TERIOR

UNITED STATES GEOLOGICAL SURVEY

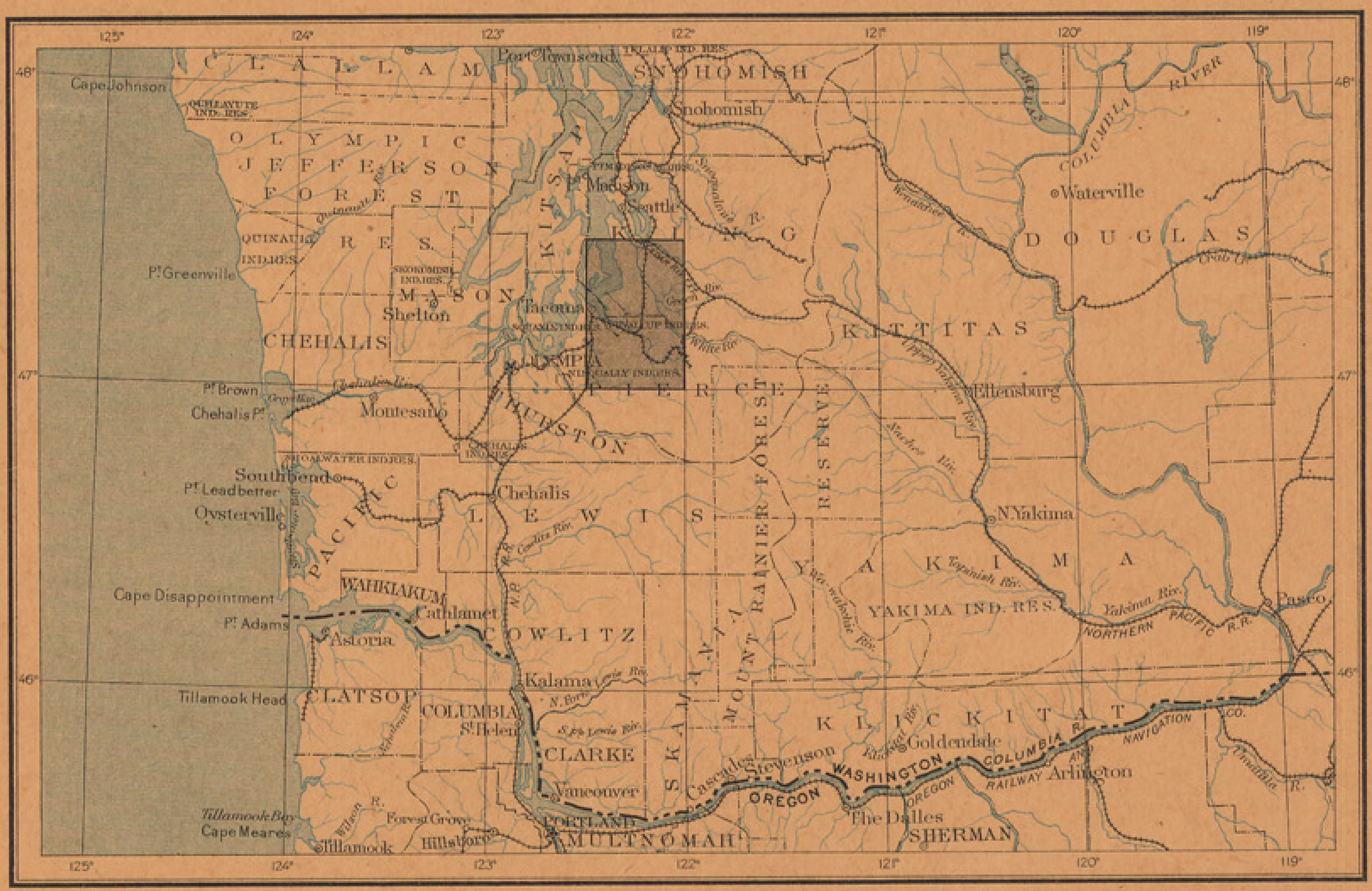
CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS OF THE UNITED STATES

TACOMA FOLIO

WASHINGTON

INDEX MAP



SCALE: 40 MILES = 1 INCH

AREA OF THE TACOMA FOLIO

LIST OF SHEETS

DESCRIPTION | TOPOGRAPHY | HISTORICAL GEOLOGY | COAL DISTRICT, MAPS | COLUMNAR SECTIONS

FOLIO 54 | LIBRARY EDITION | TACOMA

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

EXPLANATION.

The [illegible]l Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds: (1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea-level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea-level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map:

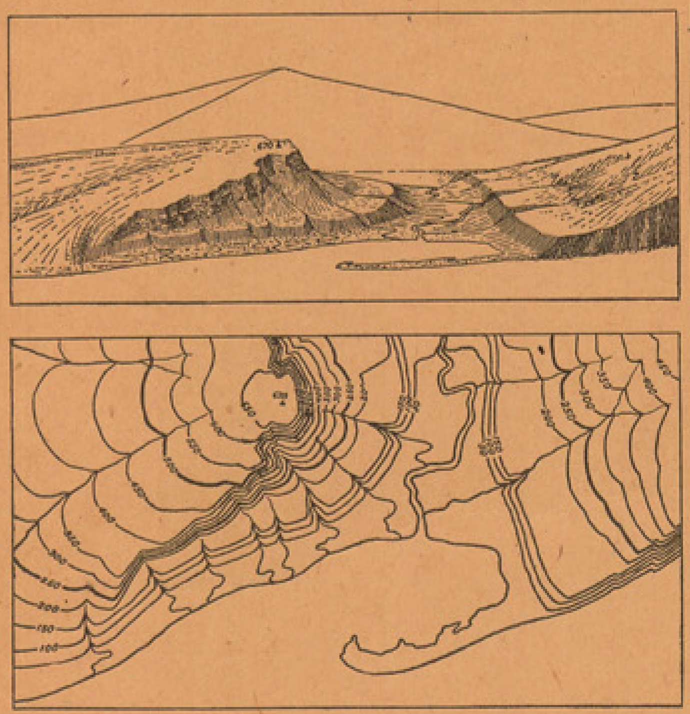


Fig. 1.—Ideal sketch and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand-bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply in a precipice. Contrasted with this precipice is the gentle descent of the left-hand slope. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates approximately a certain height above sea-level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea-level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The vertical space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is used for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If the stream flows the year round the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the scale of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,000}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree, i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-quarter of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known, and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it either consolidates in cracks or fissures crossing the bedding planes, thus forming dikes, or else spreads out between the strata in large bodies, called sills or laccoliths. Such rocks are called *intrusive*. Within their rock enclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock, it is younger than that rock, and when a sedimentary rock is deposited over it, the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks over wide expanses, and as it rises or subsides the shore-lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and redeposited as beds or trains of sand and clay, thus

DESCRIPTION OF THE TACOMA QUADRANGLE.

INTRODUCTION.

Purpose.—It is the purpose of this description to set forth, in plain language, the facts observed in a study of the natural features of the Tacoma quadrangle. The features to be described are the hills and valleys and streams, the deposits of gravel and sand and clay, and the sedimentary and igneous rocks. These features have developed during a long series of events, and under conditions in part very unlike those now existing. An account of these events in the order of their occurrence is the geologic history of the district, and this history will be related so far as it has been read in the hills and rocks. The economic resources of the quadrangle will also be set forth.

Features described.

Geologic processes.—The changes which take place in the earth's surface, such as the carving of valleys, the deposition of sediments beneath the sea, volcanic eruptions, and the gradual rise or subsidence of extensive districts, are results of solar forces which act on the earth through the atmosphere or of forces which reside in the earth. Their activities constitute several processes.

The modeling of the earth's surface through the solar forces, by variations of temperature, by winds, and by rains and flowing waters, constitutes the process of *erosion*. Its effect is to sculpture and ultimately level down inequalities of the surface; but as the carving proceeds very unequally, mountains long remain as features of the landscape, while valleys develop around them. Gravity aids the sun force by causing the downward movement of waters laden with sediment, of ice with rocks, and of all loosened rock masses.

The process of erosion.

A second process is the distribution and deposition of the gravel, sand, and mud produced by erosion. Gravity is the moving force, and the vehicles by which it distributes the material are glaciers, streams, and the waters of lakes and seas. The process has been called *sedimentation*, and its chief result, the world over, is the formation of beds of sediment, which constitute sedimentary rocks, such as sandstone or sand-rock, shale or mud-rock, limestone or lime-rock, and coal.

The process of sedimentation.

A third process is manifested in movements of the earth's crust and is called *deformation*. Along seacoasts the relative level of land and sea gradually changes. Within continents plains are raised to form plateaus; or a zone is elevated as a mountain range; or a depression develops, becoming an extensive valley or an arm of the sea. The causes of these movements are not yet understood, but it is known that parts of the earth's surface have repeatedly moved up and down through thousands of feet, and are still doing so. Volcanic activity is a special phase of deformation, of exceedingly energetic character. By its action cones like Mount Rainier may be built up, and irregular bodies of molten rock may be forced in among sedimentary beds.

The process of deformation.

The three processes of deformation, erosion, and sedimentation are related each to the others. By the uplift of a mountain range, sun force and gravity are given opportunity to erode; by erosion the materials for sedimentary deposits are provided; and by deformation sediments are again raised to be eroded. There is thus a cycle of changes, within which these processes go on from age to age and from era to era.

The cycle of processes.

The geologic history of the Puget Sound region has involved the three processes. Before the Eocene period this region had a history involving mountain growth and mountain waste; it is recorded in older rocks, now found in the Cascade and Olympic ranges, and the San Juan archipelago; but as these rocks do not occur in the Tacoma quadrangle, no account of that earlier history is here given. Later, near the begining of the Eocene period, by deformation a depression or downfold was produced, which now constitutes the Puget Sound Basin; and on either side of the downfold upfolds rose, forming the Olympic and Cascade ranges. The growth of these mountains was accompanied by energetic volcanic eruptions. Throughout a long time, covering the Eocene, Neocene, and Pleistocene periods, the processes of erosion and sedimentation have continued to act. Sedimentary rocks formed, and in them the events of their history are recorded. Among the latest occurrences was the spreading of glaciers many hundreds of square miles in extent and hundreds of feet thick, which in melting left the region covered with beds of coarse gravel and sand. This subject will be considered more fully later, under the heading "Geologic history."

Summary of the geologic history of Puget Sound.

GENERAL RELATIONS.

Situation.—The Tacoma quadrangle is bounded by the meridians 122° and 122° 30′ and the parallels 47° and 47° 30′. Its area is 812.4 square miles, of which about 64.1 square miles fall in the inlets of Puget Sound. It lies in the southeastern part of the Puget Sound Basin and includes a portion of Admiralty Inlet, adjacent uplands on the south and east, and the extreme outliers of the Cascade Range and Mount Rainier. Within the quadrangle altitudes vary from 100 fathoms (150 meters) below sea level in the depths of Admiralty Inlet to 2750 feet (4152 meters) above sea level in the foothills of Rainier. Parts of King and Pierce counties are within it, and the city of Tacoma lies on its western margin.

Extent, and counties included.

Relation to continental features.—One of the features of the North American continent is a depression parallel to the Pacific coast extending from latitude 20° N. along the Gulf of California, the Valley of California, the Willamette Valley, and the sounds of the northern coast to latitude 55° N., beyond Queen Charlotte Island. Puget Sound occupies a section of this downfold about 90 miles in length.

The Pacific Coast downfold.

Mountain ranges or upfolds lie on either side of the Pacific coast downfold. On the east rise the Sierra Nevada of California, the Blue Mountains of Oregon, the Cascade Range of Washington, and the Coast Ranges of British Columbia; on the west extend the Coast Ranges of California, the Klamath Mountains of Oregon, the Olympic Mountains of Washington, and the heights of Vancouver Island. Puget Sound lies between the Cascade Range of Washington on the east and the Olympic Mountains on the west. From range to range across the Puget Sound Basin the distance is about 100 miles. The general elevation of these mountains is 6000 to 7000 feet above sea, but isolated summits built up by volcanic eruptions reach 10,000 to 14,500 feet.

Adjacent mountain ranges.

The Pacific coast downfold is about 2500 miles long. It has been a feature of the western coast since the Cretaceous period or earlier. During several geologic periods it was so deeply depressed as to lie beneath the sea and received the sediments of successive epochs throughout some parts of its extent Now only the northern and southern ends are submerged, and the higher section extending through Oregon and California is divided by two mountain groups into three parts, the southern extending from the Gulf of California to Los Angeles, the central constituting the great Valley of California, which is blocked on the north by the Klamath Mountains, and the northern comprising the Willamette Valley and its extension through southwestern Washington.

General notes on the geology of the Pacific coast.

The mountain chains which now constitute the topographic limits of the Pacific coast downfold are composed of links that differ in age and in composition. Although they are nearly in line, the Sierra Nevada and the Cascade Range are distinct. The Sierra Nevada is composed chiefly of three classes of rocks, namely: (1) sedimentary and igneous rocks of various ages from Silurian to Juratrias, which have been profoundly altered and have developed a schistose structure; (2) large masses of granite intruded into and later than the preceding; and (3) lavas which have been erupted through and flowed out upon the other rocks. The principal deposits of gold occur in the first-mentioned series and in gravels derived from it. The northern continuation of the Sierra Nevada uplift is probably represented geologically in the Blue Mountains of Oregon, the rocks of the two being similar. The Cascade Range is younger, and is wholly of volcanic origin, from Lassen Peak on the south to Mount Rainier on the north. It is a pile of lavas which have flowed from hundreds of vents. From a few of these vents eruptions have been repeated so often and during so long an epoch as to build up the volcanic cones of which Shasta, Hood, and Rainier are examples. Northward from Rainier the Cascade Range resembles the Sierra Nevada in composition. Sedimentary and igneous rocks which have been altered to schists, granites, and younger lavas compose its mass; but there are also extensive strata of sandstones of Cretaceous, Eocene, and probably early Neocene ages.

The Coast Ranges between southern California and Vancouver Island fall into four unlike sections. (1) The southern section extends through California northward to about the fortieth parallel. It is a series of parallel ranges, frequently lying en echelon, composed of strata which are of various ages from Cretaceous, or possibly earlier, to late Neocene. Throughout this section mountain growth has repeatedly proceeded energetically, accompanied by crumpling of the strata and igneous eruptions. (2) The next section northward consists of the Klamath Mountains, a group rather than a range, occupying an area in northern California and southern Oregon. The rocks of this group range in age from early Paleozoic to Cretaceous; and in the association of sedimentary and igneous masses, as well as in the schistose structure of all except the Cretaceous deposits, they resemble the rocks of the Sierra Nevada. (3) Northward from the Klamath Mountains stretch the low Coast Ranges of Oregon, consisting chiefly of Eocene sandstones, with some early Neocene deposits. Volcanic rocks of Eocene age form a considerable part of the ranges south of the Columbia River. (4) The fourth section is the Olympic group, which rises west of Puget Sound to a height of 8000 feet. The dominant peaks are volcanoes, but they rest upon much older rocks, some of which in schistose character resemble those of the Sierra Nevada and the northern Cascades.

In a mountain range all sedimentary rocks are older than the uplift and represent conditions which preceded the growth of the mountains. The later development of the upfold is recorded in other ways, chiefly in the effects of erosion upon the rising zone. For example, before a mountain range began to grow, a lowland plain may have existed in its place. If the surface of the rising mass could change its position without being carved by streams, the plain would remain, demonstrating its previous existence though raised to a highland. But streams carve uplifts, and in time the sun force sculptures sharp peaks from the mass. Nevertheless, remnants of a former lowland plain long remain visible, especially in even-topped ridges or in peaks having generally uniform altitudes; and during the process of erosion significant profiles are cut which may long indicate the conditions of sculpture. Thus the forms of hills and valleys constitute a record of that portion of the geologic history which is later than the formation of the rocks.

In the Sierra Nevada, in the Cascades of northern Washington, and in the Coast Ranges, there are many significant features which show that the sites of these mountains were formerly lowlands, and that the history of their growth has been a succession of uplifts alternating with pauses of longer or shorter duration. Weather and streams have deeply sculptured all these ranges, carving canyons and modeling mountains; and in the northern Cascade and Olympic mountains ice in the form of glaciers has worked out grand amphitheaters amid acute peaks, such as are characteristic of alpine scenery. This work of the glaciers is intimately related to the later history of the Puget Sound Basin.

Climatic conditions.—Across the northern Pacific Ocean there blows a prevailingly west wind, and beneath it flows the warm current which corresponds to the Gulf Stream of the Atlantic Ocean. Thus the waters of the northeastern Pacific are warm and the atmosphere is mild and moist, as are those of the northeastern Atlantic. The eastern shores of the two oceans in like latitudes have similar climates, and the climates of their western shores are also mutually similar, but much colder than those of the eastern shores. Puget Sound lies in the latitude of Newfoundland, northwestern France, and the Kurile Islands north of Japan, in latitudes 47° to 49° N. In July, when the zones of equal temperature most nearly correspond to like latitudes, Puget Sound has the mean temperature of the New England coast; but in January, when the ameliorating influence of the ocean currents is more marked, the mean temperature of Puget Sound is that of Chesapeake Bay, in latitude 38° N., and of the southwestern coast of the British Isles, in latitude 50° to 54° N.

Conditions producing mild, equable temperatures and moist atmosphere.

One of the conditions which profoundly affect the climate of a district is the nearness of high mountains. The Olympic and Cascade ranges chill the warm winds from the Pacific and cause remarkably heavy precipitation on the mountains. As no observations have been carried on in the heights where the fall is heaviest no measurements of the maximum annual precipitation have been made, but it exceeds 100 inches per annum. In the Sound region the rainfall varies along the paths of air currents which sweep around or over the Olympics and which become drier as they progress farther from the ocean. The precipitation may sink as low as 25 inches per annum, though the averages range probably from 40 to 55 inches. The precipitation is distributed throughout a long rainy season, from mid-September to June, with a short summer of but little rainfall. In an average of a number of years the rainiest month is December, in which a little more than one-fifth of the total annual precipitation occurs. The normal fall then decreases, and in June it is about one-fourth the maximum. From the minimum, in July and August, there is gradual increase during September and October, with marked development in November, when the amount of rain approaches and in some seasons equals December's maximum.

The following detailed records are furnished by the United States Weather Bureau for Olympia, Tacoma, and Seattle.

Temperature, precipitation, etc., for eighteen years at Olympia, Washington.

		Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Temperature.														
Mean or normal	Deg.	39.8	39.3	44.4	48.3	54.6	58.9	62.2	62.3	56.6	49.9	44.4	40.6	49.9
Warmest month	Year	1891	1885	1889	1889	1888	1885	1885 1889	1884	1888	1889	1894	1886	......
	Deg.	42.2	45.1	49.8	52.8	57.4	61.1	64.9	65.7	60.6	54.0	47.4	44.6	......
Coldest month	Year	1888	1887	1880	1893	1880	1893	1881	1880	1878	1893	1880	1884	......
	Deg.	32.5	31.6	39.5	44.8	50.3	54.8	59.5	59.7	54.5	47.0	39.8	32.7	......
Highest	Year	1891	1889	1892	1880	1892	1878	1885	1893	1889	1892	1892	1885	......
	Deg.	60	62	74	82	91	95	97	94	85	79	68	64	97
Lowest	Year	1888	1884	1891	1887 1892	1882 1886	1880 1886 1887	1882 1887 1888 1891	1887	1877	1881	1887	1879 1884	......
	Deg.	−2	2	21	27	30	36	40	40	31	23	20	8	−2
Precipitation.														
Average monthly	Inches	7.96	6.69	5.10	3.86	2.57	1.60	0.68	0.66	2.80	4.51	7.94	10.13	54.50
Average number days .01 inch or more		19	17	18	16	12	10	5	4	9	16	17	21	164
Greatest monthly	Year	1880	1881	1879	1883	1895	1888	1879	1879	1877	1881	1877	1880	......
	Inches	19.69	16.28	14.44	10.78	5.93	4.80	2.62	2.11	6.64	8.18	19.88	16.66	......
Least monthly	Year	1893	1889	1885	1885	1890	1895	1896	1885	1890	1887	1890	1889	......
	Inches	2.21	1.40	0.50	0.39	0.13	0.05	0.00	0.00	0.07	1.51	0.71	4.14	......
Weather.														
Average number of days	Clear	2	4	6	6	9	7	13	14	9	6	3	2	81
	Partly cloudy	10	8	10	11	11	11	12	12	11	11	10	9	126
	Cloudy	19	16	15	13	11	12	6	5	10	14	17	20	158
Frost.														
Average date first killing frost in autumn	Month	......	......	......	......	......	......	......	......	......	Oct.	......	......	......
	Day	......	......	......	......	......	......	......	......	......	16	......	......	......
Average date last killing frost in spring	Month	......	......	......	Apr.	......	......	......	......	......	......	......	......	......
	Day	......	......	......	16	......	......	......	......	......	......	......	......	......
Wind.														
Prevailing direction		S.	S.	S.	S.	S.	N.	N.	N.	S.	S.	S.	S.	S.
Highest velocity	Miles	30	42	29	28	28	42	25	48	28	33	34	32	......
	From	NE.	S	S.	SW.	S.	SW.	NW.	SW.	SW.	S.	S.	SW.	......
	Year	1888	1882	1879	1881	1882	1884	1877	1882	1893	1893	1889 1893	1882 1891	......

Precipitation at Seattle, Washington.

(Inches and hundredths.)

Year.	Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Ann.
1890	......	......	......	......	......	......	......	0.15	0.01	3.05	0.69	5.89	......
1891	4.33	2.36	1.64	4.05	1.42	1.76	......	......	......	......	......	7.71	......
1892	2.61	1.94	2.36	3.82	1.42	1.35	1.29	0.99	2.28	2.75	8.76	4.92	34.49
1893	......	......	......	......	4.26	1.54	0.48	0.33	3.04	3.66	8 16	4.92	......
1894	6.01	4.21	6.25	4.21	1.99	2.47	0.14	0.04	2.50	3.70	5.81	3.75	41.08
1895	6.13	1.76	3.60	3.17	3.20	0.29	0.37	0.21	1.01	0.02	1.95	7.98	29.69
1896	7.06	3.87	2.41	3.27	3.60	0.77	0.00	0.50	1.78	2.49	9.50	7.58	42.83
1897	3.74	2.99	3.05	1.53	1.30	1.67	2.36	0.24	2.04	1.92	8.89	11.80	41.53
1898	1.99	5.98	1.39	1.51	0.66	2.13	0.22	0.15	2.92	4.69	3.52	4.12	29.28
Normal	4.98	2.86	3.22	3.34	2.46	1.41	0.77	0.35	1.81	2.51	6.25	6.82	36.78

Precipitation at Tacoma, Washington.

(Inches and hundredths.)

