20	880
Sand and shale, mostly dark gray sand	10	890
Shale, dark blue, sticky gumbo streaks	12	902
Sand lenses in clay	33	935
Shale, blue, mixed with sand	5	940
Sand, little shale, light yellow	5	945
Shale, soft gray	20	965
Slate, brownish black, petroliferous, coal seams, large chunks in bailer; gas increasing	10	975
Sandstone, soft	15	990
Shale, sandy, light blue	15	1,005
Sandstone, gray with thin limy streaks; small sandstone samples recovered are lignitic; loose sandstone conglomerate, shale streaks	5	1,010
Shale bands, thin lignitic	30	1,040
Sandstone, gray; shelly seams	40	1,080
Shale, sandy, gray to blue	3	1,083
Shale, slaty, blue to black, with thin streaks of lignitic slate, impure coal	42	1,125
Shale, black-blue	10	1,135
Sandstone, fine-grained, very hard, some lime	15	1,150
Lime sand pebbles, small	20	1,170
Shale, loose, dark blue	70	1,240
Shale, sandy, and sand	66	1,306
Shale, and limy sticky shale	3	1,309
Shale, dark-gray, and sand shells, thin	31	1,340
Shale, blue, sandy	20	1,360
Sandstone, sharp, light-gray	25	1,385
Sandstone, fairly hard, fine conglomerate pebbles, light gray to deep yellow	50	1,435
The same	20	1,455
Shale, blue, clayey	30	1,485
Shale, not so sandy	70	1,555
Shale, dark-gray, more sandy	45	1,600
Sandstone and streaks of sandy shale	25	1,625

Stopped drilling in sharp sandstone.

WELLS IN THE VICINITY OF ANDERSON CREEK

A well drilled in the SE. ¼ SW. ¼ sec. 31, T. 39 N., R. 4 E., produced artesian water from the Pleistocene sediments at a depth of 90 feet. Blue clay and fine black sand were penetrated.

Another artesian water well was drilled in the NE. ¼ NW. ¼ sec. 6, T. 38 N., R. 4 E. Water coming from a depth of 156 feet was reddish in color and carried a little gas.

A water well driven in the SW. ¼ SE. ¼ sec. 7, T. 38 N., R. 4 E., went through blue clay for 93 feet.

A diamond drill hole was put down about a mile to the northeast of Squalicum Lake in the SE. ¼ sec. 6, T. 38 N., R. 4 E. The log follows:

Log of diamond drill hole near Squalicum Lake

	Thickness. Feet.	Depth. Feet.
Glacial drift, sand, and gravel	200	200
Hardpan		
Sandstone		
Shales, brown and gray	91	291
Shales, sandy		
Coal seam No. 1		
Shale, clayey		
Shale, sandy and interbedded	92	383
Sandstone		
Coal seam No. 2		
Sandstone, coarse, white		
Shale, carbonaceous		
Shale, clayey		
Shale, carbonaceous		
Shale, clayey and thin, interbedded coal seams (a)	197	580
Sandstone, coarse, white		
Shale		
Sandstone		
Coal seam No. 3		
Sandstone, gray		
Sandstone, shaly	60	640
Sandstone, gray		
Coal seam No. 4		
Shale, clayey		
Shale, sandy		
Shale, carbonaceous	235	875
Sandstone, gray		
Shale, carbonaceous, and many thin coal seams		
Coal seam No. 5		
Shale and thin coal seams		
Sandstone		
Shale	87	962
Sandstone		
Shale and sandstone		

(a) Large flow of gas at 495 feet.

WELLS IN THE VICINITY OF CEDARVILLE

A well drilled for water on the Green farm near the north line of the NW. ¼ sec. 33, T. 39 N., R. 4 E., is reported to have gone through clay for 68 feet; then, in a layer of "hardpan," gas was struck with an estimated flow of 25,000 cubic feet per day. No water came in with the gas. After being lighted and burned at open flow for sixteen hours, the hole was deepened; water, with heaving sand, was struck, and the gas flow was lost.

Two other wells were drilled near the above and another a quarter of a mile to the south. Considerable interest attached to the gas occurrence and some tests were made. The information now available is vague. One report states that the first three wells were drilled to depths of 78, 58 and 102 feet respectively, and that all three showed gas out of dry holes. Gas from No. 1 is said to have burned 12 to 15 feet above the 4-inch casing. No. 3, according to this report, was in blue clay for 71 feet, blue shale for 2½ feet, with sandstone for 8½ feet. The remaining 21 feet is not recorded.

On the Erickson farm, a quarter of a mile west of the Green farm, a well drilled for water struck gas at 61 feet, which is now being used for domestic heating. About a mile southwest is the Barnhart farm, where a well drilled for water struck gas at 80 feet. This gas was cased off and the well deepened for water after the gas flow was accidentally ignited, nearly burning the house down.

A well drilled for water near the south line of the SW. ¼ sec. 28, T. 39 N., R. 4 E., has gas coming up with fresh water.

A well drilled near the center of the E. ½ sec. 32, T. 39 N., R. 4 E., produced fresh water carrying considerable gas at 80 feet.