Year.	Jan.	Feb	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1890	7.08	7.58	3.49	2.51	0.89	2.45	0.55	0.48	0.22	3.74	0.88	5.50	35.37
1891	5.42	2.68	2.76	4.91	1.92	2.93	0.05	2.76	4.15	5.17	7.62	10.55	50.92
1892	3.46	1.82	2.03	3.72	1.98	0.93	1.27	1.21	2.85	2.60	9.92	5.84	37.63
1893	2.27	6.55	0.77	7.63	3.68	2.31	0.51	0.40	1.77	5.63	9.93	6.64	48.09
1894	7.00	5.11	6.76	3.88	2.35	3.70	0.25	0.03	2.32	5.02	6.51	4.69	47.62
1895	7.36	2.51	2.64	2.29	4.61	0.20	0.39	0.05	1.22	0.14	4.79	10.85	37.05
1896	6.50	4.65	2.88	5.17	3.79	2.02	0.00	0.63	1.74	2.74	9.79	11.11	51.02
1897	6.72	5.19	4.73	1.64	1.46	1.54	0.87	0.58	1.41	1.63	12.31	14.48	52.56
1898	3.01	8.68	0.97	2.26	1.12	2.41	0.26	0.38	2.24	1.60	5.92	4.73	35.58
Normal	5.95	4.29	3.60	3.69	2.36	2.24	0.56	0.75	1.95	3.36	7.56	8.29	44.60

Existing glaciers.—Of the heavy precipitation on the Olympic and Cascade ranges a great part falls as snow. On exposed sunny slopes the heat of summer—May to September, inclusive—is sufficient to melt the winter's gathering, but in amphitheaters, especially those with northern aspect, snow banks and snow fields persist from year to year. Where the volume of accumulated snow is large it consolidates to ice and flows downward. Such an ice mass is a glacier. In the Cascades at altitudes of 7000 feet to 7500 feet above sea, areas covered by snow in September about equal in extent those from which the snow has melted. This zone is known as the snow line. Mountains which rise above snow line in sharp peaks afford but little gathering space for snow, and on them the accumulations are limited; but from a broad mountain dome above snow line may flow glaciers of corresponding magnitude. These ice rivers descend the canyons far below snow line, and end where the loss by melting is equal to the advance of the ice from above. There are many glaciers in the Cascade Range. Most of them are small, but from Mount Rainier radiate a number from 4 to 7 miles in length, which exhibit in great beauty and perfection all of the characteristics of alpine glaciers.

The existing glaciers are remnants of far more extensive ice sheets which not long since flowed from the east, west, and north into the Sound Basin and filled it. The shrinkage of those ice sheets was gradual and fluctuating. The remnants that still linger on the heights vary in volume from decade to decade according to precipitation and temperature. Heavy snows or short summers materially increase their volume, whereas light winter precipitation or prolonged summer heat causes them to shrink. From 1880 to 1898 the general result of variations in the glaciers was a marked retreat.

Fauna and flora.—The moderate summer temperatures of Puget Sound are favorable to southward migration of animals and plants which normally inhabit colder climates. Species indigenous to British America, belonging to what is technically called the boreal life zone, flourish in the Cascade and Olympic ranges, and many extend down to the shores of the Sound.

Mingling of northern and southern species.

South of the boreal life zone the Biological Survey of the Department of Agriculture has distinguished the austral life zone, and has divided it into upper and lower austral zones. The upper merges into the boreal zone by a broad transition belt in which the species of the two are mingled; the lower austral zone borders a tropical zone on the south. Many plants and animals of the austral zone extend into the Puget Sound Basin, and the overlapping of northern and southern species is more extensive in western Washington and Oregon than in any other part of the continent. It is a result of the equable climate which prevails over a large area.

Character of the forest.

The virgin forests of the Sound region are the deepest and densest of the Pacific coast except those of the coast redwood. The tall, light-loving trees tower to heights of 250 feet or more on relatively slender shafts, which near the ground are 6 to 10 feet in diameter. Beneath their interlacing crowns grow trees more tolerant of shade, bearing branches to within a few feet of the ground. Shrubs crowd among the tree trunks, rising from rich ferneries, vines, and matted mosses. The air is damp, the light somber, and the silence becomes oppressive. The trees are all conifers, except a few deciduous species of small growth.

The principal timber trees are: red or Douglas fir (*Pseudotsuga taxifolia*), Western hemlock (*Tsuga mertensiana*), Sitka or tideland spruce (*Picea sitchensis*), white fir (*Abies grandis*), and Pacific arbor vitæ, commonly called cedar (*Thuja plicata*). The undergrowth comprises broad leaf maples, alders, madroñas, and many shrubs, such as the salal (*Gautheria shallon*), salmon berry (*Rubus spectabilis*), Oregon grape (*Berberis nervosa*), and the devil's club (*Echinopanax horridum*).

Detailed relations of temperature to fauna and flora.

It has been ascertained by the Biological Survey of the Department of Agriculture that the southern limit of range of boreal species of animals is determined by a mean temperature of 64.4° F. (18° C.) for the six hottest weeks of summer. At Olympia the mean temperature for July and August, according to the above table, is a fraction more than 62°, or 2° below the maximum which boreal species can endure.

It is assumed that physiological activity of plants and reproductive activity of animals begin in spring, when the mean daily temperature rises above 43° F. (6° C.), and cease in autumn, when the mean falls below that figure. The sum of the mean daily temperatures for the period of activity is a measure of the total amount of heat received in any district, and the development of plants and animals is related to this sum. The Biological Survey has ascertained that austral species living in the transition zone require a sum of temperatures of 10,000° F. (5,500° C.), and typical upper austral species require 11,500° F. (6,400° C.). The Weather Bureau's reports for Olympia show that from March to November the mean temperature ranges above 43° F., and the sum of mean daily temperatures is considerably more than 11,500°. This is so, in spite of the fact that the temperature never rises very high, because the mildness lasts during nine months.

The humidity of the climate would seem most unfavorable for all species adapted to an arid habitat. But local semi-arid conditions exist which permit a few species capable of easy migration to live in the Sound region. South of Tacoma is a district, known as Steilacoom Plains, which is characterized by extremely porous soil of coarse gravel with a thin veneer of silt. The rainfall is probably about 44 inches per annum, but showers percolate so rapidly into the loose stony ground that the area is in effect arid. The yellow pine (*Pinus ponderosa*), species of gophers, and the desert horned lark, which are at home in the dry districts east of the Cascades, here occur as in an island surrounded by the dense forests of the humid region.

TOPOGRAPHY OF PUGET SOUND.

General aspects.—The topographic features of Puget Sound are peculiar in that they combine to form a branching system of land-locked straits which are remarkable for irregularity and depth. As a whole the system is rudely pear-shaped, pendent from the Strait of Juan de Fuca. The inequalities of the surface constitute long hollows, which are partly valleys and partly sounds, and irregular plateaus, whose elevation above the sea level varies from 300 to 400 feet. The greater depths of water are from 600 to 900 feet, and the amount of relief is accordingly 1000 to 1300 feet.

The hollows, their distribution and character.—Admiralty Inlet is the principal stem, the outer branches being Hood Canal on the west and the Duwamish-Puyallup Valley on the east. The southwestern group of sounds is a cluster attached to Admiralty Inlet at its southern end.

In this plan of the hollows there is a resemblance to a system of river valleys converging northward, and it is probable that such a system lies beneath the present topography. The existing heights above sea level are superficially built up of deposits from glaciers. Probably, like a thick mantle, they conform to, while they obscure, the older topographic relief.

Deltas, which are continually being extended by muddy rivers, advance into the hollows, displacing the water of the sounds. This is occurring actively at the mouths of the Duwamish and Puyallup rivers, and the valley lands along these streams are flood plains spread over the delta deposits of earlier stages. That part of the hollows which is filled by alluvium differs from that part which is filled by water only in the incident of very recent history; in their origin the broad valleys and the sounds are alike.

The plateaus, their distribution and character.—The major elevations of the Puget Sound Basin are of the plateau type. They are essentially flat-topped, though diversified by hills and trenched by channels, and they are bounded by steep slopes, descending 200 to 300 feet abruptly to the alluvial plains and to the waters of the Sound. Toward the axis of the Sound their greater altitudes vary from 400 to 500 feet above sea, and along the adjacent mountain ranges they rise as benches to 1200 feet above sea. The plateau masses between the mainland on the east and the mainland on the west are long and narrow, and resemble islands, with major axes trending north-south. The margins of the plateaus along the tops of the slopes are wavy, but in details entire, in the sense that the edge of a leaf is said to be entire. They are rarely and not deeply incised by streams. The outlines along the slopes above sea level are being modified by waves, which carve cliffs and build out adjacent spits.

The detailed topography of the Tacoma quadrangle is so intimately related to the latest stages of geologic history that the forms can not intelligently be discussed without a knowledge of the events leading up to their development. Their discussion is therefore postponed to the end of the account of the geologic history.

GEOLOGIC HISTORY.

EOCENE PERIOD.

Position of the Eocene in the earth's history.

Introduction.—The earliest period which it is necessary to consider in the account of the geologic history of the Tacoma quadrangle is the Eocene. By reference to the list of periods in the "Explanation" which is printed on the cover of this folio, it will be seen that the Eocene is one of the later periods. Indeed, as compared with the whole of geologic time, the interval between the present and the beginning of the Eocene is shorter than would appear from that list, since the three latest periods, Eocene, Neocene, and Pleistocene, were all short as compared with those which preceded them. Nevertheless, the changes which have occurred since the beginning of the Eocene have been marked, in all aspects of the North American continent. At that time the sea overlapped the Atlantic and Gulf coasts of the Eastern States more than a hundred miles. It occupied the Valley of California, much of western Oregon, and western Washington. Upon the Great Plains and in basins among the western ranges were extensive lakes. The Eocene mountain ranges throughout the continent presented aspects very different from those of to-day. The Sierra Nevada was comparatively low and the Coast Ranges had not developed. Of the shell fish living in the Eocene seas, but a small percentage have survived with the same specific characters to the present, the number of Eocene species now living being estimated at less than 5 per cent of those then existing. The Eocene flora, too, was quite different from the present, although many of the now leading families were then represented by their ancestors.

The Eocene estuary of western Washington.

During the Eocene period the Puget Sound Basin was the site of an extensive estuary or arm of the sea of as yet undetermined extent. It is known that it covered part of western Washington, including portions of the Cascades. Other portions of the range, and probably the Olympics, were land areas, either islands or coastal plains of the mainland which stretched northward and eastward. The water body reached south into Oregon, and probably far eastward toward the Blue Mountains. Lands adjacent to this extensive estuary were probably hilly rather than mountainous, and were composed of granite and older rocks of both igneous and sedimentary origin. The climate of the period was semi-tropical and moist, and the lands were covered with a luxuriant flora, including species of magnolias, figs, palms, and tree ferns. There were wide and extensive swamps in which decaying vegetation accumulated, and, being subsequently buried, formed valuable coal beds. And all the while the rocks of the adjacent hills were undergoing rapid disintegration, and their detritus was being swept down to the estuary by numerous swift and voluminous streams. The deposits constitute the Puget formation.

Description of the Puget strata.

Puget formation.—The Puget formation consists of interbedded sandstones, shales, and coal beds, aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture, and color, and are frequently cross stratified. Their composition ranges from a typical arkose, consisting of slightly washed granitic minerals, to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. Conglomerates and concentrated quartz sands have not been observed. The variations in character are not such as to distinguish upper and lower sections of the formation. In general the strata are similar and are similarly interbedded from top to bottom.

The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron, and generally more or less carbonaceous matter, which varies in character from finely divided organic material to large leaves and stems. They accordingly range in color from rather light gray and blue to black. The lighter tints weather out brown through oxidation of the iron.

The carbonaceous shales pass by insensible gradations into what the miners call bone, bony coal, and coal. The proportion of coal beds is extraordinary. Carefully measured sections show that the Puget formation contains more than 125 beds which would attract the attention of a prospector searching for coal. They range from 1 to 60 feet in thickness, and the workable coal beds in any one section may vary from 5 to 10 in number. The valuable coal is found in the lower 3000 feet of the formation, as at Carbonado, Wilkeson, Burnett, and Green River. Two-thirds of the formation, the upper part, contains little if any workable coal, although carbonaceous shale beds occur at frequent intervals.

The physical history of the Puget epoch.

The physical history which is recorded in the Puget formation is one of persistent but frequently interrupted subsidence of the area within which the sediments were deposited. It is clear that at the time when coal beds formed among the earliest of the deposits the corresponding level was a marsh close to the sea; and it is equally evident that when 10,000 feet of strata had been deposited upon these earlier coal beds the same conditions were repeated for the higher ones, which then occupied the same level: the base of the deposits had subsided 10,000 feet into the earth's mass during the interval. The alternation of coal beds with deposits of fine shale and coarse sandstone indicates that during this great subsidence the depth of water frequently changed. Accordingly it is inferred that at times the subsidence proceeded more rapidly, and that the deepened water was then filled with sediment, until the tide-swept flats became marshes, and for a time vegetation flourished vigorously in the moist lowlands. In consequence of deeper subsidence additional deposits of sand and mud were laid down, and again conditions for the development of vegetation were introduced over the estuarine area. Throughout these changes the waters appear to have generally remained fresh or brackish. The fossils other than plants are prevailingly unios or other fresh-water forms.

The following is a preliminary report by F. H.

Knowlton on the plants collected from the Puget formation:

Notes on the fossil plants of the Puget epoch.

The flora of the Puget formation is an exceedingly rich one. Over 100 species have already been named and described, and from the material in hand it seems safe to assume that the number will reach 250. Inasmuch as a very large proportion, perhaps more than nine-tenths, of the plants are new to science, it becomes extremely difficult to settle their affinities and determine satisfactorily their bearing on the question of age. It is only by a study of their general facies that results along either line can be obtained.

While the Puget flora as a whole may be considered relatively uniform, there are well-marked differences between the plants found in the lower beds, as represented at Carbonado, Wilkeson, and South Prairie Creek, and those found in the upper beds at the highest point in the Carbon River Canyon, the Clay mine on Green River, Snoqualmie Pass, and at Steels Crossing near Black River Junction. Certain few genera are found throughout the series, but thus far no species has been noted as common throughout. On the other hand, both lower and higher beds are characterized by a considerable number of genera. Thus Quercus, Juglans, Rhamnus, Populus, and Laurus are found from base to summit. The following genera have thus far been found in the lower beds, but not at all in the upper: Cladophlebis, Lastrea, Dryopteris, Anemia, Calamopsis, Sabal, Siphonites, Ficus, Eucalyptus, and Aralia; and the following have been detected in the upper but not in the lower: Rhus, Castanea, Betula, and Platanus.

The lower beds, on account of the abundance of ferns, gigantic palms, figs, and a number of genera now found in the West Indies and tropical South America, may be supposed to have enjoyed a much warmer, possibly a subtropical, temperature, while the presence of sumacs, chestnuts, birches, and sycamores in the upper beds would seem to indicate an approach to the conditions prevailing at the present day.

A number of species of plants have been found to be common to the west and east sides of the Cascades. This number is not large, but they are important and easily recognized forms, and there is indication that the number will be increased when the material in hand has been more thoroughly studied. This would indicate that approximately similar conditions of climate and topography prevailed throughout this general area during the Puget epoch. The Cascade Range as it now exists did not then intervene.

NEOCENE PERIOD.

Neocene age of the later Puget strata.

Stratigraphy.—The condition of subsidence which characterized the Puget Sound Basin during the Eocene period continued into the next, the Neocene. There is apparently no interruption or change in the sedimentary sequence to mark the transition, but plants collected from the upper part of the Puget formation differ from those taken from lower portions, and are of Neocene types.

In the northern Duwamish Valley, in the vicinity of Steels, is an isolated area of brown sandstone containing fossil plants which are younger than any collected from the recognized Puget formation, and which may belong to a later epoch of the Neocene period. A little farther northwest in the same vicinity are outcrops of greensand in which occur marine fossils of early Neocene (Miocene) age.

Pleistocene strata not identified.

Later Neocene (Pliocene) deposits of gravel, sand, and clay are voluminous along the Pacific downfold in California, and they may occur in the Puget Sound Basin; but being unconsolidated accumulations, they are not readily recognized as distinct from the later gravels of glacial origin, and as yet no fossils of Pliocene age have been found about Puget Sound. In only one locality, a mile east of Renton, on Cedar River, have strata distinctly younger than the Puget formation been observed. They consist of gray and brownish sandstone with conglomerates which contain pebbles of granite, of sandstone, and of coal of the Puget formation. These pebbles could have formed only after the Puget formation had become consolidated and been exposed to erosion. For this locality they demonstrate an epoch of erosion intervening between the earlier and later episodes of deposition.

Beginnings of folds.

Folding of the Puget formation.—It has frequently occurred in various parts of the world that deep subsidence of a zone of the earth's crust has been followed by compression of the zone in a horizontal direction. The strata which accumulated in the subsiding trough and sank as it deepened were initially slightly flexed downward and upward as a result of irregular subsidence. The force of compression acting against the edges of the strata increased these flexures, producing upfolds and downfolds, or anticlines and synclines, so that the strata were bent from the gently sloping positions they initially occupied to highly tilted altitudes. The Puget formation suffered such compression and was so flexed as to develop arches and troughs arranged alternately side by side. The result is that any one stratum is now deeply corrugated.

Folds in the vicinity of Wilkeson.

In the southeastern part of the Tacoma quadrangle the Puget formation lies in a system of folds whose general trend is N. 20° W. The axis of a principal anticline, or arch, passes through Wilkeson and Burnett, pitching northerly. From Wilkeson eastward the strata dip easterly at angles of 50° or more from the horizontal. Westward from Wilkeson are several other folds, which lie parallel to the great arch at Wilkeson and, like it, pitch northward. These folds are all narrow and steep sided. The South Prairie and Wilkeson mines are developed on the principal anticline. The Carbonado mines cover three smaller folds. The effect of this system is to present the strata of the Puget formation sloping gently north by west, the slope being marked by deep troughs alternating with arches. The upper or younger strata come to the surface farther north than the lower or older strata.

Folds in the Green River district.

In the vicinity of Black Diamond and thence eastward in the Green River coal field another system of folds occurs. They are broad as compared with the folds of the Wilkeson system, and their general pitch or slope is south by west. The McKay Basin is a well-known feature of this system, the Franklin and Black Diamond mines being developed within it and on the western flank. At Renton there are outcrops of the Puget formation which indicate that the beds are sharply folded along a synclinal axis that pitches from Renton southeastward. This basin is probably continuous with the Green River system of folds, and the Puget formation underlies the intervening area, but at considerable depth.

Topography of the Neocene lands.—The great volume of the Puget formation represents the work of erosion on adjacent lands during the epoch of deposition. There is no evidence in the sediments or their contained fossil plants that the lands were high even at the beginning of the epoch. The landscape appears to have had constantly the aspect of a narrow and often marshy coastal plain extending back to low hills. In order that such a topographic condition should persist in spite of erosion, there must have been a gradual uplift coordinate with subsidence in the estuarine basin.

Vertical movements resulting from horizontal compression of the deeply buried lower strata of the Puget formation probably resulted in narrow and relatively long uplifts (anticlines) of moderate height alternating with depressions (synclines) of similar form and dimensions. If the depressions lay below sea level, the region presented long, narrow sounds surrounding islands and peninsulas; if the surface was wholly above sea level, parallel valleys and ridges characterized the district. Erosion actively attacked the anticlines during their growth, and their height at any time was the difference between uplift and denudation; probably it was never great. The waste from the uplifts was deposited in the depressions. It may be represented by the later Neocene strata, such as have been observed near Renton. In the deeper synclines marine strata may have accumulated, as in the lower Duwamish Valley.

Beginning and close of the eruptions.

Eruptive activity.—Igneous rocks erupted contemporaneously with the deposition of the Puget formation are not known in the Puget Sound Basin; but it is probable that the earlier lava flows of the Columbia basalt plains were being poured out toward the close of the Puget epoch, since in the Mount Stuart quadrangle they occur conformably in strata which contain a flora similar to that found in the Puget shales. At a little later date, along the site of the present Cascades, large masses of igneous rock were intruded into strata of the Puget and older formations, and volcanic eruptions occurred on a stupendous scale. The activity of some of the volcanoes continued down to historical times.

Relation of eruptions to uplift of the Cascades not known.

The relation of this igneous activity to the uplift of the Cascade Range is not yet understood. The zone of the upfold had been in part a rising in part a subsiding area during preceding epochs, and an increase and extension of the elevating force may have sufficed to produce the range. It is consistent with what is known of the growth of other mountain ranges to assume that the growth of the Cascades was an effect independent of the eruptive activity. And if the latter was not the cause of the uplift, it is possible that the uplift provided conditions favorable to eruption. Processes resulting in igneous activity so energetic and so prolonged may probably have been of gradual development. Events of Eocene and Neocene times led up to the subsequent growth of the range and the attendant eruptive phenomena.

Occurrence and petrography of the igneous rocks.

The occurrences of igneous rocks within the Tacoma quadrangle are few in number and small in extent. The two areas in which these rocks were found are in the southeastern and northeastern portions of the quadrangle. The former is the more important, and the volcanic rocks occurring here seem directly related to those which were erupted from the crater of Mount Rainier. Like the rocks which make up the cone of this old volcano, they include both lavas and tuffs. In this area these rocks are only imperfectly exposed along a few of the cuts of the St. Paul and Tacoma Land Company Railroad, and at a few points along the course of Voight Creek. On the summits of the hills angular blocks of the volcanic rock are found in the moss and other vegetal matter which so thickly covers the surface. In the canyon of Carbon River there are a few better exposures, as well as along the upper valley of the Puyallup.

The lavas are gray to purple in color and usually fine grained, although in a few cases the rock is full of gas cavities. The tuffs are, in the main, rather lighter in color, being yellow or brown. They are fine grained for the most part, and are composed of fragments of the lavas and of their constituent minerals, material probably ejected from one of the craters of the Mount Rainier volcano.

The other area of igneous rock is probably connected with another center of volcanic activity, perhaps situated to the east, on the slopes of the Cascades. Squak Mountain and the peak on the opposite side of Issaquah Creek, in the extreme northeastern part of the quadrangle, are composed of volcanic rocks, which extend to the north and east beyond the limits of the Tacoma quadrangle. Here, again, both the lavas and the clastic volcanic rocks are found, and the tuffs are coarser than those in the other area. Smaller masses of igneous rock are indicated on the map as occurring in the Duwamish Valley, where they intrude and cap the exposed sandstone. These remnants are sufficient only to suggest the former importance and extent of the lava flows in this valley. They are found also for several miles farther down the valley.

The lavas occurring in the Tacoma quadrangle are pyroxene-andesites. From the nature of the outcrops of these rocks, fresh and unaltered material is rare. The lavas, however, when studied microscopically, exhibit the typical andesitic textures. The felted character of the groundmass is common, and flowage is sometimes beautifully expressed by the fine feldspar laths. The lava is usually somewhat porphyritic, both the plagioclase and the pyroxenes occurring as phenocrysts. The latter are often zonal in structure and large, but are not plentiful. Both augite and hypersthene were observed in these andesites. The presence of the latter pyroxene allies these andesites to the Mount Rainier type of lava. In the occurrences where the geologic relations indicate that the igneous rock is intrusive rather than a part of a lava flow, the texture of the rock is rather that of a porphyry than of an andesite.

PLEISTOCENE PERIOD.

The Pleistocene period dates from the beginning of the Glacial epoch. It was initiated by that climatic change which resulted in the accumulation of glaciers in northern North America and the extension of a vast ice sheet over Canada, the northeastern and north-central States, and British Columbia.

Physical conditions when glaciation began.

Glaciation of the Cascade Range, Washington.—No general glaciation extended over the State of Washington. Glaciers formed in the mountains and spread widely from them, but an extensive district east of the Cascade Range, on the plains of the Columbia, remained free from ice. The general configuration of western Washington was then what it now is. The Cascade Range and the Olympic Mountains bounded a broad depression, then a valley above sea diversified by sharply cut hills, now the submerged basin of Puget Sound. The upbuilding of Mount Rainier had probably been accomplished and the great volcano was quiescent, although St. Helens and perhaps other centers were still active.

Oceanic currents modified the climate in pre-Glacial time, and precipitation was copious, especially on the high ranges. In passing from the earlier warm climate to the severe conditions of glaciation the region experienced temperate summers and winters. This epoch probably was of long duration. The mountain ranges became deeply cut by canyons, disposed in general as are the upper courses of the rivers to-day. The valleys of the lowlands, however, were then differently related, as they were occupied by ice during the Glacial period, and the streams found their present courses only when the ice melted.

Glacial development began in the high mountains. From a condition milder than that now obtaining, the climate gradually, though with fluctuations, increased in severity. As cold seasons grew longer and warm ones shorter, snow banks in the shadows of high peaks increased in volume and drifts accumulated in hollows less protected from the sun. As they grew, the snow banks consolidated to ice and, flowing downward, became glaciers. Each canyon received an onward-moving ice stream, proportionate in size to the tributary area above. The air was chilled, precipitation increased, the glaciers extended, and thus the effect of climatic change was accelerated. The mountains became mantled with white, except over sharp, wind-swept peaks and ridges. Issuing from the foothills, the glaciers spread, and adjacent ones coalesced, forming broad piedmont glaciers, of which the Malaspina Glacier, lying south of the St. Elias Range in Alaska, is an existing example. A piedmont glacier is related to the mountain or alpine glaciers which feed it as a lake is to its tributary streams.

Three glaciers confluent in Puget Sound.

Three great piedmont glaciers met in the Puget Sound Basin. One was fed from the Olympics; the second and larger one gathered along the base of the Cascades; the third and largest flowed south from between Vancouver Island and the mainland of British Columbia. The last poured a great mass westward into the Strait of Juan de Fuca and another into Puget Sound. Tongues of these piedmont glaciers advanced along the valleys until opposing ice streams met and coalesced. Then the ice mass deepened, as water may deepen in a lake. Land divides became peninsulas and isolated hills stood as islands. To such islets in the ice the term nunatak is applied. Hills of the Puget Basin were finally submerged, the ice reaching a thickness of 2500 feet or more in the present site of Admiralty Inlet, and the southern extremity of the ice sheet spread beyond Tacoma and Olympia to the south and west.

Conditions of a glacial retreat.

The glaciers ceased to increase in the mountains and to deepen in the valleys as the climate changed either to milder seasons or to less precipitation, or both, a change due to ultimate causes which, like those that brought on glaciation, are not understood. Then followed an epoch during which the ice melted, earlier and more rapidly in the lowlands, later and lingeringly in the canyons of the ranges. When the piedmont glaciers had shrunk till they parted and each mantled the foothills of its parent range, the scene may well have resembled the aspect of the Malaspina Glacier and the St. Elias Alps. The margins of the glaciers consisted of masses of stagnant ice buried beneath accumulations of gravel, sand, and loam, and hardy vegetation may have flourished in soil upon the ice. Rivers flowed on the glaciers, through tunnels in them, and from beneath them. Ice-bound lakes were formed in embayments of the hills. Changes succeeded one another frequently, and each phase of ice and stream and lake left a meager record of its existence in deposits of detritus.

Two episodes of glacial advance recognized.

Two advances of the piedmont glaciers are recorded in the Pleistocene deposits of the Tacoma quadrangle, and two retreats. The oldest glacial formation as yet recognized lies at sea level along the shores of Admiralty Inlet. Beneath it may be others, due to earlier stages of glaciation, and they may be found in more extended studies of the land. At present there is a gap which observation has not spanned between the latest formation of the Neocene period and the oldest known records of the Pleistocene period.

Source of glacial drift.

Genesis of Pleistocene formations.—The conditions under which glacial deposits form require explanation, because they are rarely observed in ordinary experience. From the mountains in which they have their course, glaciers receive rocky débris loosened by frost. Heaped upon the surface, embedded in the ice, and concentrated in the bottom of the glacier, this material is carried forward. It is composed of sand and stones of all dimensions up to large blocks. Stones which are ground against the glacier's bed are scratched and planed off, and in part worn to a fine silt; those which are taken up by rivers flowing on, or in, or beneath the ice are rolled, rounded, and partially sorted from admixed sand and silt. All the stony detritus thus carried and modified by glaciers is called glacial drift, or simply *drift*.

Conditions of deposition of glacial drift.

Drift may be deposited (1) by glacial ice, or (2) by ice and streams working together, or (3) by streams issuing from the ice; and drift is classified accordingly. Only those types which have been recognized in the Tacoma quadrangle need here be described.

Deposits made by ice.

Deposits made by ice alone are usually characterized by the mingling of fine and coarse detritus in chaotic association. The most typical formation is a dense clay in which are embedded large and small stones which are scratched and planed; it is spread beneath the ice, and is known as *ground moraine* or *till*. Another type is produced upon and under the margin of a glacier as it melts. The upper and clearer ice disappears, while the bottom ice, which is densely charged with drift, remains. At this stage the ice no longer moves; it is stagnant, and, melting away, it leaves the drift in irregular heaps and pitted with hollows called kettle holes. Such a formation is called a *lodge moraine*. The formations in the Tacoma quadrangle attributed to ice alone are the Admiralty till in part, the Osceola till, and the Vashon drift in part.

Deposits made by ice and water.

Deposits made by ice and water are composed of masses of coarse and fine drift in sorted and unassorted masses, irregularly arranged and heaped in ridges. A common condition for their development may be a tunnel beneath the ice, through which runs a stream overcharged with sediment. Sand and gravel bars built by the stream and heaps of drift fallen with ice masses from the roof may fill the tunnel confusedly. When the surrounding ice melts the outer slopes of the deposit roll down to an angle of rest, and thus an irregular ridge may result. Ridges and hills of this general class have been subclassified according to their forms, their arrangement parallel to the direction of the glacier's movement or in lines transverse to it, and their internal structure. Those which occur in the Tacoma quadrangle appear generally to have formed in tunnels whose course corresponded to the slope of the ground beneath stagnant ice; they have been called *eskers* or *osars*. In the Tacoma quadrangle they occur only in areas of modified Vashon drift. A close study of the eskers may show that some of them belong to other types of the general class.

Deposits made by waters beyond the ice.

The drift deposits formed by waters flowing from the ice are of the character of deltas and lake beds. Glacial streams are thick with sediment, and may be so swift as to sweep along quantities of very coarse gravel. Common among the topographic accidents of glacial history is the development of transient lake basins. They may form in the ice, or in a ravine or valley dammed by an ice wall across its outlet, or by glacial heaping of drift to constitute a dam. The loaded streams emptying into such a lake build deltas of coarse gravel and sand, and deliver sediments which accumulate in layers beneath the quiet waters. When the lake is emptied the deltas and the lake bed remain as topographic features, recognizable by their forms and their internal stratification. Such deposits occur in the Tacoma quadrangle, and are here described under the names Stratified drift, Gale sands, Steilacoom gravels, and Midland sands.

Blue clay, unstratified and including stones, or finely stratified.

Admiralty till.—The oldest known formation of Pleistocene age is a stiff blue clay which is exposed along the shores of Admiralty Inlet. It has been named Admiralty till. It usually reaches only a few feet above sea level, and since its upper surface is gently undulating, much of the Admiralty till doubtless lies below sea level and is therefore concealed for the greater part of the distance along the shore. This till is a blue clay, in many places minutely stratified with great regularity, or a pebble clay with included subangular pebbles, or a bowlder clay containing both pebbles and bowlders, which vary greatly in size and are confusedly arranged. The several types pass one into another horizontally. They are locally more or less sandy. The best section of typical Admiralty till in the Tacoma quadrangle is in the vicinity of Stone Landing, where there is a bluff nearly 40 feet high of sandy bowlder clay. An exposure of the stratified variety occurs in the bluff above the steamer wharf at Tacoma, the upper surface of the clayey till being marked by a line of springs. The bowlder clay is cut through by streets in the southeastern part of the city, about 30 feet above tide.

The Admiralty till was laid down directly by ice and in still waters partially or wholly surrounded by ice. It records the earliest glacial occupation within the Tacoma quadrangle of which we have any knowledge; but, being the oldest of the glacial deposits, it is so poorly exposed as to furnish little data relative to this first epoch in the glacial history of the region.

Stratified drift.—Under this head are included several formations, which may be separated upon the basis of lithologic characters. The stratified drift is exposed only in the bluffs bordering the valleys and the shore of the Sound, and where tributary streams have cut back into the plateaus; and in these limited exposures the relations are largely obscured by landslides. Divisions of the series on the geologic map therefore can not be represented.

Lignite in stratified sand and clay.

The oldest of these deposits consist of finely stratified clay and sand with thin beds of lignite. This lignitic series is usually found directly overlying the Admiralty till, and sharp separation from the latter is not always possible. The lignite occurs in bits stratified with the clay or in larger pieces, one slab of wood 4 feet in length having been observed. Elsewhere the lignite forms well-defined beds of detrital material of a vegetal nature, which are interstratified with clay or sand, the latter sometimes showing the plunge structure of deposits from swift streams. The lignitic beds attain a thickness of 4 to 6 feet, and contain impressions of leaves.

Orange-colored gravels; Orting.

Beds of gravel occur in the horizon of these lignitic clays and sands, and may have accumulated at the same time. They are coarse and heterogeneous in character, usually orange-brown in color, and often interbedded with sand. Cross stratification is common. These gravels vary in thickness from 40 to 140 feet. The beds are usually weakly cemented; and a characteristic distinguishing this formation from later gravels of similar composition is the occurrence of decomposed granite pebbles and bowlders. They have been called the Orting gravels, from a conspicuous occurrence in a bluff near that town.

Even bedded fine sands.

The Puyallup sands, which overlie the Orting gravels, are essentially deposits of fine material evenly stratified. Gravel lenses or scattered pebbles occasionally occur, but for the most part the sands are clean and uniform in character. They may be loose and incoherent or consolidated to coherent bluish sandstone with hard clay concretions. In places these sands are strongly cross stratified, the current bedding exhibiting dips of 20°. This deposit is usually about 40 feet thick, but at one locality on Vashon Island clean sands 200 feet in thickness are exposed.

Erosion interval followed by irregular local deposits.

In some of the sections of stratified drift, irregularly stratified deposits of sand and gravel are found resting upon the Puyallup sands. Occasionally the surface of the latter is uneven, showing erosion prior to the deposition of the overlying gravels. Such relations are observed in the bluffs along Carbon River, and here the Douty gravels, as they have been termed, contain large pebbles intimately associated with sand and smaller pebbles, while at one point bowlders of subangular form up to 4 feet in diameter were found in association with the coarse stratified gravel. The Douty gravels are 55 feet thick at this locality.

Another local deposit, even later in age, is of clay and fine sand, free from pebbles, bluish in color, but weathering dark brown. This is horizontally stratified in layers 3 inches to 6 feet thick, which differ slightly in the proportions of clay and sand, so that they weather out as ribs on the face of the bluff. Its deep-brown color where oxidized makes the clay appear carbonaceous when seen from a distance, but it contains no vegetal remains. It may be related to the Osceola till.

Interpretation of the Stratified drift as recording episodes of glacial retreat and advance.

This Stratified drift series indicates varying conditions of deposition. The deposits, so different in character, record episodes equally diverse. Taken as a whole, this series of gravels and sands was laid down in an interglacial epoch, a period of milder climate than that which permitted the accumulation of extensive glaciers. This epoch included the stage of withdrawal of the Admiralty ice sheet, as well as that of the advance of the Vashon glacier. How completely the former glacier had disappeared from this area when the readvance began can only be inferred. A probable hypothesis is that the conditions of the Sound Basin at this time were not unlike those of to-day along the margin of the Malaspina Glacier in southern Alaska. If such was the case, the streams from the higher levels of the ice sheet deposited sand and gravel around and upon the stagnant ice in the center of the basin. In fact, such relations are observed in this series of stratified drift.

The stratified clay and sand associated with the lignitic beds at the base of the sections accumulated in water which was ponded as the Admiralty ice began to retreat. This was a time of comparatively temperate climate, and vegetation, including shrubs and trees, furnished the material for the beds of lignite. The Orting gravels were deposited by the swift waters of streams issuing from the glacier front. Such deposits were heterogeneous in composition, and often covered masses of the stagnant ice, the subsequent melting of which caused the gravel beds to be traversed by numerous small normal faults.

The Puyallup sands may be considered as having been deposited in quiet waters, being of the nature of lake deposits. In some cases the sands show current bedding, but in others it appears that the waters were deep enough to check the currents, so that the beds show horizontal stratification. Local variation of depth often permitted the deposition of lenses of gravel, while floating ice transported the large rock fragments which are found in these sand beds.

The later deposits of coarse material and of clay and sand resulted from local conditions. In the Carbon River section the Douty gravels indicate a river flowing from a glacier and sweeping down loaded ice cakes. Similar streams doubtless were at work in other parts of the area at the time of the reappearance of climatic conditions favorable to a glacial advance. This advance of the ice also obstructed the drainage at different points, and in the waters thus ponded the finely stratified clay and sand were deposited. The epoch was one of many changes, only a few of which are thus indicated by the deposits as exposed in this quadrangle.

Blue sandy clay deposited during the latest advance of the Cascade glacier.

Osceola till.—Much of the eastern and southeastern portion of the Tacoma quadrangle is covered with a dense blue sandy clay or silt containing angular and subangular fragments of sandstone and volcanic rocks. This has all the characters of an ice-laid deposit, and has been named the Osceola till from the locality where its occurrence is most typical. It covers the plateaus along the eastern edge of the quadrangle, having an elevation of from 500 to 800 feet. It also occurs at similar levels on the plateau east of the Steilacoom Plains, while on the slopes of the hill bordering the Carbon River this till reaches an elevation of over 2000 feet within the area here described. On the plateaus the topographic expression of this till is a plane surface slightly undulating; and as water stands on the impervious blue clay, swampy conditions prevail throughout its occurrence.

The Osceola till was deposited directly by the piedmont glacier, which was formed by the confluent alpine glaciers from the canyons of the Cascades immediately to the east. The rock fragments included in the till exhibit relatively little variety, and have been derived from rocks at no great distance. The silt making up the most of the Osceola till is a glacial meal, such as the White River carries at the present time.

Sandy and gravelly loam deposited during the latest advance of the northern glacier.

Vashon drift.—The Vashon drift covers a large part of the northern half of the Tacoma quadrangle. It is composed of sand and gravel, with pebbles commonly rounded. Angular and striated stones are much more rare than in the Osceola till. The pebbles are of granite and other crystalline rocks which form the mass of the northern Cascades. The granite pebbles are fresh as compared with the decomposed granite in the Orting gravels. In many cases the till in its composition shows a marked dependence upon the formation that occurs just below or in the immediate neighborhood. Thus the till may be sandy where it directly overlies the Puyallup sands, or it will contain large blocks of volcanic rock for a considerable distance on the lee side of a knob of that rock. So, also, angular blocks of coal are found in the till in the vicinity of Kent, probably transported from the outcrops of the Puget formation near Renton.

The topographic configuration of the Vashon till varies from smooth to hilly plains. Many shallow kettle holes or undrained basins occur, which are now filled with swamp alluvium. Other marginal features belong rather to the modified drift areas, and will be described later. The till forms a surficial deposit which varies much in thickness; in general it is less than 100 feet thick, and in places on Vashon Island the till covering is only 1 to 2 feet thick, yet it is remarkably persistent in its distribution.

As the Vashon drift has a less clayey character and contains fewer angular pebbles than the Osceola till, the former apparently is less completely the work of ice alone. Its structureless distribution with local bedding indicates deposition from ice with more or less aid by subglacial streams. Where the stream action appears to have been the more important factor in the deposition, the drift has been termed modified, and such areas are distinguished on the map and their description follows.

Water-washed drift of the northern glacier deposited beneath its margin.

Modified Vashon drift.—In the greater part of the area here considered, the drift deposited by the Vashon ice sheet is not a characteristic till. The subglacial deposit has been modified by glacial waters to such an extent that it can be readily distinguished from the drift resulting from ice action alone. The sands and gravels are better sorted and appear stratified. The difference is even more marked in the topographic features exhibited in the areas of modified drift.

The plateau east of Kent is marked by such a zone of modified drift, about 5 miles in width. Here the topographic forms are broad and lack definition. Broad ridges of coarse material merge longitudinally into mammillated surfaces, while between are hollows irregular in shape and now containing swamps or lakes. The ridges trend from west of north to east of south. To the south, on the plateau between the White and Stuck rivers, the relief is more marked. The ridges have the same southeastward trend, but are bold. Among them lies Lake Tapps, typically fingered. West of Puyallup Valley this zone continues toward Tacoma. Kettle holes and mounds are confusedly arranged next to the edge of the valley, while farther west occur a number of well-marked parallel gravel ridges trending north-south.

These topographic features characterize the marginal zone of the Vashon drift and mark the limits of this ice sheet to the east and south. The irregular heaping of sand and gravel into hillocks and hollows constitutes what are known as lodge moraines, which originated immediately beneath the low ice front. Such deposits are never made continuously for a great length of time in any particular place, and thus differ from a well-marked terminal moraine, a form which has not yet been recognized in the Puget Sound region.

The parallel ridges of coarse, more or less stratified gravel are eskers. These trend in a direction parallel with the flow of the ice, and represent the deposits of streams which probably occupied tunnels beneath the ice. The walls of the tunnels confined the gravels as deposited by the stream in its tortuous course, so that the esker often has a serpentine form. A striking example of this type of esker occurs near Beede Lake, about 2 miles west of Auburn. Here a ridge with a sharp summit stands up prominently, and at its southern end separates Beede Lake from another small lake. On the western side of the Duwamish Valley, 3 miles northwest of Kent, there is a group of ridges which lie upon the slope rising from the alluvial plain to the plateau above. These ridges are 40 feet or more in height, and their trend is nearly north-south at an angle with the inclination of the slope. They are roughly parallel, but coalesce at points along their course, forming inclosed kettles. Clayey gravel makes up the greater part of these ridges, and is in part roughly stratified. Large bowlders occur, but are not at all common. In form, position, and material these ridges are homologous to certain lateral moraines along the present Carbon Glacier on Mount Rainier. As lateral moraines they furnish a record of the shrinking of the glacier tongue that occupied Duwamish Valley after the Vashon ice sheet had left the uplands.

One other area of modified drift is worthy of mention, being of a type somewhat different from that of the areas already described. In the extreme northern portion of the quadrangle, about a mile east of the shore of the Sound, is a group of rounded hills and ridges whose longer axes are parallel with the course of the rather broad valley making to the south. The central hill is oval in plan, and somewhat over 100 feet high. Two of the smaller hills or mounds which surround this central hill have basin-like depressions in their summits. The surface is a sandy loam, with few pebbles, although some large erratics occur. Below there is gravel and sand interbedded and cross stratified. From their composition and shape these hills appear to have been formed by subglacial streams, and they may belong to the class of deposits called kames.

Clayey sands along channels of transient glacial streams.

Gale sands.—In the plateau south of South Prairie a well-marked gap appears, extending from the valley of South Prairie Creek to the brink of the canyon of Carbon River. Similar gaps are seen to the east, which have the same general elevation of from 700 to 800 feet and connect with this. In these areas, which are lower than the rest of the plateau, occur sands, stiff and clayey, which have been named the Gale sands from the creek which flows across part of the area covered by them.

The level character of these sand-covered gaps, and the fact that, taken together, they constitute a well-marked channel with several tributary channels, indicate that the Gale sands occur along the course of a stream which, though short lived, was important from the volume of its waters. The sands are derived from the Osceola till, and are partly stratified as deposited in a quiet water body which was more extensive than the stream channel, and partly washed and redistributed. This stream received much of the present White River drainage, as well as that of South Prairie and Gale creeks. It flowed westward along the retreating southern edge of the Vashon ice sheet. Beyond the point where this channel reaches the Carbon River Canyon the old river doubtless became a superglacial or a subglacial stream, the ice at that time still remaining in Puyallup Valley. Thus, any deposits that would represent the lower course of this river are concealed beneath the later alluvium of the valley.

Coarse clean gravel forming level plains and terraces.

Steilacoom gravels.—Under this name are included deposits of coarse gravel and shingle which cover several large areas within the Tacoma quadrangle. The Steilacoom Plains furnish the type area, although the several areas differ somewhat both in appearance and in origin. The gravel is commonly washed clean, but some sandy beds occur. On the surface there is a thin veneer of silt. The deposit differs from the Gale sands in its prevailing coarseness.

The different areas need to be separately described with respect to their topographic features. The most northern is in the upper valley of Issaquah Creek. Here well-washed gravels occupy the valley, and are in striking contrast to the finer alluvium now being deposited by the present stream in its lower course. Terraces occur along the sides of the valley, and older channels are indicated. The relations here are complicated by the presence of glacial accumulations, but it is evident that the gravels have resulted from stream action.

What may be termed the Wilderness area of gravels comprises some 30 square miles between Cedar and Green rivers. Here are gravel plains from 300 to 500 feet above sea level, on which well-defined terraces occur and many distinct channels can be traced. The gravels are such as occur in the stratified drift, and may in part represent worked-over material from that horizon. The deposit in the main, however, is regarded as the work of heavily loaded streams. The area is one which was bared of ice at an early stage of glacial retreat, and therefore was the scene of important changes in drainage at the close of the Vashon epoch. It lay between the separating ends of the Northern and Cascade glaciers. Big Soos Creek is tributary to this area, and was probably at that time a subglacial stream occupying a pre-Vashon channel. Its volume was increased by extraglacial drainage, while channels leading southwestward from the valley of Cedar River indicate that this river was also tributary to the Wilderness area at one stage in the ice recession. The streams which deposited the washed gravels were thus both large and powerful, especially at this time of maximum supply from the melting ice. The upper portions of these plains show some traces of deposits of an overwash character, but the terraces below are stream-cut forms rather than delta terraces. In the southern portion of this area, in the vicinity of Neilson Lake, there are remnants of an older surface covered with Vashon till, bounded by stream-cut terraces.

Cedar River later occupied channels with a more northern course, along a belt of these washed gravels which can be traced north of the present valley. Three narrow channels connect this belt with the Issaquah area of gravels, and various changes in drainage are here recorded.

On the point between White and Green rivers, just southeast of Auburn, these gravels also occur, ranging in elevation from 250 to 425 feet. Their upper limit is marked by a terrace, above which is the plain covered with Osceola till. Here the gravels appear to have been deposited by the waters of one or the other of the two rivers before the present drainage lines were determined. A somewhat later channel eroded in the stratified drift is now occupied by White Lake.