WELLS IN THE VICINITY OF GOSHEN

A dug water well in the NE. ¼ SE. ¼ sec. 24, T. 39 N., R. 3 E., showed the following log:

Log of dug well near Goshen

	Thickness.		Depth.	
	Ft.	In.	Ft.	In.
Soil	3	0	3	0
Coal, decomposed		10	3	10
Shale		2	4	0
Coal and shale		8	4	8
Shale	3	0	7	8
Coaly seam		3	7	11
Shale and water				

A water well in the NE. ¼ NW. ¼ sec. 24, T. 39 N., R. 3 E., was drilled to 74 feet after finding bedrock at 11 feet.

A water well in the SW. ¼ SW. ¼ sec. 13, T. 39 N., R. 3 E., was drilled through 12 feet of soil and 88 feet of bedrock. It encountered some coal at 70 feet.

A water well in the NW. ¼ NW. ¼ sec. 24, T. 39 N., R. 3 E., was drilled five or six feet to bedrock and continued to 62 feet. It encountered sandstone underlain with a little coal and then blue shale.

A water well on the Shell farm, in the SW. ¼ SW. ¼ sec. 12, T. 39 N., R. 3 E., went through eight feet of soil to sandstone bedrock, which continued to 100 feet except for three feet of coal at 70 feet.

An old well on the Hemmi place, in the SE. ¼ SW. ¼ sec. 14, T. 39 N., R. 3 E., found sandstone at 24 feet, about four feet of coal at 70 feet, and more sandstone to 93 feet.

Water wells in the NE. ¼ sec. 26, T. 39 N., R. 3 E., show bedrock to be about 30 feet deep.

A water well drilled near a school, in the SE. ¼ SE. ¼ sec. 35, T. 39 N., R. 3 E., was carried 198 feet without reaching bedrock, although gray sand and wash coal at 195 feet indicated nearness to it.

WELLS IN THE VICINITY OF LAUREL

A water well drilled on the Sinnes farm is located in the NW. ¼ SW ¼ sec. 24, T. 39 N., R. 2 E. This well gave some gas. A 6-inch casing was carried to 317 feet, but the first water was at 385 feet.

Log of well on Sinnes farm

	Thickness. Feet.	Depth. Feet.
Quicksand	35	35
Clay, blue	19	54
Quicksand	24	78
Clay, blue	162	240
Cement sand and gravel (bedrock below)	85	325
Shale, blue	140	465
Coal	5	470
Shale, blue, and coal	8	478
Coal	2	480
Shale, blue	12	492

A water well drilled in the NW. ¼ sec. 36, T. 39 N., R. 2 E., was carried to a depth of 100 feet. It encountered no bedrock but produced water "as salty as sea water."

A water well drilled in the SW. 1/4 NW. 1/4 sec. 30, T. 39 N., R. 3 E., went through clay and "hardpan" to 108 feet, then quicksand and silt to 138 feet.

Six water wells in sec. 31, T. 39 N., R. 3 E., show to a depth of 85 to 95 feet only very irregular deposits of loose boulders, gravel, sand, and clay.

A water well drilled in the SW. 1/4 SW. 1/4 sec. 28, T. 39 N., R. 3 E., reached a depth of 176 feet. There was 50 feet of blue clay, then sand and gravel, and the last 18 feet was gray sand.

WELLS IN THE VICINITY OF BLAINE

A water well drilled near the old Dakota Creek mill, in the NE. 1/4 sec. 8, T. 40 N., R. 1 E., went to 600 feet without finding bedrock.

Four water wells drilled 40 feet apart, in the SE. 1/4 sec. 33, T. 41 N., R. 1 E., went through blue clay to water at 50 feet.

WELLS IN THE VICINITY OF BIRCH BAY

The gas test on the Robert Selien farm is located in the center of the E. 1/2 sec. 32, T. 40 N., R. 1 E. No gas was found and the hole was abandoned.

Log of gas test on Robert Selien farm

	Thickness. Feet.	Depth. Feet.
Clay, gas showing at base	32	32
Clay, soft, with cobbles	68	100
Clay, increasingly sandy, hard to hold	40	140
Clay	12	152
Sand, coarse, and fine gravel, water-bearing	3	155
Sandstone (top of Chuckanut?)	24	179
Conglomerate	1	180
Sandstone, soft, light-gray	17	197
Sandstone, hard, light-gray	14	211
Sandstone, soft, light-gray	17	228
Shale, hard, blue	3	231
Shale, sticky	7	238
Shale, hard, black	4	242
Shale, sticky, blue	2	244
Shale, light-gray, sandy	17	261
Sandstone, hard	6	267
Shale, soft, sandy	30	297
Shale, black, with some coal seams	2	299
Shale, soft, sandy	36	335

The gas test on the Anderson farm is at about the center of the W. 1/2 sec. 32, T. 32 N., R. 1 E. At 250 feet in sandstone a heavy flow of gas was struck. This came in with a small flow of brackish water.

Log of gas test on the Anderson farm

	Thickness. Feet.	Depth. Feet.
Clay, few cobbles near bottom	190	190
Sandstone, water at base	20	210
Sandstone and shale alternating	40	250
Sandstone	18	268

Based on topographic maps by U. S. Geological Survey

TOPOGRAPHY AND STRUCTURE OF WESTERN WHATCOM COUNTY

Geology by Sheldon L. Glover 1934