The type locality for the Steilacoom gravels occupies a similar position with reference to the retreating ice front, but here the conditions of deposition were quite different. The Steilacoom Plains constitute a marked topographic feature, extending for many miles south of Tacoma. These plains in their lower levels exhibit some characters of morainal topography, such as mound and basin surfaces and isolated kame-like hills; but these forms are mostly covered by gravel deposits of delta character. Terraces occur at various elevations, forming level-topped embankments from 1 to 20 feet in height. Such deltas were formed beneath quiet waters, which were ponded by the ice. The fact that the lower deltas are somewhat masked by later deposits, while the deltas at higher levels are sharp and complete, indicates that during the development of these terraces the waters were deepening. This ice-bound lake was probably not a permanent body of water at any level, but its presence is well shown by these characteristic delta deposits.

Sands and sandy loam; deltas of glacial streams.

Midland sands.—Delta deposits other than those just described occur at a number of localities in the Tacoma quadrangle. These are grouped together on the basis of general similarity in origin and in character of material. Sands and sandy loams with occasional deposits of diatomaceous earth characterize these deposits, thus distinguishing them from the gravel deltas of the Steilacoom Plains. The surface of the areas of Midland sands is flat or gently sloping, except the instance near Carbonado, where the slope is steeper.

Deltas of Midland sands occur at low levels along the eastern edge of the Duwamish Valley south of Renton. These were deposited by the streams flowing down from the plateau at a time when the ice lingering in the valley ponded the water there.

South of Puyallup and of Tacoma are two larger areas of sand at a somewhat higher level. The village of Midland is located on the western one, and gives the name to the formation. These sand deposits, from their position and their relations to the other formations, appear to represent deltas formed by streams which flowed northward as the ice retreated into the old hollow of the lower Puyallup Valley. The eastern of these two areas occupies an outlet of the former Steilacoom lake.

Deposits of the Midland sands also occur at even higher levels. An important area lies northwest of South Prairie, on the plateau between White and Stuck rivers. A swamp area borders the modified Vashon drift to the north, and in turn is bounded on the south and east by a well-defined terrace about 100 feet high, back of which stretches an even plain. This terrace is composed of well-stratified sand and fine gravel. The relations indicate that this topographic feature belongs to a delta formed by streams flowing from the south and southeast. The delta deposit encircles hills of modified drift which then stood as islands above the waters ponded by the ice sheet to the north.

About 6 miles farther south are similar terraces at higher levels. These are composed of stratified sand with some fine gravel; thus in form and composition they are allied to the other delta deposits. These high-level deltas were formed where the topography was favorable for confining the waters against the ice front, when the northern ice sheet began to retreat.

Since these several deltas are scattered over a large area they must represent deposition at different stages in the glacial retreat, yet they all belong to the same epoch and have resulted from similar conditions.

Muck and peat beds.

Swamp alluvium.—Under this head are included the deposits which fill the many undrained or poorly drained depressions in the quadrangle. These deposits are of black muck, not infrequently interbedded with layers of silt and white earth containing the siliceous skeletons of diatoms or microscopic algæ. Peat occurs in some of these basins, and at one locality, 2 miles east of Wabash, bog iron ore was found. At the bottom of such deposits there is usually an impervious layer of clayey hardpan.

The origin of such a deposit may be read in the history of the filling of one of these basins. Rivulets or brooks emptying into it formed a shallow pond, on the sides of which their deltas were built out. In the water of some of these ponds diatoms flourished, the siliceous skeletons of which sank and formed deposits at the bottom. Gradually the pond became more and more shallow until swamp vegetation was able to find a footing. Then the accumulations of decaying organic matter formed the muck and peat which overlie the clayey hardpan. In many cases this deposition of swamp alluvium is still going on; in others the basins have been almost completely filled with the accumulations, so that the area of the former depression is only indicated by the rich black soil, with its characteristic vegetation of cedar and vine-maple where the forest has not been cleared. As can be noted from the map, several of these areas follow present drainage lines or indicate former ones.

Flood plains of the larger rivers.

Valley alluvium.—The wide valley floors within this area are covered with fine silt, similar to that which Puyallup, Carbon, and White rivers are to-day bringing down from the glaciers of Mount Rainier. Occasional lenses of sand and gravel occur. The depth of this deposit of silt can only be inferred; it may be considerable, but as exposed in the cut banks of the rivers no change in its character can be observed for a depth of 20 feet.

The narrow canyons which enter the heads of these broad valleys are covered with gravel or shingle. A few areas of silt and sand occur here, and the alluvium is for the most part of the nature of torrent gravels, with bowlders 2 or 3 feet in diameter. In its upper course, where confined in the canyon, the river with its swift current is able to transport this coarser material, but where such a stream debouches into a broad valley it immediately deposits some of its load, first the coarser gravel, then the sand, and lastly the silt. Its course being obstructed by the bars thus formed, the stream may divide and spread out in fan shape; and each little current, carrying and depositing its appropriate part of the load, spreads the detritus in a cone or fan.

One of these alluvial fans occurs at the head of the main Puyallup Valley, near Crocker, where Carbon River passes out of its canyon. The gravel is spread out into the wider valley, forming a marked contrast with both the finer alluvium of Prairie Creek Valley, which also enters here, and the fine silt of the lower main valley. White River is also building an alluvium cone, at the apex of which White and Stuck rivers separate, at an elevation of 160 feet above tide. The outer portions of this cone form a divide which extends across Duwamish Valley, so that the two distributaries or divergent streams are turned abruptly, the one northward and the other southward, to empty into Admiralty Inlet 40 miles apart.

Beyond the radius of the alluvial cone, streams loaded with fine silt transport a large amount of material, which is deposited in the eddies on the concave sides of bends and is constantly reexcavated by swift currents on the convex side of the bends. In consequence of this process such streams meander in constantly increasing sweeps from side to side of the valley, as is well shown in the course of White River in the vicinity of Kent. When in flood season the waters spread beyond the banks, they are checked in their flow and deposit their silt unequally. The greater part is laid down close to the main channel, and a finer layer is spread over the more distant plains. By this means the banks of the stream are built up until the stream itself runs at a higher level than other portions of its flood plain; if then the water breaks the natural dikes it devastates the adjoining fields. In Duwamish Valley north of Orillia, White River is on higher ground between such natural dikes, and is bordered on either hand by swamps. The same is true of the Puyallup in its lower course. Both of these streams carry large quantities of very fine mud from the glaciers of Mount Rainier, and their rich flood plains present to the engineer the same problems for protection against inundation as do the flood plains of the Mississippi Valley, though on a smaller scale.

Deltas of the larger rivers now forming.

In the building of the delta the loaded current is checked at a definite level by a body of quiet water, whether it be lake or sound. The current of the river suffices to sweep sediments forward on a gentle incline to certain lines, beyond which it is no longer able to transport them. Thence the embankment slopes steeply to whatever depth the still water may present. Thus the delta is a form characterized by a flat but gently sloping surface and limited by a relatively steep bank. It is, in fact, a submarine terrace which swings in an irregular curve about the mouth of the parent stream. Both Puyallup and Duwamish rivers are energetically extending their deltas into the waters of the Sound, but the advance is slow in consequence of the very great depth.

Topography of the Tacoma quadrangle.—The development of the topography of the Tacoma quadrangle is a part of Pleistocene history, and many of the characteristic features have been described in stating the sequence of events during the Glacial epochs. But the quadrangle falls naturally into separate topographic districts, each of which includes several types of features; and these districts may appropriately be described, for from a view of their relations may follow a clearer conception of the conditions and processes that have produced the peculiar aspects of the Sound region.

Aspects of Vashon and Des Moines islands.

The northwestern quarter of the Tacoma quadrangle is occupied by Vashon and Maury islands and, east of Admiralty Inlet, by the elevated land mass which is isolated by Puyallup and Duwamish valleys. The last is, in fact, an island, and has elsewhere been called Des Moines Island. Throughout these three islands, each of which is a distinct plateau, the topography of broad areas presents a gently undulating aspect. The surface is deeply trenched by streams only near the margins of the plateaus; there are extensive basins containing lakes or swamps, and the hills are indefinite elevations of no great height, nowhere sharply chiseled. Running water has effected but little toward shaping the gravel heaps left by the last retreating ice sheet. The western edge of Des Moines Island rises 250 feet above the Sound; the eastern locally attains 500 feet, and the longer streams all flow west or south. Opposite the heads of several streams the eastern margin is notched in a manner which suggests that during the glacial retreat an ice tongue may have continued to fill the Duwamish-Puyallup Valley when the level of the ice had sunk lower in Admiralty Inlet, and that streams flowed from the former into the latter.

Along many stretches of the shore of Admiralty Inlet there is a terrace about 20 feet above the present sea level. In some places it appears to be a wave-cut bench; and elsewhere it is a delta terrace built out by a tributary stream. This 20-foot terrace probably represents an earlier relation of the sea level, when it stood 20 feet higher against the land than it now stands. Other benches have been observed varying from 60 to 100 feet above sea level. Lacking the uniformity of level of a wave-cut terrace, these are attributed to cutting by streams, which are supposed to have flowed transiently between the land mass and an ice mass lingering in the broad adjacent hollow.

East and south of the Dawamish-Puyallup Valley are several plateau masses, apparently distinguished one from another by the channels of Cedar, Green, White, South Prairie, Carbon, and Puyallup rivers, but in fact related through the topographic zones which extend across them. From Cedar River on the north to Tacoma on the west the valley is bounded by a broad hilly belt, behind which lie plains that extend to the foothills of the Cascades. The hilly belt is coincident with the zone mapped as modified Vashon drift. The plains correspond to the extent of the Steilacoom and Osceola formations.

Aspects of the plateaus east and south of the Duwamish-Puyallup Valley.

The hilly belt is characterized by ridges which trend southeast, south, and southwest, diverging from the Duwamish-Puyallup Valley. The ridges rise 50 to 150 feet above the general surface. Between them streams flow through swamps and in ill-defined channels, which have not been materially cleared out since the retreating ice left them confusedly obstructed. The larger streams, Big Soos, Fennel, and Clover creeks, head in the plateau margins near the valley and flow into the interior away from the valley. The two former reach the lowland by short courses in recently cut channels. Lakes occupy many basins among the ridges. Embankments of the type of lateral moraines occur along the sides of the hollow now occupied by Big Soos Creek west of Swan Lake.

Interpreting this group of facts as significant of the distribution of the glaciers during their retreat at the close of the Vashon epoch, it may be inferred that the northern ice at one stage occupied the northwestern portion of the quadrangle, its margin lying as far east and south as the hilly belt now extends. The ice margin had then withdrawn from confluence with the Osceola Glacier. The ice contained great quantities of gravel, and other volumes were brought by streams flowing in and on the ice southward and southeastward from the higher glacial mass to the stagnant tongues. Thus irregular ridges were heaped under and on the ice upon the plateau, and among them were buried masses of ice, which, as they melted, left lake basins. One of the late lingering tongues occupied the hollow of Big Soos Creek, and recorded its transient occupation by the lateral moraines already referred to.

Conditions of development of the aspects of the plateau.

The plains along the eastern side of the quadrangle, which are mapped as conforming to the Osceola till, extend over an area on which the piedmont glacier of the Cascades lingered after separating from the Northern glacier. The space between the two ice fronts north of Green River became temporarily, first the scene of tumultuous deposits from the glacial streams, later a lake in which delta terraces were built, and when the icy bounds of the lake were withdrawn a plain scoured by transient streams and Cedar River, whose former courses are marked by bold stream terraces. The coarse deposits of gravel consistently support the interpretation of the topographic forms. Similar conditions prevailed over Steilacoom Plains, and the topographic characteristics have been described in connection with the account of the geologic formation to which that name is given.

The topographic aspects of the plateaus within the Tacoma quadrangle are found to be of types attributable directly or indirectly to the last glacial occupation and retreat. The conditions during the melting of the ice probably closely resembled those now existing in southern Alaska, where the forest grows up to and over upon the stagnant Malaspina Glacier. The form in which the ice left the surface persists under the forest growth. It has been modified by streams only where they fall rapidly from the plateau to the lowland.

The hollows of Puget Sound which are represented in the Tacoma quadrangle by part of Admiralty Inlet and the Puyallup-Duwamish Valley have some of the characters of valleys produced by stream erosion. They have generally been considered to be of that origin, and it has accordingly been inferred (1) that since the last Glacial epoch the land stood high enough above sea to permit rivers to cut as deeply as the bottom of the Sound, and (2) that the land has subsided, submerging the valleys to the present depth. That is to say, the hollows have been thought to be valleys of post-Glacial development. There is evidence to show that they were occupied by ice during the last glacial retreat, and therefore must have existed before the Vashon epoch. This evidence consists of minor topographic features, terraces, deltas, and, most significant, lateral moraines, which occur along the sides of the Puyallup-Duwamish Valley down to and buried in the alluvial deposits. The best examples occur west of O'Brien, east of Summer, and north of South Prairie. These features indicate that the ice occupied the hollows and lingered in them after it had disappeared from the plateaus. Finally melting, it left them to be occupied by the sea, and to some extent to be filled by alluvial deposits.

Conditions of development of the hollows.

The tendency of a glacier which invades, occupies, and retreats from a lowland diversified by hills and valleys is to build up the hills by deposits of unstratified and stratified drift, and to leave the valleys, where only till is deposited, at least as deep below the hilltops as they originally were. The conditions in the Puget Sound Basin appear to have been very favorable for this process, which was probably effective during the Admiralty epoch and is evident in the record of the Vashon epoch. It is accordingly probable that the separate plateau masses include divides or groups of hills, and that the hollows conform to the valleys of the pre-Glacial topography. The evidence is discussed in detail in an article entitled "Drift Phenomena of Puget Sound" and published as a brochure of the Geological Society of America, Vol. IX, pp. 111–162, February, 1898.

The following sections are records of detailed measurements of the Pleistocene formations:

Section A.—*Bluffs, north bank of Carbon River, 3 miles northwest of Carbonado; by aneroid barometer ascending southeast edge of nearly vertical face.*

(Read from the bottom upward in the order of relative age.)

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
Feet. 740	Gravel and sand under humus, forming a generally level surface, with occasional kettles; a section of a kame terrace.				
705 to 740	Coarse gravel, well rounded; numerous large pebbles of quartz and granite; bowlders up to 2 feet in diameter.	Irregularly stratified with sandy lenses.	Swift currents of loaded glacial streams at and under the ice margin.	Vashon epoch: early stages of ice retreat.	Vashon drift.
655 to 705	Clay and very fine sands, bluish, weathering dark brown.	Horizontally stratified in layers 3 inches to 6 feet thick; horizontally ribbed on weathered face.	Still water, supplied with sediment from glacial sources.	Vashon epoch: Osceola till; stage of advance of the Cascade Glacier prior to its complete confluence with the Vashon ice, and while the two ice sheets inclosed a water body in this locality.	Osceola clays.
615 to 655	Coarse gravel; pebbles up to 6 inches in diameter, finer toward the base.	Generally stratified, with gentle dip, somewhat cross stratified; coarse and fine materials mingled.	Swift currents of loaded streams, probably fed with glacial débris.		
605 to 615	Coarse gravels; inclosing subangular bowlders up to 4 feet in diameter.	Stratified	Temporary flooded state of streams carrying ice masses and bowlders in them.	Vashon epoch: advance of the Rainier ice, with streams building coarse deltas before it.	Douty gravels.
600 to 605	Gravels, relatively finer than those above, but with pebbles up to 6 inches in diameter.	Stratified and cross stratified; coarse and fine materials mingled.	Swift currents of loaded streams, flowing probably from glacier on the south.		
600	Unconformable contact of gravels on eroded surface of sands			Interglacial epoch.	
560 to 600	Sands, loose, incoherent, forming talus; upper surface irregular, varying 1 to 5 feet from its general plane.	Strongly cross stratified; dip 20° SW.; edges of layers come up to the contact.	Delta building by a stream swiftly flowing southwest, carrying finer materials farther into a water body.	Admiralty epoch: stage of retreat while yet the ice dammed the northern outlets and held a local water body here.	Puyallup sands.
545 to 560	Coarse gravel, finer below, grading up to pebbles 10 inches in diameter above, orange colored.	Stratified	Swift currents of loaded streams spreading in shallow waters or deltas, or distributing superglacial material.	Admiralty epoch: stage of retreat; fluctuations of the streams and ponded waters, affording alternations of conditions of deposit; climate relatively mild; oxidation of ferruginous solutions; lignite horizon.	Orting gravels.
530 to 545	Homogeneous sands, coarse as compared with those above 560 feet, orange colored.	Stratified			
505 to 530	Gravels, coarse and fine, interbedded, up to 6 inches in diameter, orange colored.	Strongly cross stratified; dip 20° to 25° E.			
460 to 505	Blue clay, sandy, including gravel lens, fine sand on top.	Minutely stratified; dip 15° E.	Gentle currents flowing from the ice and depositing sediment derived from the till.	Admiralty epoch: stage of retreat; early ponded waters if the ice advanced so far south as this at this point the till probably lies below.	Admiralty clay

Section B.—*East side of Puyallup Valley at Orting; section observed along the road grade.*

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
	Observations begin at the highest exposure of sands beneath the Vashon drift, which forms the summit of the hill and extends 200 to 300 feet down the slopes.				
Feet. 640 to 900	Vashon drift, coarse rounded gravel and loam, with large bowlders; no eastern or southern drift seen.	Confusedly mingled, occasionally stratified, heaped in ridges trending northwest about Orting Lake.	Subglacial by combined action of ice and streams.	Vashon epoch: during stage of confluent glaciation.	Vashon drift.
410 to 640	Prevailingly uniform sand, fine, occasional pebbles up to 1 inch in diameter, incoherent, no bodies of gravel.	Probably concealed by sliding; material is water sorted and probably stratified in place; no definite bedding observed.	Swift currents depositing cleaned sands, a delta formation, from a copious source.	These sands and gravel lenses apparently form a delta of a large stream which gathered from the sources of White River. The deposit may correspond with the Douty gravels and the Puyallup sands, both being divided by an unconformity, or it may be wholly either one or the other of these formations. The section is generally covered by sliding sands.	
410	Gravel in sands, rounded pebbles up to 5 inches in diameter, one angular stone 1 foot in diameter in gravel at the upper contact.	None observed; exposure very limited.	Probably a local deposit from a swift current, possibly with ice.		
340 to 410	Sand prevailing, with layers of gravel irregularly distributed.	Obscurely stratified	Swift currents, possibly from different directions.		
200 to 340	Coarse gravels, bowlders, gravel, and sand, orange colored, heterogeneously mingled, firmly cemented, granite bowlders occasionally decomposed.	Locally stratified; generally without definite structure.	Swift currents of loaded streams spreading morainic material over and around stagnant ice.	Admiralty epoch: episode of retreat, mild climate, favorable ferruginous solution; no lignite.	Orting gravels.
200	Level of the bridge across Carbon River.				

Section C.—*West bank of Puyallup Valley, 4½ miles north by west from Orting.*

(Read from the bottom upward in the order of relative age.)

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
	The margin of the plateau presents a very irregular slope toward the east, descending from a ridge (elevation, 530 feet to 540 feet) of very coarse gravel and loam across deep kettle holes to the escarpment, which is better defined.				
Feet. 360 to 535	Coarse gravel, with loam and large bowlders.	Confusedly mingled	Beneath the margin of the ice which occupied Puyallup Valley.	Vashon epoch: stage of retreat while the ice still overflowed onto the plateau.	Vashon drift.
360	Edge of very steep slope, sometimes vertical, to the valley.				
250 to 360	Gravels, well exposed only below 275 feet, relatively fine and coherent.	Stratified up to 275 feet and perhaps higher.	Swift currents of loaded streams.	Vashon epoch: stage of advance, with streams building in front of the ice.	
240 to 250	Gravels, with sand lenses inclosing bowlders up to 5 feet across with sharp corners.	Sands stratified; gravels mingled irregularly.	Swift currents discharging sand and gravel into ponded waters, while floating ice carried in bowlders.	Vashon epoch: stage of advance.	
240	Unconformity marked by sharp contact of coarse gravel deposits on level surface of fine sands; no erosion noted.			Interglacial epoch.	
230 to 240	Sands, very fine and uniform, consolidated to a coherent sandstone, bluish, with sandstone concretions; calcareous.	Horizontally stratified	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	Puyallup sands.
230	Fine shale, 2 inches thick		Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
222 to 230	Sands, more clayey than those above.	Horizontally stratified	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
219 to 222	Fine whitish clay, with minute bits of carbonaceous material.	Horizontally stratified	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
200 to 219	Sands, clayey, coherent, forming vertical bluff.	Horizontally bedded with overlying strata.	Quiet waters, ponded by ice	Admiralty epoch: the later stages of retreat.	
200	Top of talus slope. In adjacent exposures coarse gravels similar to those forming the lowest bed at Orting, orange colored and characterized by decomposition of the granite pebbles, are seen to occur up to about 160 feet above sea, and to extend down to the present alluvial plain of the valley.				Orting gravels.
100	Level of the alluvium, which floors the valley.				

Section D.—*East bank of Puyallup Valley, 4 miles north of Orting, 1¼ miles east of the preceding section.*

Elevation above sea.	Thickness.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
		Section exposed in a bank undercut by Puyallup River, measured near the southern end of the exposure. Surface above is a slope of Vashon drift, with large kettle holes.				
Feet. 171		Top of cut bank.				
	5 ft.	Coarse gravel with some loam, 1 to 6 inches in diameter, rounded and compact	Irregular and confused	Subglacial or marginal	Vashon drift.	
	2 ft. 6 in.	Sand with much gravel; dark gray, fine.	Distinctly stratified; dip is nothing at each end of the long bluff, but the section exposes a syncline, with dips of 10° toward the center of the bluff; the strata are traversed by numerous normal faults which increase the depth of the syncline. The structure is that which the beds might assume if deposited on an ice mass that slowly melted away.	Swift streams of variable power building a delta on the previous deposit of gravels which buried a stagnant ice mass.	Admiralty epoch: water body retained by the ice.	Orting gravels or Puyallup sands?
	6 ft.	Sand and fine gravel interstratified, layers 2 inches to 1 foot thick; gravel predominating.				
	3 ft.	Sands, coarse and fine, minutely interbedded, inclosing occasional pebbles up to 3 inches in diameter.				
	2 ft. 6 in.	Sands, inclosing pebbles along the lower contact up to 8 inches in diameter.				
	1 ft. 3 in.	Gravel and coarse sand, pebbles, one-half inch to 3 inches in diameter.				
	1 ft.	Sand, coarse.				
	1 ft. 3 in.	Gravel with much coarse sand.				
	6 in.	Sand, coarse.				
	2 ft.	Gravel, with pebbles up to 3 inches in diameter; finer below.				
	2 ft.	Sand, coarse with fine pebbles.				
	4 ft.	Gravel and coarse sand intimately interstratified.				
	40 ft.	Coarse gravel, irregularly bedded with limited sandy lenses including bowlders up to 10 inches in diameter.	Irregularly bedded, sharing also the synclinal structure of the upper beds.	Subglacial and marginal streams depositing gravels on stagnant ice.	Admiralty epoch: stage of retreat.	Orting gravels.
	71 ft.					
100		Puyallup River.				

Section E.—*East bank of Puyallup-Duwamish Valley, 9 miles north of Orting; bluff adjacent to the main road; supplemented by observations at higher levels on the road to Lake Tapps, one-fourth mile northeast.*

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name,
Feet. 600 to 335	Undulating, boldly ridged surface of coarse gravel, loam, and sand, with large bowlders all of Vashon drift, forming the system of osars about Lake Tapps and out to the margin of the plateau. The road to Lake Tapps ascends the scarp along a narrow ravine, in which are delta terraces as follows:				
335 to 350	Sands, argillaceous and pebbly, resting on Vashon drift.	Stratified and cross stratified	Delta formation by stream flowing down the ravine into waters ponded by the glacier in Duwamish Valley.	Vashon epoch: stage of retreat when the ice had left the plateaus but filled the valley.	
255 to 335	Slope of the upper delta.				
230 to 255	Sands, argillaceous and pebbly, forming a delta surface like the upper one, but of later development.			A slightly later stage of retreat, when the ponded waters subsided to this level.	
205 to 230	Not exposed in section, slope of Vashon drift.				
205	Blue clay, finely sandy; thickness, 3 feet, in gravels.	Horizontally stratified	Deposit in ponded waters; material possibly derived from Osceola till.	Vashon epoch: stage of advance when the rising ice inclosed waters in front of the Cascade Glacier prior to confluence.	Osceola clays.
135 to 205	Slope of plateau scarp, Vashon drift, not exposed in section.				
135	Top of bluff adjacent to main road, south of the ravine.				
100 to 135	Coarse gravel, pebbles 1 inch to 15 inches in diameter, with loam and sandy lenses.	Horizontally bedded and cross stratified.	Swift streams building gravelly delta in front of the ice.	Vashon epoch: stage of advance prior to confluence with the Cascade ice.	
100	Surface of sands, irregular, eroded			Interglacial epoch.	
90 to 100	Fine sands, with gravel lenses, and compact gray clay.	Strongly current bedded	Swift streams loaded with much sediment and some coarse gravel, building deltas.	Admiralty epoch: stage of retreat while the ice held ponded waters.	Puyallup sands.
82 to 90	Coarse gravels; pebbles 1 inch to 5 inches in diameter, with sandy lenses.	Horizontally stratified and cross stratified.	Swift streams loaded with gravel.	Temporary condition favorable to transportation of coarse material.	
75 to 82	Fine sands, uniform, coherent, without calcareous cement.	Indistinctly bedded	Currents depositing in water too deep to permit current bedding.	Admiralty epoch: stage of retreat while the ice confined waters.	
75	Level of the main road.				

Section F.—*South bank of Green River, 2 miles east by south from Auburn; section measured on road descending from the plateau to a bridge across Green River.*

Elevation above sea.	Character of material.	Structure of deposit.	Conditions of deposition.	Probable correlation.	Formation name.
The surface to the south and east of this locality is relieved by ridges, 60 to 100 feet high, of coarse waterworn detritus mingled with sand and loam, inclosing extensive kettle holes and hollows. These are probably subglacial deposits or osars.					
Feet. 580 to 640	Coarse gravel and loam, forming a ridge on the edge of the scarp which slopes to the river.	Heterogeneously mixed, locally stratified.	Subglacial by cooperation of ice and streams.	Vashon epoch: stage of retreat of Cascade ice.	
580	Gap in the valley rim, leading to a wide swampy level to the southwest; a former outlet for a stream from the valley.	....	....	Vashon epoch: stage of retreat subsequent to the deposit of subglacial gravels.	
560 to 580	Sands, coarse and fine, well washed, interstratified with clayey layers, 2 to 20 inches thick.	Horizontally bedded, wavy, with fine cross bedding in sandy layers.	Quiet waters within range of fluctuating currents; glacially ponded waters receiving till sediment.	Vashon epoch: stage of advance prior to confluence of the Cascade and Vashon ice sheets.	
530 to 560	Blue clay, sandy, very compact, numerous rounded pebbles one-half inch to 12 inches in diameter; angular stones of Eocene sandstone and shale, 18 inches to 3 feet on a side; till.	Not stratified, firm, homogeneous.	Subglacial by ice alone, movement from the east.	Vashon epoch: Osceola till of the Osceola tongue of the Cascade Glacier.	Osceola till.
520 to 530	Bowlders, 3 inches to 2 feet in diameter, irregularly distributed.	Locally indistinctly bedded, generally confused.	Marginal or submarginal to the ice.	Vashon epoch: moraine of the advancing Osceola tongue.	
520	Uneven, eroded surface of sands; unconformity			Interglacial epoch.	
490 to 520	Sands, interbedded with gravel lenses.	Stratified and cross stratified; stream bedded.	Quiet waters, receiving delta deposits from fluctuating streams.	Admiralty epoch: stage of retreat while the ice still ponded waters in the district south and west of its front.	Puyallup sands.
455 to 490	Sands, blue, clayey, compact, weathering brownish; weathered surface ribbed according to proportion of clay in the layers.	Horizontally stratified, jointed, exceedingly firm, almost consolidated to sandstone.	Quiet waters, receiving sediment, probably from streams corrading till beyond the zone of gravel deposition.	Admiralty epoch: stage of retreat while the ice held ponded waters.	Puyallup sands or Orting gravels?
240 to 455	Talus slope.				
240	Bridge across Green River.				

ECONOMIC RESOURCES.

COAL.

Location of coal fields.—The southern coal fields of the Puget Sound Basin lie on either side of the meridian of 122°, extending 10 miles east and 10 miles west, with irregular outlines. From north to south they stretch through less than a degree of latitude, from near 47° 35′ to about 46° 45′. The fields now developed lie between the latitude of Seattle and the parallel of 47°, a north-south distance of 40 miles. Their relative positions are indicated on the outline map.

With reference to Puget Sound, this productive district lies from 7 to 25 miles east and southeast from, and extends parallel to, the southeastern inlet, which ends in Commencement Bay. The western foothills and valleys of Mount Rainier reach into the southern portion of the area of coal-bearing rocks. By railroads 12 to 35 miles in length the mines are connected with the cities of Seattle and Tacoma.

The coal districts included in the Tacoma quadrangle are the Renton-Cedar River, the western margin of the Green River, and the Wilkeson-Carbonado. The Newcastle-Gilman district and the central portion of the Green River lie just beyond the eastern limit of the quadrangle. Their relative positions are indicated on the accompanying index map.

Character of the coal.—The character of the coal varies from field to field, as it has undergone chemical change by loss of water and concentration of fixed carbon to a greater extent in some districts than in others. The coals range in character, therefore, from lignites, whose representative analyses have the limits—

	Per cent.
Moisture	8 to 12
Volatile hydrocarbons	35 to 45
Fixed carbon	30 to 45

to bituminous lignites or steam coals, in which the moisture is reduced to 5 per cent or less and the fixed carbon ranges from 40 to 50 per cent, or to bituminous coking coals, which are fairly represented by the figures:

	Per cent.
Moisture	1 to 3
Volatile hydrocarbons	25 to 35
Fixed carbon	50 to 60

The ash of these coals is frequently as much as 10 per cent, particularly in commercial samples taken fairly to represent the marketable product. But the earthy constituents occur largely in distinct streaks in benches of purer coal, and the proportion which goes to market is determined by the cost of removing the associated bone and slate. Methods of mining and preparing the coals depend upon the characteristics of individual beds, but for each district there are also general factors which determine the handling of the product. One of these is hardness. The lignites are hard. The bituminous lignites of the Green River district are softer, but still firm. The bituminous coking coals of the Wilkeson field are very soft. The two former may be hand picked; the last named require washing.

The variations from lignite to bituminous coking coal are of regional extent; that is to say, where lignites are found they may be expected to maintain a uniform composition over a relatively wide area, and bituminous varieties are equally

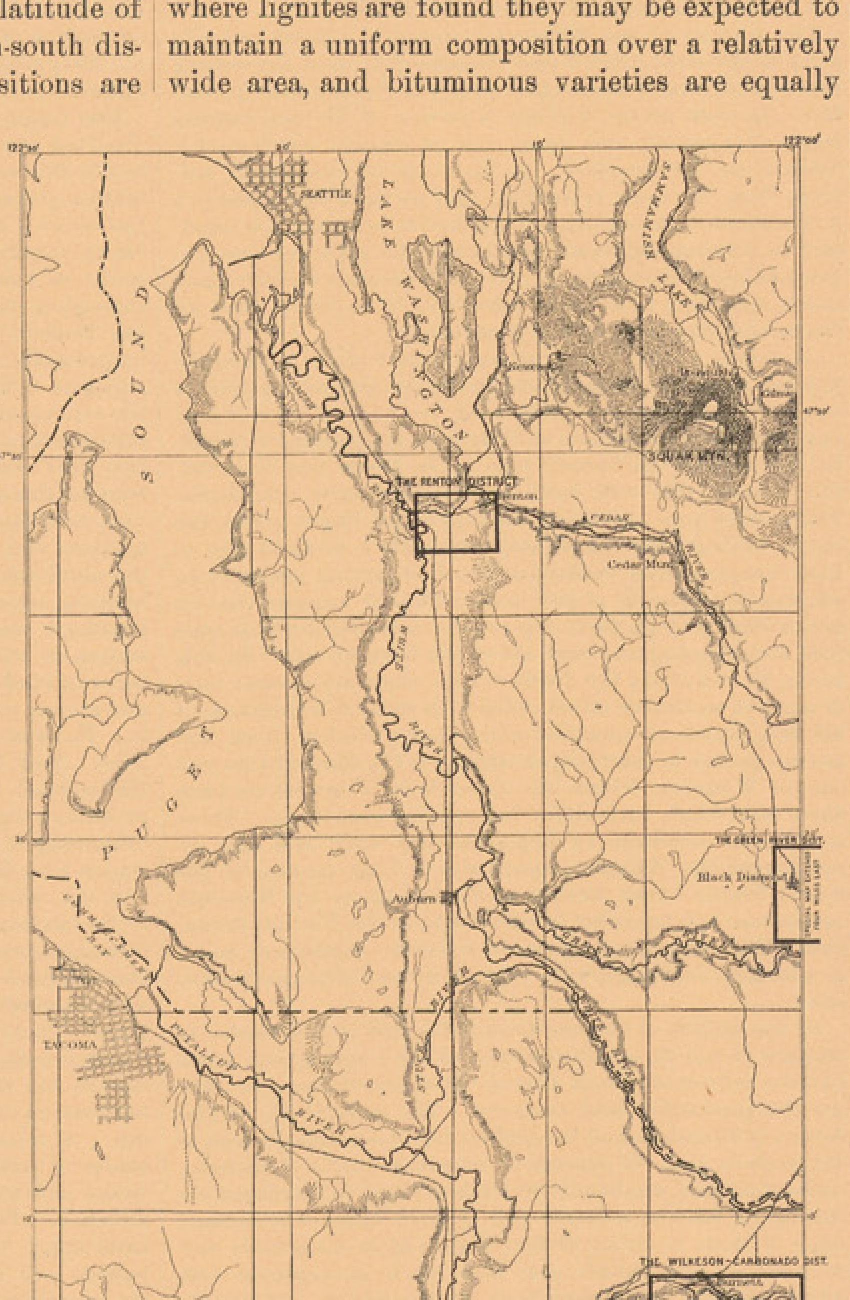


Fig. 1.—Index map of the southeastern coal fields, Puget Sound, Washington.
Scale, 6 miles to the inch.

constant in character within the fields in which they occur. There are, however, occurrences of more condensed coals, ranging into anthracite, which are, so far as is definitely known, of local distribution only.

The cause of variations in quality among these coals may be sought in the pressure and movement which they have suffered. The lignites retain the compact structure originally assumed by the peaty deposit under the load of overlying strata. Their beds have been tilted, but internally not much disturbed. They have therefore undergone comparatively moderate chemical change. The Green River steam coals have assumed a more or less cubical structure, due to shearing under pressures which caused movement within the bed. The resulting chemical effect was to expel 5 to 8 per cent of water. Beyond the area of this mechanical influence the coal changes into lignite by transition within a single bed. The coking coals of the Wilkeson field, and those of the extreme eastern portion of the Green River field, have been rolled out between their walls and crushed. Their softness and their concentrated condition have resulted from this mechanical disturbance. The further transformation of the coal to anthracite and coke occurs in the vicinity of igneous rocks, to whose influence it is due.

Newcastle-Gilman district.—Fifteen miles east of Seattle, beyond Lake Washington, is the valley of Issaquah Creek, which flows northward through Squak Mountain into Sammamish Lake. Squak Mountain has a height of 1980 feet, and at an elevation of 1000 feet sends off a bold spur northward. Northwest of Squak Mountain a range of hills, rising to a height of 1500 feet, extends for 5 miles between lakes Washington and Sammamish. Newcastle is situated on the western slope of these hills. Between them and Squak Mountain, Tibbetts Creek flows northward, parallel to Issaquah Creek and about a mile west of it, also emptying into Sammamish Lake. The town of Issaquah, formerly called Gilman, is situated on Issaquah Creek about 2 miles south of Sammamish Lake, at an elevation of 95 feet above the sea. The valley is here half a mile broad, and wide and fertile bottom lands extend to the lake. A mile south of the town the pass through Squak Mountain narrows to a wild ravine, bounded by high cliffs overgrown with timber and underbrush.

The Gilman mines are opened in the northern spur of Squak Mountain, and extend from east to west through this spur to and beyond the valley of Tibbetts Creek into the Newcastle Hills. The Newcastle mines, also extending east-west, are opened along Coal Creek on the western slopes of these hills and about 1 mile north and 5 miles west of the Gilman mines. The Gilman mines are reached from Seattle by the circuitous route of the Seattle and International Railway, which passes around the northern end of Lake Washington and along the eastern shore of Sammamish Lake. The Newcastle mines are connected with Seattle by a narrow-gauge road constructed around the southern end of Lake Washington and about the slopes of its eastern shore. There is no direct connection, except by wagon road or trail, between the two mining points.

No very complete section of the coal-bearing strata could be measured in this locality, as the hillsides are covered with drift and forest so as to obscure the rocks. From the mine map, however, the following intervals between coal beds were noted:

Vein No. 4 (thickness 7 feet), highest of the known series.
Interval of 300 feet, including vein No. 3 (thickness 5 feet).
Vein No. 2 (thickness 6 feet).
Interval of 175 feet to vein No. 1 (thickness 16 feet).
Interval of 412 feet to vein No. 5 (thickness 8 feet).
Interval of 360 feet to vein No. 6 (thickness not measured), the last of the known series.

The detailed cross sections of all the veins except No. 6 are given in fig. 2.

The structure of the district is that of a simple monocline, dipping northward. Squak Mountain, extending south of the mines, is a mass of igneous rock, which may have caused the northern tilting of the coal measures, or may simply have been uplifted with them. The strata strike S. 86° W., from Issaquah Creek to Tibbetts Creek, and have dips varying from 20° to 40°. They are remarkably free from faults, only one of importance having been met with in the course of mining. This fault, a simple pinch, was encountered in the water-level gangway of vein No. 4, and extended about 400 feet. The walls of the vein were continuous, and were separated throughout by a recognizable coal streak, which, however, was often squeezed to a fraction of an inch. An examination of the wall rocks made it evident that they had simply slid past one another in such a manner as to bring two continuous surfaces into opposition and to force the coal out from between them. This fault does not traverse the strata, but is limited wholly to the vein in which it occurs, and gives no occasion to infer the existence of similar faults in the other veins.

The relation of the Gilman section to that of Newcastle has not been determined. There are resemblances between the veins in the two sections, and it is possible that they present opposite sides of a coal basin. This supposition is rendered more plausible by the fact that younger strata of Miocene age are known to occur in the southeastern portion of the Newcastle Hills, where the center of the basin should be. The extent of the coal-bearing district, if it be continuous from Gilman to Newcastle, is not less than 5 square miles, and may be 12 square miles. The relations of the district beyond the immediate vicinity of the mines have not been studied.

Renton-Cedar River district.—Between White River and Cedar River extends a plateau, whose terraced slopes and uneven surface appear to be composed wholly of gravel deposits. The valley level has an elevation of about 30 feet, and the plateau surface a height of 400 feet, above the sea. The intervening slopes are steep. Along the northern front, facing Cedar River, eroded surfaces of the bank expose the edges of coal-bearing strata dipping eastward, and explorations made many years ago revealed the continuation of these coal veins on the southwestern face farther south. Thus it is known that beneath the deposits of stratified and unstratified gravels the plateau has a core of coal-bearing strata. Six miles farther east, also on the banks of Cedar River, the rocks are again exposed, and the Cedar Mountain mine has been worked both eastward and westward from the Cedar River Valley.

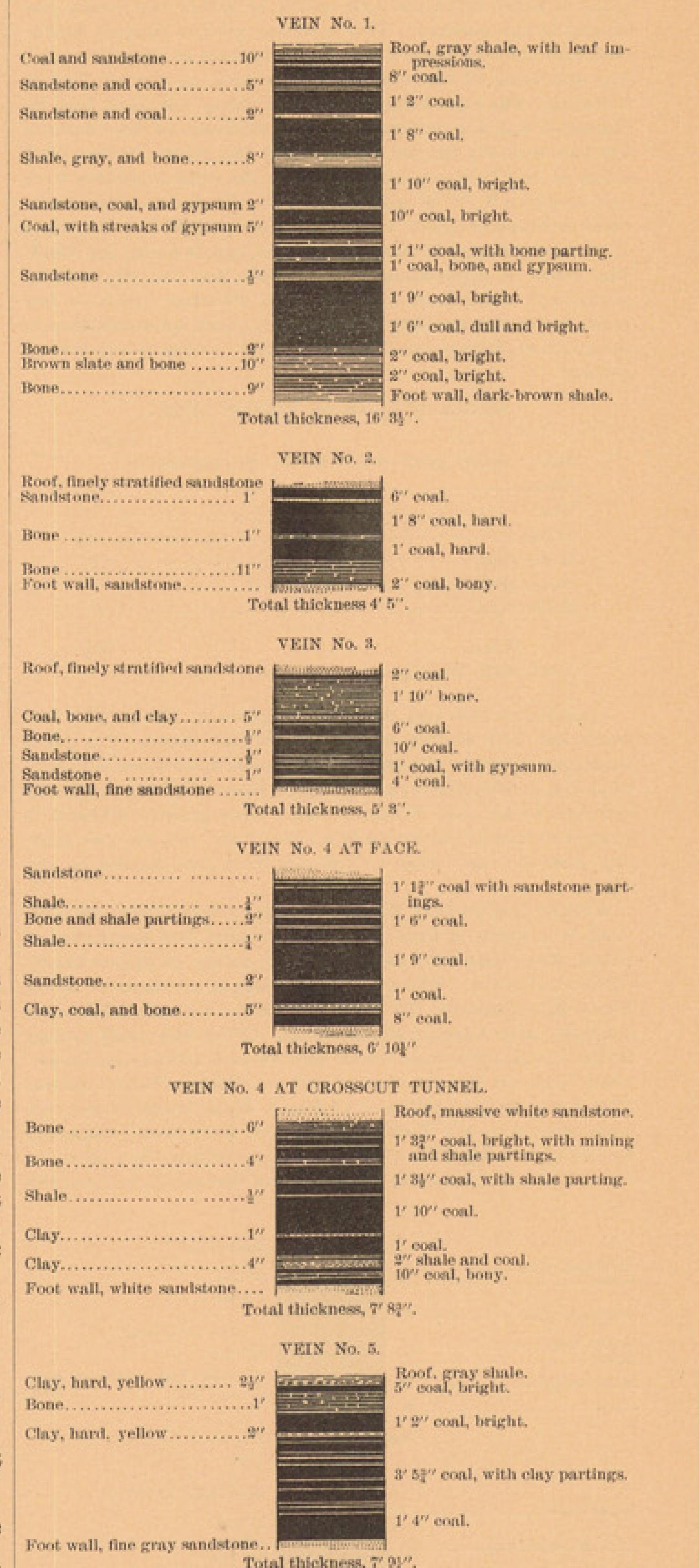


Fig. 2.—Sections of coal veins, Gilman mine.

At the point where Cedar River passes out into the plain of the broad valley is one of the early settlements of this region, the town of Renton, which takes its name from that of the old coal mines worked in the hillside above it. Renton lies 11 miles southeast of Seattle, and is connected with it by the Northern Pacific Railway, the Columbia and Puget Sound Railroad, and electric car lines. The area of the Renton coal field, which lies in T. 23 N., R. 4 E., is probably 4 and possibly 8 square miles.

The strata of the Renton district do not appear in exposures in such manner as to afford any considerable section of the measures. Although several beds have at different times been opened, but one is now worked, and its relation to the others was not determined. The old Renton mines were worked southward from Cedar River on a general north-south strike and a dip of 14° to 16° to the east. Another mine, known as the Renton-Talbot mine, was opened about a mile south and was worked southward. Both of these workings are now abandoned and are full of water. In a space of ground remaining between them the Renton Cooperative Coal Company opened a new slope in 1895. Sections of the principal coal beds were obtained in the new workings, and they are given in fig. 3.

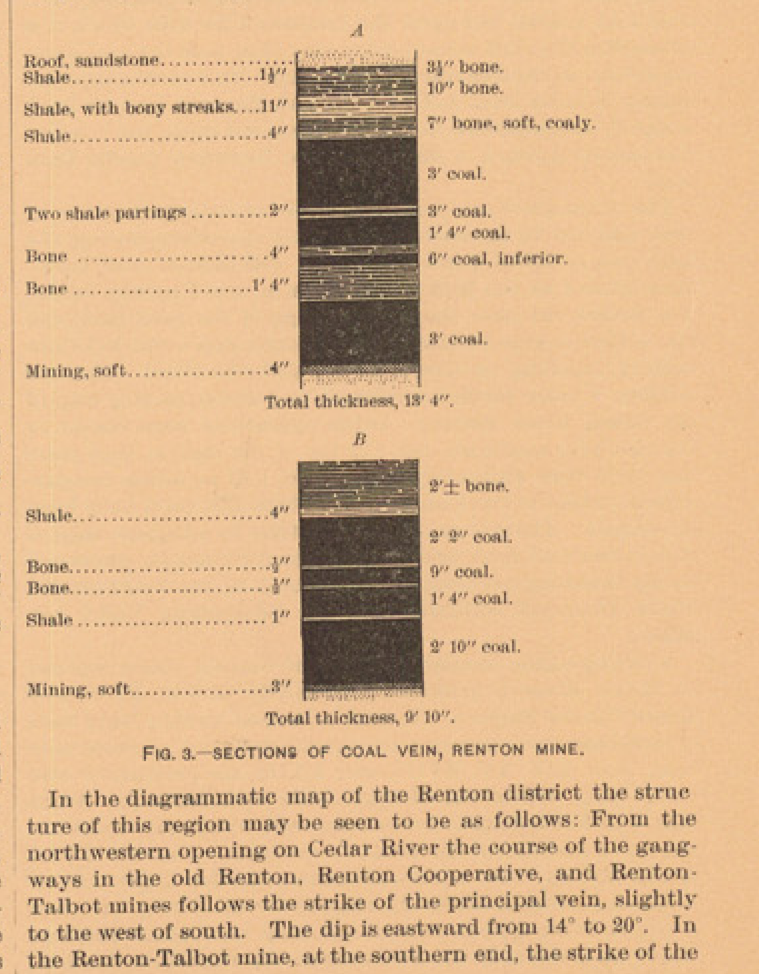


Fig. 3.—Sections of coal vein, Renton mine.

In the diagrammatic map of the Renton district the struc ture of this region may be seen to be as follows: From the northwestern opening on Cedar River the course of the gangways in the old Renton, Renton Cooperative, and Renton-Talbot mines follows the strike of the principal vein, slightly to the west of south. The dip is eastward from 14° to 20°. In the Renton-Talbot mine, at the southern end, the strike of the vein, as indicated by the gangways, bends to the westward around a broad, low arch. In the old Talbot mines this western course is continued out to the edge of the alluvium in the valley. The eastern dip of the northern mines is continuous as far down as the slopes have been driven, but the southern dip of the old Talbot mines is converted into a northern dip along a sharp synclinal axis, south of which the strata rise steeply to the surface. This syncline pitches sharply southeast, and the coal basin accordingly extends in that direction. The existence of the fold was determined in the old Talbot workings, the vein being disturbed along the axis, but its character was not understood. The existence of the northern dip was recently proved by exposing the strata in the bluff south of the Talbot workings, where the solid measures were seen to strike N. 58° W. and to dip 58° N. From this point southward to Panther Creek, a distance of about 5800 feet, the edges of the strata may be seen at several points along the bluff. The strike is approximately east-west, and the dip steeply northward, sometimes vertical. On Panther Creek, a few yards below the crossing of the county road, an excavation in the bank exposed a small bed of lignite having the following section:

Section of lignite on Panther Creek.

	Inches.
Roof: shale, gray, finely sandy, homogeneous.	
Bone	1
Coal	5
Bone	½
Bony coal	8
Bone and sand	2
Bony coal	6
Total	22½
Foot wall: fine, gray sandstone.	

Apparently this bed lies stratigraphically about 5000 feet below the bed worked in the old Talbot mines. The great thickness of strata exposed on the constant northern dip indicates the probability of an extensive basin pitching southeast between Cedar and White rivers. This general attitude is related to that of the Green River coal field, and the coal-bearing rocks are no doubt continuous from one district to the other.

West of the town of Renton the valley is occupied by alluvium to a width of three-quarters of a mile, but northwest of Black River the hills rise somewhat gently in slopes thinly covered with till. The coal-bearing strata are exposed along Black River and on the higher slopes in a nearly horizontal attitude, with a gentle southern dip. They obviously belong to the broad dome from which the low arch pitches southeastward between the old Talbot and the Renton-Talbot mines. The strata to the northwest of Black River underlie the coal beds worked in the Renton mines, and have been prospected by boring to a depth of 400 feet without the discovery of workable coal beds. Early in the history of the search for coal the

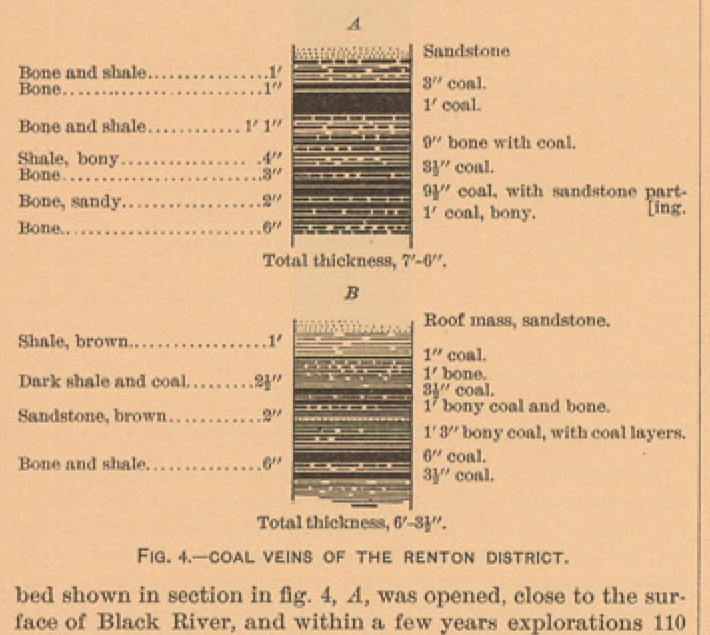


FIG. 4.—COAL VEINS OF THE RENTON DISTRICT.

bed shown in section in fig. 4, *A*, was opened, close to the surface of Black River, and within a few years explorations 110 feet above it developed the bed shown in fig. 4, *B*. Surface explorations south of the old Talbot mines should cross the strata which are exposed north of Black River, and might well be undertaken in advance of more extensive boring operations.

Green River district.—Midway between Seattle and Tacoma, but from 15 to 20 miles east of a line connecting those two cities, is the Green River district. Green River, descending from its canyon in the Cascade Mountains on the east, passes out into an extensive gravel plain, across which it cuts a tortuous and steep-walled canyon from 50 to 300 feet deep. In the walls of this canyon the Puget series is exposed, the strata cut through ranging in dip from near a horizontal to a vertical position. In terms of the Land Office subdivision, the exposures of the coal-bearing rocks extend through T. 21 N., Rs. 6 and 7 E., and into the adjacent townships north and south. Away from Green River Canyon the surface is generally covered with gravel, but upon the rounded hills with which it is diversified the drift is frequently very thin, and the coal-bearing strata can be discovered by digging. This area is approximately 30 miles from both Seattle and Tacoma, and its most westerly development, the Black Diamond mine, lies 11 miles due east of Auburn, a station on the Northern Pacific Railway.

The outcrops of coal on Green River attracted attention in 1880, and led to extensive prospecting operations during the next two or three years. A single well-defined coal basin, then known as the McKay and since as the Franklin basin, was traced out near the western edge of the coal field, and two collieries were located upon the same vein—the Franklin colliery, opening on Green River, and the Black Diamond colliery, 3 miles farther northwest (see accompanying map of the Green River district). Other operations were begun to the east and southeast, but the lay of the coal in that tract has never been accurately determined, and no mines comparable in extent to the Franklin and Black Diamond have been developed. There is at the present time no adequate map of this entire coal field, and the definite information presented in the following paragraphs relates only to the Franklin and Black Diamond collieries and the intervening Light Ash mine.

A stratigraphic column of the coal-bearing strata exposed on Green River is given on Pl. LXXXI of Vol. XV of the Tenth Census Reports. In that columnar section forty beds of carbonaceous character are enumerated, but of these only four, Nos. XIV, XV, XVIII, and XXIII, are productive coal veins lying within the district under consideration. Veins Nos. I to XII belong to lower measures, which are exposed to the north and east of the Franklin collieries. Vein No. XVIII is the McKay vein, otherwise known as the Light Ash or White Ash vein, or the Black Diamond vein. In fig. 5 is given a typical cross section reproduced from the Census Reports. This vein is the only one now extensively worked in the field, and is the one from which the principal supplies of steam coal are drawn.

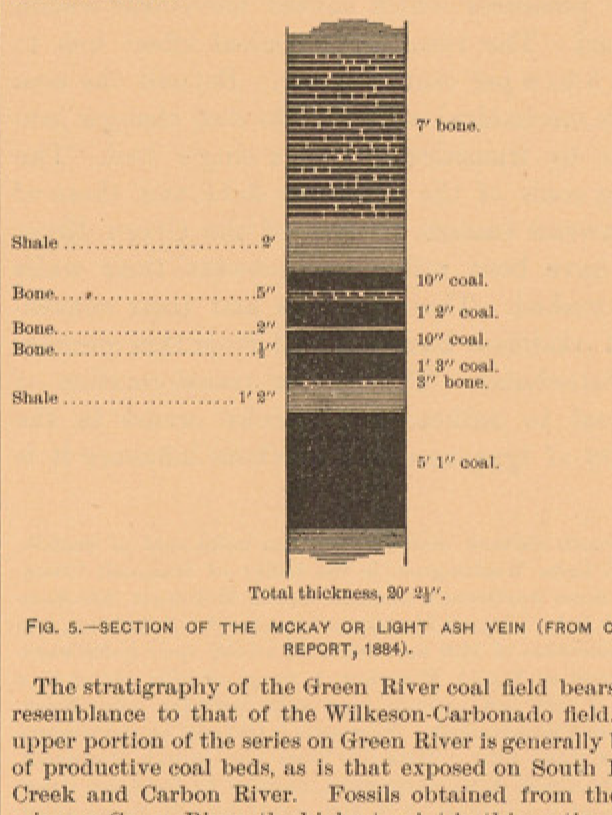


FIG. 5.—SECTION OF THE MCKAY OR LIGHT ASH VEIN (FROM CENSUS REPORT, 1884).

The stratigraphy of the Green River coal field bears some resemblance to that of the Wilkeson-Carbonado field. The upper portion of the series on Green River is generally barren of productive coal beds, as is that exposed on South Prairie Creek and Carbon River. Fossils obtained from the Clay mine on Green River, the highest point in this section, correspond to those obtained from the highest exposures on Carbon River. The lower portion of the Green River section, like that of the Wilkeson Carbonado district, contains numerous beds of coal, concentrated in a moderate thickness of sandstone and shale. It is probable that future work, particularly with the fossil plants, may develop a close correlation between the strata of these two districts.

The structure of the Green River district is comparatively simple. It consists, broadly speaking, of a sheet of strata inclined toward the southwest and fluted in broad folds. Of these folds the McKay coal basin and the Black Diamond anticline were traced out in the work prior to 1884. The general strike of the important McKay vein No. XVIII was then determined along the line through sections 18, 7, 12, 13, and 14, as may be seen by reference to the diagrammatic map, Pl. XC of the Census Report. The extensive development of the collieries has since demonstrated the general correctness of the outline then drawn. At that time, also, the axis of the Green River anticline on the east of the McKay basin was determined, but then, as now, the structure still farther eastward remained obscure. In the special map of the field the strike of the McKay vein No. XVIII is traced from its northwestern occurrence in section 11, through the workings of the several collieries and around the Green River axis, in the position which it would have on a plane 400 feet above sea. As the dip of the vein is toward the southeast, south, southwest, or west, it extends for levels above 400 feet to the north, or north and east, of this line. This extension may be seen in the Franklin and Black Diamond collieries, where the workings, which are to a great extent more than 400 feet above sea, lie east and north of the red line. The strike of the McKay vein is indicated with assurance of accuracy from section 11 to section 20, with the exception of a short space in section 23.

In minor details of structure the Green River field presents some interesting facts. In the Black Diamond mine, in driving the gangway northward in section 14, three normal faults have been encountered, with a downthrow to the north. Two of these, which have been traversed by the gangways, are apparently related in the amount of throw, one dying out downward, the other upward, so that the total throw of the two remains approximately the same. The third has not been crossed, as it is intended to leave the intervening mass of rock between the No. 14 mine and the No. 11 mine.

In the Light Ash mine, at 600 feet from the entrance, a normal fault was struck which throws the vein horizontally 150 feet to the northwest. The plane of the fault hades steeply to the northwest, and is scarcely distinguishable in the tunnel among the bedding planes of the strata.

In the northern part of the basin, as developed in the Black Diamond mine No. 12 and in mine No. 7 of the Franklin collieries, there are a number of small faults, some of them apparently due to the wrinkling of the walls of the coal bed.

In general, the structure of this field is much more simple than that of the Wilkeson-Carbonado district, and there is a direct stratigraphic relation beneath the moderately developed folding and the moderately concentrated condition of the coals. Toward the east, where the structure is more complex and the development of the folds is the result of greater compression, the coals of the Green River field are more highly bituminous. Toward the northwest, where the degree of compression and movement was less, the coals become lignites.

Wilkeson-Carbonado district.—The Wilkeson-Carbonado district (see accompanying special map) lies southeast of Puget Sound, about midway between the city of Tacoma, from which the mines are 20 to 23 miles distant, and the volcanic mass of Mount Rainier. It is traversed by the eastern tributaries of Puyallup River, the strata being exposed particularly on South Prairie Creek, Gale Creek, and Carbon River. It may be said to lie upon the extreme northwestern foothills of Mount Rainier, about 25 miles from the summit of the peak, and its western limits are determined by the gravel plateaus of the Puget Sound drift. According to subdivisions of the United States Land Survey, it stretches from T. 19 N., R. 6 E., southward, with some interruptions of exposure, to Nisqually Valley, in T. 15 N., R. 6 E. The most northern mines are opened on South Prairie Creek at Burnett. The Wilkeson mines begin 2 miles south of the Burnett mines, while the Carbonado mines lie 2 miles to the southwest from the Wilkeson. All of these mines, therefore, are developed in the extreme northern portion of the field. The more southern districts, although prospected in the years 1883 and 1884, have remained undeveloped on account of inaccessibility. The general slope of the foothills across which this coal field extends is toward the west and northwest, and the descent is terraced by accumulations of drift with characteristic development of moraines and potholes. The drift has been traced up to an elevation of 1700 feet, and is known to range in depth from 50 to 300 feet. The ravines of South Prairie Creek and Gale Creek expose occasional bluffs of the coal-bearing sandstones, but their banks are usually composed of gravel and sand. Carbon River, which traverses the field for a distance of 8 miles, flows through a rugged canyon 400 feet in depth. A portion of this canyon just above Carbonado is cut in volcanic rocks and is almost inaccessible. In the vicinity of Carbonado itself a fine section of the coal measures is exposed, and they form the banks of the stream for a distance of 2 miles below the mines. The river then enters the drift deposits, sections of which appear in bluffs 300 feet high. The surface covering of drift and the dense growth of forest make this field exceedingly difficult of exploration.

The Burnett mines are opened from South Prairie Creek southward in sections 16 and 21, extending in the farthest gangways into section 22. The principal mine consists of a slope sunk on the vein to a depth of 625 feet vertically below its mouth, or 90 feet below sea level, and of three levels driven southward, the farthest to a distance of a mile and a half. Near the middle of section 21 a crosscut tunnel was driven westward, and a second workable vein was discovered 310 feet below the first. This vein was also opened in a water-level gangway, but its outcrop could not be discovered on South Prairie Creek. The dip of these two veins is about 50° E. In the southwestern portion of section 16 two other openings have been made, on veins on the western dip, which are believed to correspond precisely to the two veins opened on the eastern dip. Of these western openings but one has been driven to any distance, namely 1500 feet, but as the vein was soon found to be seriously faulted work has not been continued.

The Wilkeson mines are opened on four veins which outcrop on the southern side of Gale Creek, in the western part of section 27. At the point where the creek makes a sharp bend from a northerly to a westerly course its channel is cut upon the axis of an anticlinal fold, and the beds to the east of the stream dip about 50° E., while those to the west dip about 85° W. On the eastern dip the lowest of the known workable veins, the Kelly, has been worked to a short distance, but the mine is now abandoned. On the western dip all four veins have at different times been worked, and present operations have pushed the gangways south through section 34 and beyond an extensive fault into section 3.

The Carbonado mines are opened in sections 4 and 5 and extend northward into section 32 and southward through sections 8 and 9. The complexity of the geologic structure is such that numerous croppings of the veins are exposed in the canyon walls, and in the early history of the mines the operations were conducted in a haphazard fashion, to develop whatever was in sight. Most of these older workings are now inaccessible, and no information concerning them beyond the record of their position on the mine maps is to be obtained. The principal mines now operated are those south of the river and mines No. 6 and No. 3, which form the northwestern developments.

In addition to the developments made by the three great mining companies, there are numerous minor prospects opened along Gale Creek, and much information concerning the extent of the coal measures and the distribution of the coal veins was obtained by explorations conducted through the Northern Transcontinental Survey from 1881 to 1884.

The geology of the Wilkeson-Carbonado district presents some of the most difficult and consequently most interesting problems arising in connection with the Puget Sound formation. In each group of mines a section of the coal-bearing strata is exposed, and from each a distinct stratigraphic column can be compiled. As there are no continuous outcrops from one mine to another, and as the strata present a monotonous sequence without distinctive horizons, it is necessary to correlate the coal beds across the gaps between the Burnett and Wilkeson mines and the Wilkeson and Carbonado mines according to the best inferences to be drawn from all the facts of stratigraphy and structure.

On South Prairie Creek, above Burnett, there is partially exposed a section of sandstones and shales generally barren of workable coal veins, but containing five beds of inferior coal near the top of the section at Pittsburg, aggregating 4770 feet. In this section the Burnett vein is the lowest bed observed, but beneath this vein itself lies the productive coal series. The section does not reach the top of the Puget group, the strata having been traced eastward, with a uniform dip, to their disappearance beneath a lava flow, giving probably an additional thickness of 3500 feet. Thus it appears that on South Prairie Creek there is exposed a total section of at least 8000 feet, dipping eastward above the Burnett vein. In this series, 84 feet above the Burnett vein, there are several beds of massive sandstone interbedded with shale to a thickness of 940 feet, which are quarried along South Prairie Creek and are recognized in their proper relation to the Burnett vein just east of Wilkeson, where the upper beds of sandstone form three bold bluffs with slight hollows between them. These sandstones constitute an important key rock, and may be designated the Wilkeson sandstones. That portion of the South Prairie Creek section which lies above the Wilkeson sandstones will hereafter be referred to as the Burnett formation. The section, including the Wilkeson sandstones, so far as measured east of Burnett, is given in the Columnar-Section sheet.

In the canyon of Carbon River northwest of Carbonado, in sections 31 and 32, a partial section of the Puget group, much like the section on South Prairie Creek above Burnett, overlies the productive coal measures. The general dip of this section is westward, and the highest bed is accordingly seen at the western end. It consists of a small pinnacle of carbonaceous shale and sandstone, which is exposed in a railroad cut through a mass of volcanic tuff or mud flow. The exposed mass of shale is about 45 feet high, and is completely surrounded by the darker gray and black homogenous tuff, which contains many waterworn river bowlders. Above the face of tuff and shale extend glacial gravels. It is obvious that at some date during the Glacial epoch a former river canyon afforded a course for the mud flow from a volcanic vent to the southeast, and that the bluff of shale and sandstone which projected from the side of the channel was buried in volcanic mud, which swept with it bowlders from the stream bed. The shale in this small exposure contains numerous leaf impressions, which appear upon comparison with specimens obtained from Green River to correspond with those obtained from the Clay mine, the highest exposure in that section. From this point to the slope on the Wingate vein, mine No. 6 north, Carbonado, a section was measured which yielded a total thickness of 3845 feet of strata. This section in general resembles that measured on South Prairie Creek, including the Wilkeson sandstones. Workable coal veins are few in number, although it is possible that careful prospecting may yet discover good beds in either one or both of the sections. The similarity between the two is such as to justify a general correlation. The division stated on the section, into the Wilkeson sandstones and the Burnett formation, is, however, somewhat arbitrary, since no precise identification of strata is possible.

The section exposed on Carbon River is continuous southwestward beyond the slope on mine No. 6 north into the productive coal measures. Although the strata are greatly disturbed, the mining operations afford measurements of the thickness between the coal beds, and observations along the canyon make it possible to fill in most of the intervals with the appropriate descriptions of the rocks. The resulting section below the Wingate vein aggregates 1125 feet. The complete section from the highest point beneath the mud flow on the west to vein No. 7, the lowest vein in the series worked at Carbonado, has a total thickness of 4970 feet. This section is given in detail in the Columnar-Section sheet.

The exposures at Wilkeson do not afford any such continuous section as those obtained on South Prairie Creek and Carbon River. Northeast of Wilkeson, along the line of the railroad and on to South Prairie Creek, are sandstone bluffs with occasional croppings of coal and bone, which evidently represent the strata of the Burnett formation. They are in the line of strike, and only a mile distant from the section on South Prairie Creek. The bluffs of the Wilkeson sandstone, which, as already stated, are quarried on South Prairie Creek just above the Burnett vein, are also prominent in the vicinity of Wilkeson, on both the eastern and the western dips, and have been quarried for building stone at several places. For a section of the workable coal veins, however, it is necessary to accept that which may be seen in the crosscut tunnel in the southern part of section 34. Here, in the course of mining, a series of beds have been cut, the lowest a dirty vein, the highest the workable vein of mine No. 3. A careful measurement of the strata in this crosscut gives the section shown in the Columnar-Section sheet.

The independent measurements of strata having thus been presented, we may seek to compare the sections and to correlate the different coal beds according to the best hypothesis available with our limited knowledge. Correlations of coal beds are frequently made simply upon the occurrence of similar thicknesses of coal or similarity of cross section where there are several benches of coal; but it is shown by experience that coal beds are subject to great variations in quality and character, and probably this is especially true of the beds of this field. The several sections of the Wingate vein sufficiently indicate the changes to which it is liable. A simple comparison of the sections for a correlation of the coal beds and the intervals between them, shows immediately that the strata are subject to much variation. Not only the coal beds, but also the strata between them, fail to give any definite clue to their relations. It is necessary, therefore, to select the most characteristic sequence of rocks as a starting point, and to base the more specific correlation of coal beds upon that assumption.

The conspicuous fact of general significance is that the Puget series as exposed in this field may be divided into three members, namely: (1) the comparatively barren uppermost member of 7000 feet or more, consisting of shales and sandstones, the Burnett formation; (2) at the base of this, and indeed forming a part of it, the Wilkeson sandstones, 1000 feet, which are separated from the South Prairie formation only because of their importance as a recognizable horizon and not because of essentially distinctive characteristics; and (3) the productive series, which may be called the Carbonado formation, and which includes all the coal veins below the Wilkeson sandstone down to the lowest bed developed in the field. The correlation of the details of the productive series depends upon the recognition of the outcrops of the Wilkeson sandstone in different parts of the field.

The typical occurrence of the Wilkeson sandstone may be observed upon the eastern dip, either in the quarries along South Prairie Creek immediately east of Burnett or in the bluffs a quarter of a mile east of Wilkeson on the north side of the valley. The sandstones reappear on the south side of the valley, somewhat to the east of their proper course, and their strike at this point indicates that they extend southward through section 27 into section 35. The course of the levels of the Burnett mine and the discovery of the Burnett vein immediately beneath this sandstone on the north side of the valley at Wilkeson sufficiently identify the strata, although the exposures are not so ample at either place as to yield complete sections for detailed comparison. The Wilkeson formation does not appear prominently on South Prairie Creek west of Burnett on the western dip, but along Gale Creek west of Wilkeson, near the middle of section 28, it forms conspicuous and important outcrops. In the point of the hill on the north side of the valley are Mitchell's quarries, from which building stone has been obtained, and the massive sandstone strata are traceable to lower Wilkeson and the north line of section 28, where they form the hillside above Hill's mine and occur in bluffs which strike northward into section 21. They also appear in the face of the terrace near the center of section 21. These strata are on the western dip of the Wilkeson anticline. Near the middle of section 28, on the western side of the railroad, similar massive beds of sandstone outcrop with an eastern dip. They are traceable southward from near the branching of the railroad toward Carbonado almost to the wagon road from Wilkeson to Carbonado.

In the outcrops east of Wilkeson, in Mitchell's quarries, and in the last-mentioned outcrops on the west of the railroad, this formation presents a threefold sequence of massive beds, with characteristic absence of bedding planes in the sandstones and with interbedded layers of dark-gray, sometimes carbonaceous shale. There is no reasonable doubt that the occurrences represent the same horizon outcropping three times—first on the eastern dip east of Wilkeson, next at Mitchell's quarries on the western dip, and again beyond the railroad on the eastern dip. A recognition of the relations of these strata in the center of section 28 determines the existence of a coal basin whose axis extends along the valley in a nearly north-south direction. This axis is marked on the accompanying structural map. Identification of the Wilkeson sandstone on the eastern and western dips of the Wilkeson anticline leads to the identification of Hill's vein with the Burnett vein as developed in mine No. 2, and Driver's prospects are thus placed between the Hill or Burnett and the upper veins of the Wilkeson mines. It is possible that vein No. 3 of the Wilkeson mines is represented by the easternmost of these prospects, that on the Gopher vein.

The next step in the correlation is to extend it to the veins worked at Carbonado. This can not be done with certainty, but there is a reasonable degree of probability in the following suggested relation: The Wilkeson sandstones in the eastern part of section 28 have a low dip and a strike which swings to the west. Immediately adjacent to the branch railroad to Carbonado there is a coal bed, known as Joe John's prospect, which dips but 10° to the north and strikes northwest. This coal lies in the Wilkeson sandstone. In the southwest quarter of section 28, immediately northwest of the road from Wilkeson to Carbonado, is a prominent hill which attains an elevation of 1200 feet above the sea. The surrounding region is completely covered with irregularly heaped gravels and smooth sand plains of glacial origin, but this hill consists of sandstone, which is exposed in upturned tree roots, and which, in an opening made in the northwest corner of section 33, was found to dip westward with a strike of N. 15° E. The relations of this strike and dip to those of the Wilkeson sandstone and to Joe John's prospect indicate the existence of an anticlinal axis pitching northward, with a western limb which extends into section 32. In the southeast quarter of section 32, in mine No. 6 north, the gangway driven on the Wingate vein ends at a faulted syncline. The sequence of strata from the Wingate vein upward includes a series of massive sandstone beds, and in this series is a large, dirty coal bed, known as the Miller vein. This section closely resembles that of the Burnett or Hill vein in its relation to the Wilkeson sandstone with the overlying coal opened in Joe John's prospect. The strike of the Wilkeson sandstone in the northeast corner of section 33 is directly toward the basin discovered in mine No. 6. It is highly probable that the coincidence of facts of stratigraphy and structure correctly indicates the identity of the Wingate vein with the Hill-Burnett vein, of the Miller vein with Joe John's prospect, and of the massive sandstones associated with the Miller vein with the Wilkeson sandstones. The further correlation of coal beds of the productive measures is based upon this identification.

Were the sections of the coal measures from the Wingate or Burnett vein No 1 downward completely exposed at Carbonado and at Wilkeson, a correlation of the distinct veins could probably be made with assurance of accurracy. The section at Carbonado is probably complete in its statement of workable coal veins, but it may be incomplete in the omission of beds of black slate or bone, which, though unimportant for mining, may represent workable coal beds of the Wilkeson section. The Wilkeson section is complete from its lowest coal bed up to the vein worked in No. 3 mine From the No. 3 vein up to the Burnett No. 1 is a gap, which can be bridged only by interpolating the beds opened in Driver's prospects in their proper relations. These relations are not definitely known. A study of the maps and sections indicates that the outcrop which is called the Gopher vein is on the strike of the Wilkeson No. 3 vein and bears some resemblance to the upper part of it. It is accordingly assumed that the Gopher vein represents the Wilkeson No. 3 vein. Above the Gopher vein is an interval of 500 feet or more which has not been prospected, extending to the Bobby vein, which is correlated with the Burnett No. 4. Above the Bobby vein there is an interval of 230 feet to the Hill vein, which is thought to represent the Burnett vein No. 1 and the Wingate.

Proceeding upon these assumptions, the following comparative columns are made out:

Hypothetical correlation of the Carbonado and Wilkeson sections.

CARBONADO.	Feet.		WILKESON.	Feet.
Wingate vein	4		Burnett No. 1 or Hill	4
Interval	304		*Interval*	230
Vein No. 2 and No. 5 north	5		Burnett No. 4 or Bobby vein	5
Interval	176			
Vein No. 4 south	7			
Interval	107		*Interval* not prospected	500±
Vein of bony coal	9	525		
Interval	105			
Coal	1			
Interval	120			
No. 3 south	3½		Gopher vein or Wilkeson No. 3	2½
Interval	12		*Interval*	15
No. 5 south	5		Bogus vein	12
Interval	20		*Interval*	20
Coal	2		Coal	2
Interval	244		*Interval*	96
No. 7 south	7⅛		Wilkeson No. 2	9
	1,131⅝			895½

This correlation depends upon approximate coincidences of thickness, which are by no means complete and which may be misleading. The lowest interval in either column disagrees with that in the other and raises a doubt as to the completeness of the Carbonado section or the accuracy of the correlation below the Burnett No. 4 or Bobby vein.

The total thickness of measures determined in the Wilkeson field is, for the South Prairie formation, 7000 feet; for the Wilkeson sandstones, 1000 feet; and for the Carbonado formation, containing the productive coal veins, 1100 to 2000 feet, according to the correlation. Thus the total thickness is between 9000 and 10,000 feet, a greater amount than has been determined in any other part of the region.

Proceeding to the discussion of the structure of the Wilkeson-Carbonado district it is desirable to call attention to the special map of the Wilkeson-Carbonado district and to explain the manner of constructing that map. The topographic features of the district are determined by the drift deposits, which extend to such a depth that any attempt to trace the outcrops of the coal measures from point to point upon the topographic surface is futile. It is accordingly necessary, in order correctly to represent the structure of the field, that all the observations be reduced to a plane at some definite level. In the special map such a reduction has been made to a datum plane assumed at 500 feet above sea. The known facts of the positions of the mines and of the observed dips and strikes on the various strata are indicated on that map in their proper geographic relations, and the streams are drawn as a means of reference. From the observed dips and the known elevations of the points of observation the position of each coal bed where intersected by the 500-foot datum plane has been determined. The intersection of any coal vein with this datum plane is the strike of the vein at that level, and is the course which a gangway would follow on the vein. This course is a sinuous one, trending back southward at an anticlinal axis or northward at a synclinal axis, the pitch of the folds being northward. The courses of some of the principal veins, as determined on the 500-foot datum plane, are mapped in red lines. The map therefore constitutes a skeleton horizontal section, or outline plan, of the coal beds as they would appear if the region were planed down uniformly to a level of 500 feet above sea.

The structure of the Wilkeson-Carbonado district is that of a large anticlinal fold or arch within which the lower strata are bent into a number of minor folds. The principal arch is indicated by the outcrops of the South Prairie formation and the Wilkeson sandstones. These two formations, aggregating 8000 feet in thickness, exhibit almost constant dips and strikes. East of Burnett and Wilkeson they dip to the northeast at angles varying from 50° to 80°. This is the eastern limb of the great arch. West of Burnett and Carbonado the same strata dip northwestward at angles of 30° to 70°, except that northwest of Wilkeson they are involved in a broad and gentle arch of one of the folds of the second magnitude. The westward-dipping strata constitute the western limb of the great anticline. A section across this anticline at Burnett, between the outcrop of the lowest beds of the Wilkeson sandstone, measures 2800 feet. Southward the arch rises, and widens out correspondingly. At Wilkeson the width between the outcrops of the Wilkeson sandstone is about 3700 feet. This arch continues as a prominent structural feature for at least 10 miles.

Immediately south of Wilkeson the great arch widens westward, through the appearance of a number of secondary folds, and attains a width on the line of the section AB, through Carbonado and the Wilkeson mines, of 13,000 feet. The details of structure in this wide portion of the great arch are of the utmost importance to mining operations.

The facts from which the details of the secondary folds may be inferred are observed in the Wilkeson mines, in the outcrops of the sandstones in section 28 about the lower town of Wilkeson, and in the northern mines of Carbonado.

It is necessary first to determine, so far as possible, the actual structure of the Wilkeson mine. In driving southward through section 34 on the three veins, Nos. 1, 2, and 3, each of the gangways encountered a fault, at which the vein apparently terminated. The nature of this fault was not determined. From the end of mine No. 3 a short rock tunnel was driven into the hanging wall, and a dirty vein was encountered, which was followed about 300 feet. It was also much disturbed, and a rock tunnel was again driven into the hanging wall. At a distance of about 80 feet above the dirty vein this crosscut encountered the vein marked No. 5 and known to underlie the Kelly vein. As the Kelly vein is 564 feet below the No. 3 vein, its appearance here in the strike of No. 3 indicates a throw of the measures to the west.

Various hypotheses have been suggested to account for this throw by a normal fault. The more probable course of such a fault would be in a northwest-southeast direction, determined by the fact that the eastern gangways extend farther southward than the western. The downthrow would be to the north. Such a fault is purely hypothetical. The following facts suggest a different structure: In the southern extension of the mines the gangway which is designated mine No. 7 has been driven around the point of a soutward-pitching anticline, and after passing eastward across a flat dip, turns northward and ends at a point where the vein is badly crushed, and presents dips varying from 85° E. to 80° W. A study of the end of the gangway, together with other observations of the structure in the crosscut tunnels lying to the northwest, shows that the crushing of the rocks in this line is such as accompanies an overthrust fault. A line drawn from the end of the gangway on mine No. 7 to the point where the fault was first encountered in mine No. 3 holds that relation to the great Wilkeson anticline that would be sustained by an overthrust on the western limb. The southward-pitching anticline and flat dip afford the minor details of structure favorable to the development of an overthrust. As is shown in the section accompanying the geologic map, an overthrust of the western limb upon itself readily accounts for the duplication of the veins to the west. The positive demonstration of the existence of such an overthrust may yet be obtained in the gangways on mines Nos. 1, 2, and 3 in driving northward from the long western crosscut tunnel. If the hypothesis of the overthrust be correct, these veins will be found to extend in good form nearly if not quite through section 34, parallel to the positions in which they have already been mined. This would practically double the amount of available coal in the western part of that section.

The northwestward continuation of the overthrust is traced in accordance with the following facts: On the northern side of Gale Creek, at the foot of the bluff about 1000 feet west of the entrance to mine No. 3, is a bold outcrop of sandstone, which upon close examination exhibits evidence of having been greatly crushed. The massive rock is twisted and bent as if by great pressure and friction. It has clearly been involved in a fault. In the northern part of section 28, northeast of the lower crossing of Gale Creek and the county road, the massive beds of the Wilkeson sandstone are dislocated and overthrust, so that they have a false eastern dip of 65°, the true dip of the measures in this locality being westward. Such an overturn is of frequent occurrence in connection with overthrust faulting. These overturned sandstone beds, the bluff of crushed sandstone north of Gale Creek, the fault first encountered in mine No. 3, and the fault met at the end of mine No. 7, all lie approximately in a line whose strike is N. 25° W. This line is platted on the map as the intersection of an overthrust by the 500-foot datum plane.

At the southern end of the Wilkeson mines the dip is as low as 24°, and the strike is changed from a little east of south to southwest. These facts indicate that the coal beds dip into a synclinal basin whose pitch is northward. There can be little doubt that this basin is the same as that marked by the outcrops of the Wilkeson sandstone about the lower town of Wilkeson, in section 28. The axis of the basin is indicated on the map as passing through the eastern part of section 33 to a little east of the center of section 28. This basin is named the Western Wilkeson Basin on the map.

Continuing the discussion of the features of the Wilkeson anticline, reference should be made to the reasons for tracing the courses of the several veins indicated on the map in section 34. On the western limb the course of vein No. 3, and of other veins associated with it, including the Kelly vein, has been determined by mining. Vein No. 3 being with probability identified as the Gopher vein, its trace is extended northward to intersect the anticlinal axis north of that exposure. On the eastern dip the location of the Kelly vein is platted from its known positions in the gangway of the old Kelly mine, and as determined by diamond-drill holes sunk in 1883 by the Northern Transcontinental Survey. The positions of the Wilkeson vein No. 3 and the Burnett vein No. 1, on the eastern dip, are platted from their relations to the Kelly vein.

In the western portion of the district a complex structure has been developed in the workings of the mines at Carbonado. For the purposes of this discussion, that portion of the mines south of the normal fault may be omitted. In mine No. 6 north, on the Wingate vein, the gangway driven northward on the western dip encountered an anticlinal axis and was extended around the axis southeastward to a faulted syncline, the Central Carbonado Basin. This is in the southeast quarter of section 32. A study of this mine and of the section exposed on Carbon River for a quarter of a mile northwest of the incline shows that the vein worked in mine No. 5, 230 feet below the Wingate vein, is the same as the vein worked in mine No. 2. The duplication of the vein in mine No. 2 is due to a fault, which is indicated on the map, and which lies along the eastern side of a small synclinal wrinkle that points out on the anticlinal axis in both mine No. 5 and mine No. 6.

The synclinal axis of the Central Carbonado Basin in the southeast corner of section 32 may be traced in the windings of the old gangways to the southeast. It was crossed in the northern rock tunnel east of the incline, and eastward of it the same tunnel penetrated to the eastern limb of an anticline, which is also exposed on Carbon River above the dam. We thus have as the most easterly observation at Carbonado an eastern dip, and the dominant structure of this portion of the field is seen to be represented by two arches with the intervening central coal basin. Much of the apparent complexity is due to the fact that the strata are dislocated and overthrust, as well as folded.

Between the eastern dip of the measures at Carbonado and the western dip determined in the southern end of the Wilkeson mines, the structure is unknown. It is possible, however, to infer it with some degree of probability. Referring to the dips in section 28 and in the northwest corner of section 33, observed on the Wilkeson sandstones, it is evident that they represent a northward-pitching anticline which occupies the center of section 33. This anticline lies between the western dip of the Wilkeson mines and the most eastern dip of the Carbonado mines. It appears to limit the Western Wilkeson Basin on the west and to determine the existence of another basin east of Carbonado, which may be called the Eastern Carbonado Basin, and which lies in the western half of section 33. These two basins and the intervening anticline are shown on the map by the red lines, which extend the strike of the Wilkeson vein No. 3 westward and of the Wingate vein eastward to the probable continuation of Hill's vein. By reference to the section AB, it will be seen that the hypothetical folds in section 33 are supposed to be of such magnitude as to form a gradation from the greater Wilkeson anticline down to the smaller folds of the Carbonado mines. This is in accordance with the laws of development of such structures. But, although the facts of structure are sufficient to justify the interpolation of these hypothetical folds, a precise determination of the course of the veins is not possible. All that can be stated with positiveness is that the Wingate vein follows a sinuous course approximately near that which is indicated on the map, and that the Wilkeson vein No. 3, together with all the other associated veins, follows a similar course south of the Wingate vein. The possible dislocations by normal faults or overthrusts can not be foreseen.

The southward extension of the coal beds developed at Wilkeson and Carbonado can not be traced continuously on the surface. West of Carbon River the volcanic rocks are known to form the hills along Voight Creek, and they are probably continuous with those which are found on the head waters of that stream between Carbon River and the Puyallup, in R. 6 E. East of Carbon River, from 1 to 3 miles south of Carbonado, a high terrace of alluvial sands covers the coal-bearing formations to an unknown depth. In section 10, T. 18 N., R. 6 E., this terrace abuts against the westward slope of a hill in which numerous coal beds were opened in the early exploration of the field. Still farther south, on the slope into Carbon River Canyon, a number of coal beds have been opened between the top of the hill and the terrace of river gravels which skirts its base. The cross sections of these beds are given on the coal-section sheet. Their underground extent has not yet been traced. A short distance to the northeast the summit of the hill is formed of eruptive rock. The strata exposed in the section along Carbon River in the southern part of T. 18 N., R. 6 E., lie at a nearly vertical dip. The river exposes a section, probably without repetition, whose lowest beds are to the east, with the higher and less productive formations coming in toward the west.

CONSTRUCTIONAL MATERIALS.

Building stones.—The sandstone of the Puget formation affords a building stone of pleasing gray or olive-green tint. In some places blocks of fair size may be obtained, and it is easily dressed. Its strength, however, is only moderate, and it is liable to discolor and to exfoliate, on account of the feldspar and carbonate of iron which it usually contains. The principal quarries opened in the Tacoma quadrangle are in the Wilkeson sandstone near Wilkeson. The strata are repeated east of Wilkeson and Burnett, and may there be less broken.

Lime.—No important deposit of lime is known in the Tacoma quadrangle. In the river bluff east of McMillin, in Puyallup Valley, there was a body of lime, locally known as "coral lime." It was a spring deposit, probably from a hot spring, which accumulated on the slope of the gravel bank. It has been practically exhausted.

Clays.—Clay suitable for making ordinary bricks is of widespread occurrence. The Admiralty till and possibly the Osceola till afford a dense blue brick clay. Local deposits of it may be found in the Vashon drift. Some shales of the Puget formation yield a fire clay, such as is mined at the Denny clay mine on Green River just east of the quadrangle. A higher grade of white clay is exploited northeast of Maple Valley. Its geologic relations were not ascertained.

Sands and gravel.—Sands and gravel are of almost universal occurrence throughout the quadrangle. They will be found in irregular lenses, more or less thoroughly sorted in the modified Vashon drift and in the stratified drift. Small deposits occur in the valley alluvium. The sands are almost all somewhat clayey and contain a large proportion of ferruginous minerals.

SOILS.

The soils of the Tacoma quadrangle are chiefly varieties of sandy and gravelly loam; in the one extreme they are incoherent brown sand, in the other coarse gravel ranging into sterile pebble beds. Fine silt, derived from volcanic rocks by grinding of glaciers, is an important constituent of the alluvium. All the soils are transported, distributed, and spread by ice or water; none are residual—that is, produced by decay of the underlying rocks. The several Pleistocene formations include all the varieties of soils, and their characters are briefly described in the legend of the map, while their distribution is shown on the map. Inspection of the topographic and geologic maps will yield a general knowledge of the configuration and soil of any particular area.

Soils of the valleys.—Soils of the valleys are bottom-land soils in the sense that they are deposited from river floods and accordingly vary from gravel to fine silt. The latter is most common, gravel and sand occurring more abundantly near the mouths of the canyons, as, for example, above Orting in Puyallup Valley.

The silt, consisting of ground-up volcanic rock, is rich in plant food, and when properly drained is very fertile. The lands generally lie but a few feet above the average spring and autumn floods, and over large areas are subject to inundation by any unusual rise. This is especially true of the valley through which White and Stuck rivers flow, and the regulation of these streams by engineering works is of the first importance. The primeval growth in the valleys was a forest of cedar and fir, with dense undergrowth of vine maple, devil's club, and ferns, characteristic of wet ground. In the marshes vine maple and varieties of huckleberry prevailed. The land is now generally cleared. The principal crop has been hops. Grass, wheat, and small fruits are grown to advantage, but excessive moisture is favorable to rust and fungus growths. The most extensive and uniformly fertile tract of agricultural land in the Tacoma quadrangle is the valley which lies between the commercial cities of Tacoma and Seattle and which is traversed by the railroad connecting them, and here truck gardening will probably become important.

Soils of the uplands.—The uplands correspond with the summits of the plateaus. They may be divided into lands unfit for agriculture and lands suited to cultivation. The former comprise all the areas of the Steilacoom formation and of the modified Vashon drift, and part of the tracts of Vashon drift. The latter include the remainder of the Vashon drift, the Osceola till, the Midland sands, and the swamp alluvium.

The Steilacoom formation is sterile because of its coarse gravelly character and open texture. A thin veneer of silt supports scanty grass and flowers during the frequent spring rains, but in July and August the areas become a dry, brown prairie, in strong contrast to the luxuriant forest and undergrowth on clayey soils.

The modified Vashon drift is frequently a strong soil, but generally it is unfavorably disposed for cultivation, the slopes being steep and the ridges sharp. Large stones and bowlders abound in it. When exposed to rain the loam washes down below them and they come to the surface in great numbers; the result is a field unfit for tillage and incapable of yielding an adequate return for the labor expended on it. Over limited areas, however, the loam may be relatively sufficient to afford a good soil. Such is the case at Sunnydale, where on rounded hills a strong loam of moderate depth overlies a gravelly subsoil. Sandy or dense clayey soils extend in long but very narrow strips along the hollows between the ridges of modified drift. They are not of sufficient importance to be mapped, except where they are shown as swamp alluvium. The primeval growth on the modified drift is usually a heavy forest of fir and hemlock, with undergrowth of salal and ferns. Devil's club, vine maple, and cedar grow where the land is wet, along the hollows and tributary gullies.

The Vashon drift is prevailingly a gravelly loam. In some areas, although the surface has the gentle undulations characteristic of the ice deposit, the proportion of bowlders to sandy clay is almost as great as it is in the modified drift. A strip of this nature lies west of Bow Lake, extending north-south for about 2 miles. Again there are stretches of clean sand and gravel too irregular and indefinite to be mapped as distinct washes, although probably worked over by streams. These specially stony and specially sandy tracts are not favorable for culture. Elsewhere, and generally, the Vashon till affords a strong though usually gravelly soil. The proportion of gravel is, on the whole, larger on the upland between Duwamish Valley and Admiralty Inlet (which has been called Des Moines Island) than on Vashon Island, where the loam is peculiarly fertile. "Shot-clay" is a term locally applied to a phase of the Vashon drift which yields small clay pellets that wash out on the surface. The forest grows luxuriantly on the Vashon drift, except where the porous sand and gravel fail to retain sufficient moisture; there, although the trees stand in close ranks, they do not attain the splendid proportions of more favorable situations, and the undergrowth is limited to salal and Oregon grape.

The Midland sands support the heaviest growths of trees and underbrush in the Tacoma quadrangle. They consist largely of volcanic and granitic sand, much decomposed and mixed with a small proportion of clay. They are commonly deep, upon an impervious clay subsoil, and are saturated with water. Their surface is smooth. They are not generally under cultivation because the labor of clearing the forest and swamp undergrowth is so great.

The Osceola till affords a soil of sandy clay, usually dark colored on account of a large proportion of humus. The subsoil is a blue clay, which is impervious to water, and the area was to a great extent a swamp, supporting mosses, huckleberry bushes, and alder. Being cleared with comparative ease, large areas have been brought under cultivation. When drained the soil is warm and fertile.

Scattered throughout the various other formations are small patches of swamp alluvium. They consist of black mud or peat on a clay subsoil. When cleared and drained they yield a good soil, except that it is sometimes rather light and in droughts may become too dry.

FORESTS.

The forest may become a permanent resource of the Puget Sound district. Its character has been described. Its present value is known and it is being rapidly and destructively exploited. The fact that it may profitably reproduce itself is not yet appreciated.

Extensive tracts of the Vashon drift, of both the unmodified and modified types, are unsuited to cultivation, yet are being cleared at excessive cost to make unprofitable farms. This clearing and wasteful lumbering are accompanied or followed by destructive fires, and the process involves a loss to the community. Lands unsuited to culture may be set apart for conservative forestry. Account being taken of the present stand and rate of growth of the several kinds of valuable trees, the cut may be so regulated as to yield a present profit while preserving the immature trees for the second, third, and future cuts. Fires can be prevented. Lumbering may thus become a steady and permanent resource instead of a destructive and transient activity. In a region like the Puget Sound Basin, where the forest growth is rapid and where extensive areas unfit for culture will produce magnificent forests, this practice of conservative forestry is of the first importance to individuals and to the community. The geologic map of the Tacoma quadrangle in part indicates lands suitable for segregation for forestry.

BAILEY WILLIS,

Geologist.

GEORGE OTIS SMITH,

Assistant Geologist.

June, 1899.

TOPOGRAPHIC SHEET

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WASHINGTON
TACOMA QUADRANGLE

CONVENTIONAL SIGNS

CULTURE *(printed in black)*

- Roads and buildings
- Private and secondary roads
- Trails
- Railroads
- Street railroads
- Tunnels
- Bridges
- Ferries
- Fords
- Dams
- Locks
- U.S. township and section lines
- Located township and section corners
- Township and section corners not found
- Triangulation stations
- Bench marks
- Mines and quarries
- Prospects
- Shafts
- Mine tunnels *(showing direction)*
- Mine tunnels *(direction unknown)*

CONVENTIONAL SIGNS

RELIEF *(printed in brown)*

- 5463 Figures *(showing heights above mean sea level instrumentally determined)*
- Contours *(showing height above sea, horizontal form and steepness of slope of the surface)*
- Depression contours
- Levees
- Cliffs
- Mine dumps

DRAINAGE *(printed in blue)*

- Streams
- Falls and rapids
- Intermittent streams
- Canals and ditches
- Lakes and ponds
- Intermittent lakes
- Glaciers
- Springs
- Salt marshes
- Fresh marshes
- Tidal flats

The above signs are in current use on the topographic maps. Variations from this usage appear in some maps of earlier dates.

Henry Gannett, Chief Topographer.
R. U. Goode, Geographer in charge.
Control by W. T. Griswold and U.S. Coast and Geodetic Survey.
Topography by G. E. Hyde and R. H. Mc. Kee.
Surveyed in 1894-95.

McK
Hyde

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.

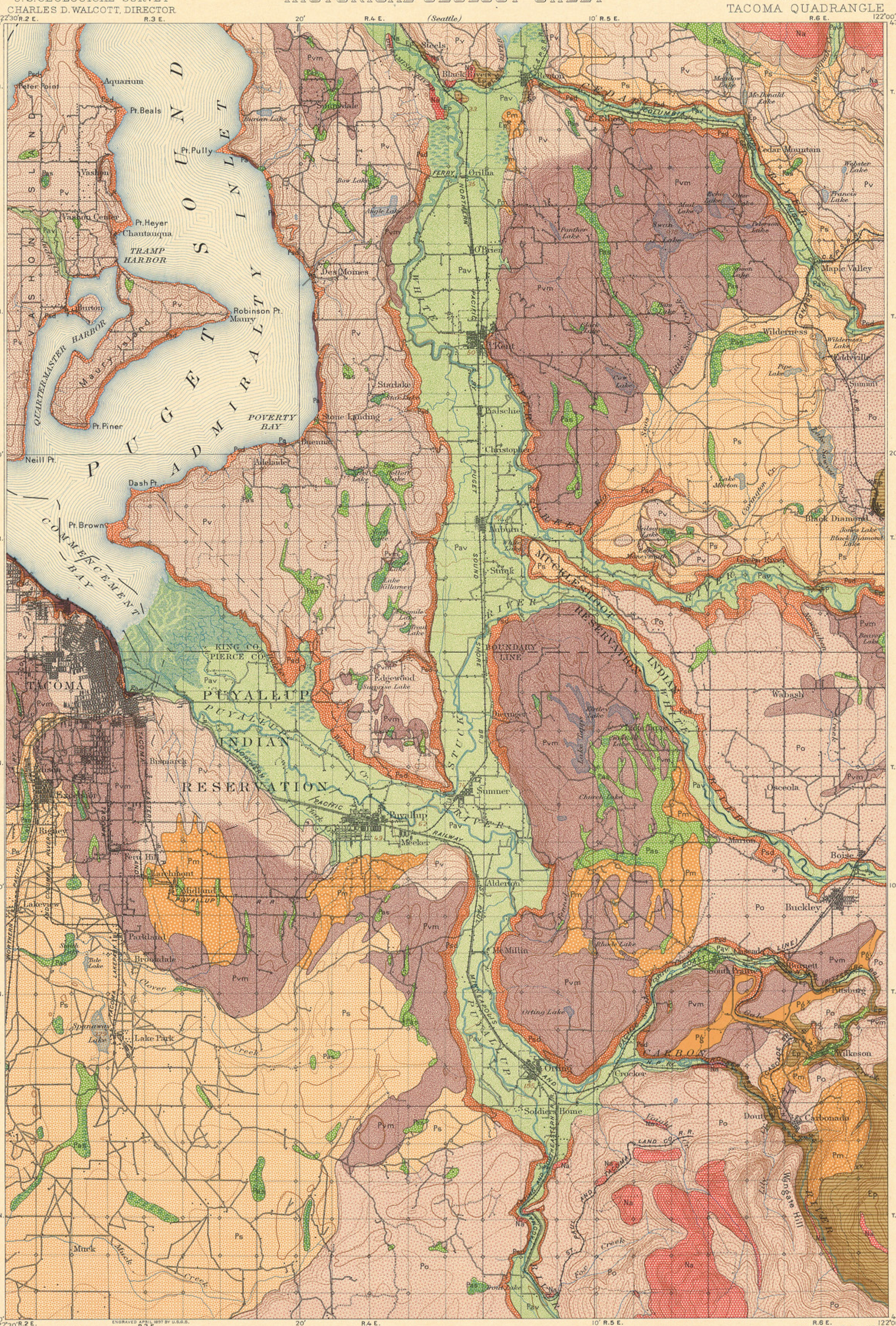
Datum is mean sea level.

Edition of Nov. 1898.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HISTORICAL GEOLOGY SHEET

WASHINGTON
TACOMA QUADRANGLE



Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Control by W.T. Griswold and U.S. Coast and Geodetic Survey.
Topography by G.E. Hyde and R.H. Mc.Kee.
Surveyed in 1894-95.

ENGRAVED APRIL 1897 BY U.S.G.S.

McK.
Hyde

Scale $\frac{1}{125000}$

Miles

Kilometers

Contour interval 50 feet.
Datum is mean sea level.
Edition of Feb. 1899.

Geology by Bailey Willis
and George Otis Smith.
Surveyed in 1896.

LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

PLEISTOCENE

POST-GLACIAL EPOCH

Pas Swamp alluvium *(usually a dark-colored muck overlying clayey hardpan.)*

Pav Valley alluvium *(fine glacial silt from living glaciers, bedded with sand and gravel; includes shingle near the mouths of canyons.)*

VASHON GLACIAL EPOCH

STAGES OF GLACIAL RETREAT

Pm Midland sands *(delta sands and sandy loam, with occasional deposits of diatomaceous earth; surface usually flat or gently sloping.)*

Ps Steilacoom gravels *(coarse gravel and shingle, washed clean, usually covered by thin layer of fine silt; surfaces level, terraced in benches 1 to 20 feet high.)*

Pg Gale sands *(stiff sandy clay without gravel, finely stratified.)*

STAGES OF GLACIAL OCCUPATION

Pv Vashon drift *(coarse gravel, sand, and clay, occasionally stratified, generally mixed; surface undulating but not hilly; probably deposited by ice as a till.)*

Pvm Vashon drift modified *(coarse gravel and sand irregularly stratified, heaped in roughly parallel ridges-eskers-or in hummocks with kettleholes-lodge-moraines, deposited by ice and streams beneath the ice.)*

Po Osceola till *(blue sandy clay, compact, containing subangular stones; surface plane, undulating, and hilly.)*

INTER-GLACIAL EPOCH

STAGES OF INTER-GLACIAL CONDITIONS

Psd Stratified drift *(includes the Douty gravels, Puyallup sands, Orting gravels, and lignite, exposed in bluffs, usually much obscured by landslides.)*

ADMIRALTY GLACIAL EPOCH

STAGE OF GLACIAL OCCUPATION

Pa Admiralty till *(stiff blue clay, usually stratified, locally filled with subangular stones and large bowlders.)*

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines.)

EOCENE *and probably early Neocene*

Ep Puget formation *(arkose, sandstone, shale, carbonaceous shale, and coal beds.)*

IGNEOUS ROCKS

(Areas of Igneous rocks are shown by patterns of triangles and rhombs.)

NEOCENE *and probably later*

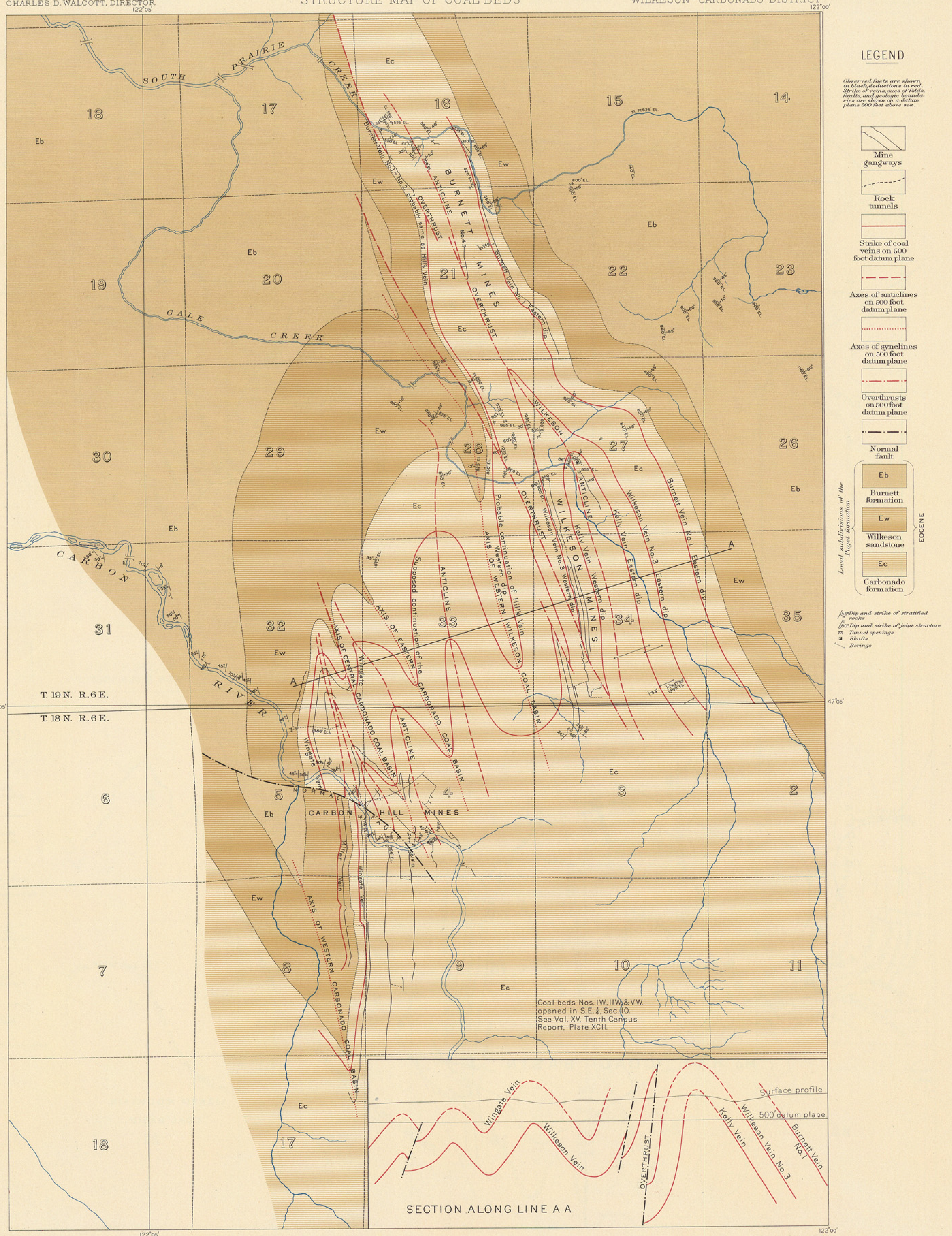
Na Pyroxene andesite *(lavas, tuffs, breccias, and dikes.)*

⚒ Coal mines
× Coal prospects

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STRUCTURE MAP OF COAL BEDS

WASHINGTON
WILKESON-CARBONADO DISTRICT



Scale $\frac{1}{24000}$

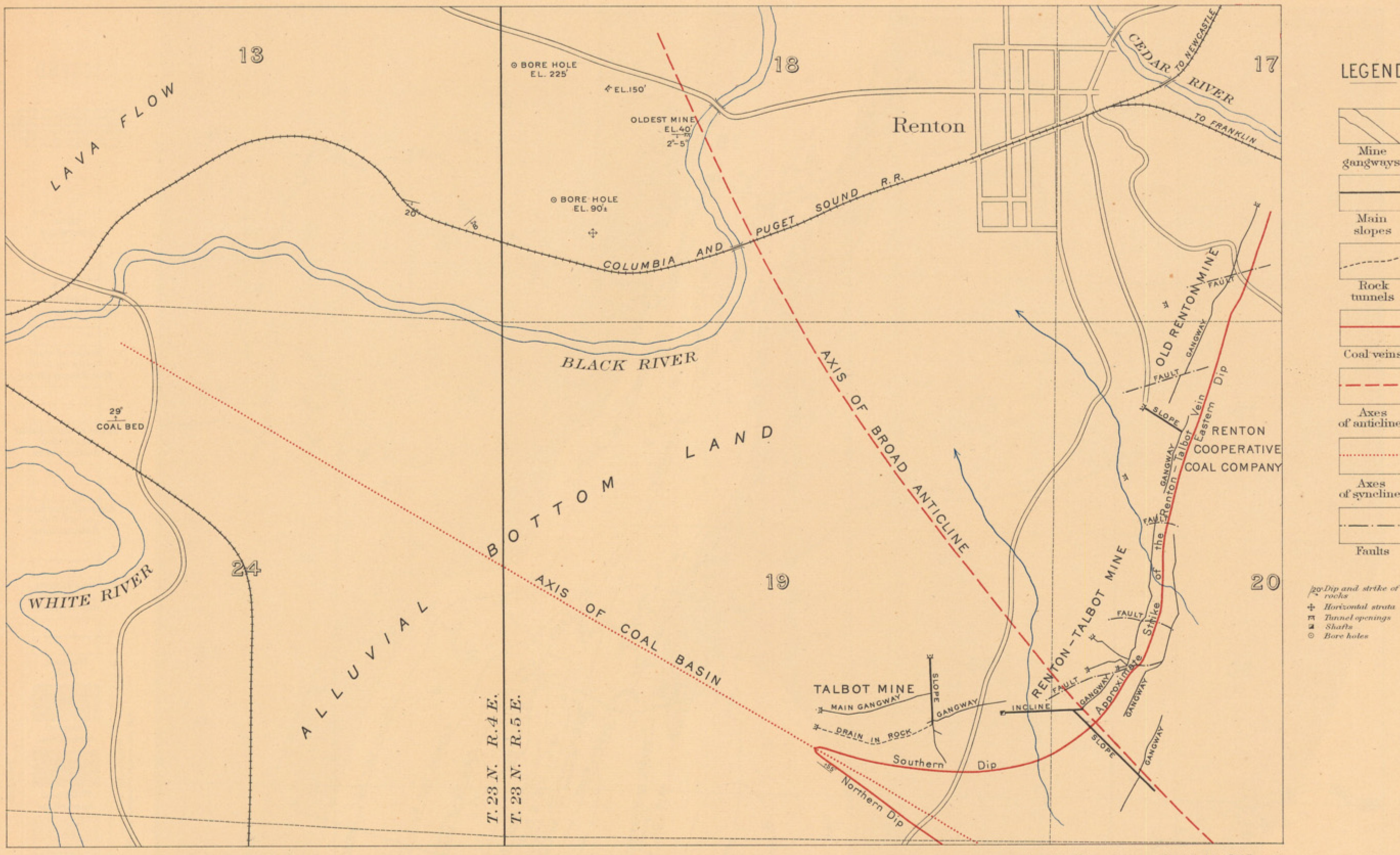
1 Mile

Edition of Dec. 1899.

Geology by Bailey Willis.

STRUCTURE MAP OF COAL BEDS

WASHINGTON
RENTON DISTRICT



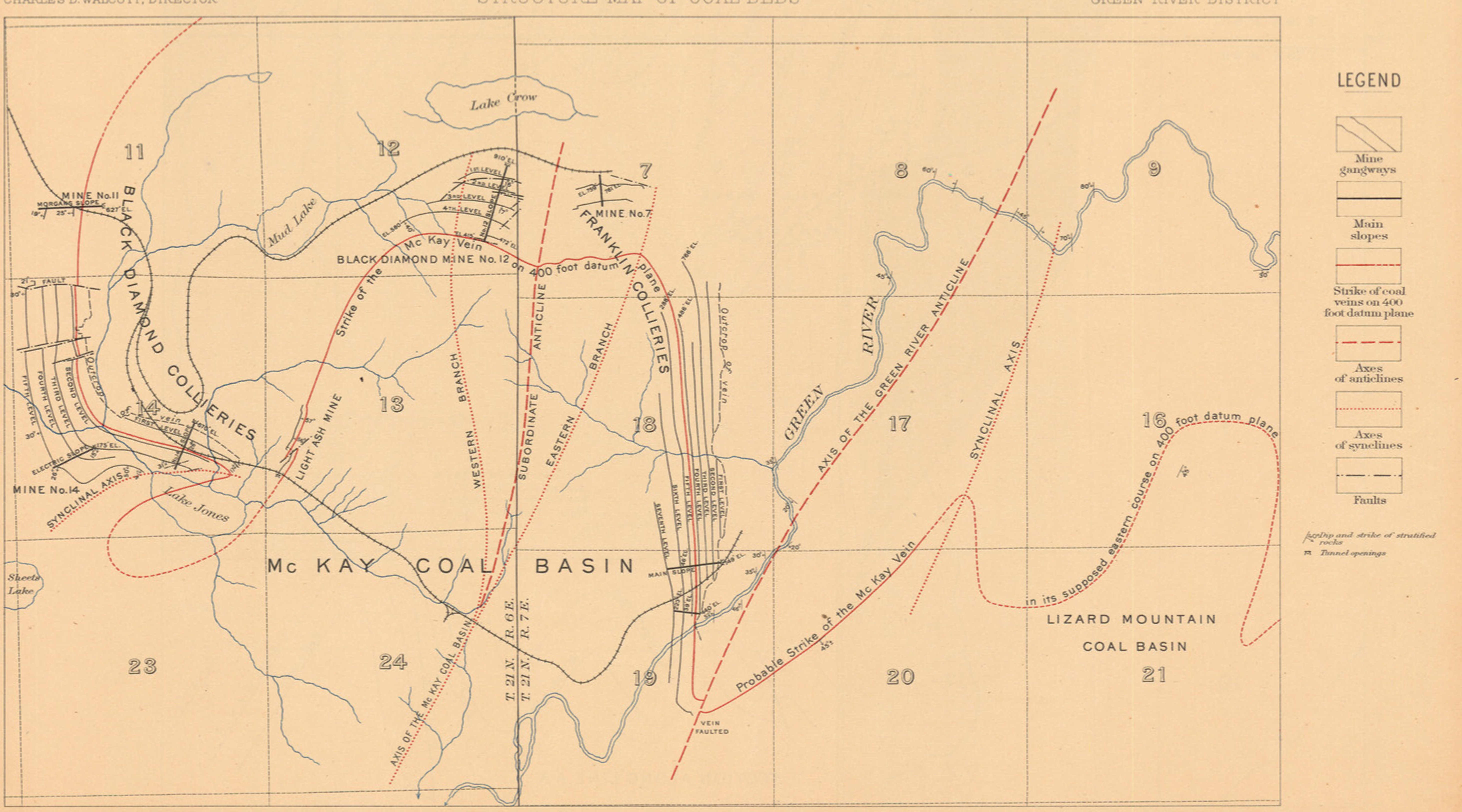
Scale $\frac{1}{12000}$

Compiled from mine maps furnished by C.H. Burnett and the Renton Cooperative Company and from personal observations by Bailey Willis.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

STRUCTURE MAP OF COAL BEDS

WASHINGTON
GREEN RIVER DISTRICT



Scale $\frac{1}{24000}$

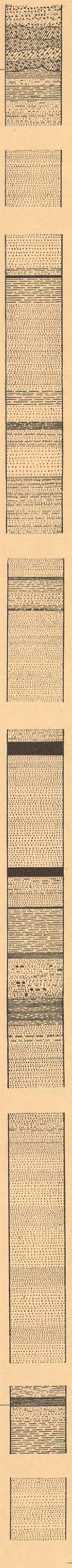
Compiled from data furnished by the mining companies and from personal observations by Bailey Willis.

Edition of Dec. 1899.

COLUMNAR-SECTION SHEET

COLUMNAR SECTION OF THE BURNETT, WILKESON, AND CARBONADO FORMATIONS, LOCAL SUBDIVISIONS OF THE PUGET FORMATION, MEASURED IN CARBON RIVER CANYON, NEAR CARBONADO.

SCALE: 80 FEET=1 INCH.

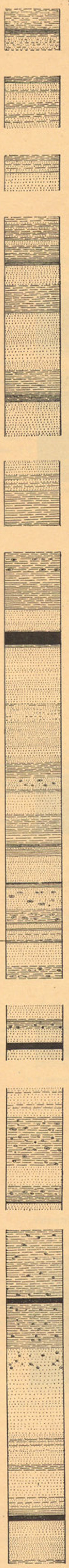


BURNETT FORMATION

Feet.	
20±	Drift.
40±	Tuff.
6	Shale, black.
7	Sandstone, shaly.
12	Shale, gray.
20	Sandstone, shaly.
570	Concealed.
50	Sandstone, massive, gray.
186	Concealed.
30+	Sandstone, massive.
6	Shale, dark gray, passing into shaly sandstone.
2½	Coal, bony.
24	Shale, weathering gray, hackly.
70	Sandstone, gray, thin bedded.
6	Sandstone, massive, weathering brown.
12	Shale, gray, hackly.
16	Sandstone, massive, gray.
7	Shale, dark, carbonaceous, hackly.
15	Sandstone, with thin shale beds.
20	Sandstone, massive, gray.
50	Sandstone, gray, in layers 6 to 30 inches thick, with interbedded dark-gray shale 2 to 6 inches thick.
25	Concealed.
16	Sandstone, massive, weathering brown.
2½	Coal, bony, and black shale.
10	Shale, gray.
11	Sandstone, shaly.
6	Shale, gray, and bone.
80	Sandstone, massive, gray, coarse, some beds cross stratified; in two principal benches.
350	Concealed.
10±	Sandstone and sandy shale.
12	Coal.
100	Sandstone, massive.
8	Coal.
14	Sandstone, shaly.
12	Sandstone, massive.
1½	Coal.
40±	Shale, dark gray, sandy below, hackly.
5	Shale, dark, bony.
36	Sandstone, shaly, concretionary.
20	Bone and black shale.
5	Shale, dark, bony.
30	Sandstone, thin bedded, shaly.
25	Sandstone, massive.
174	Concealed.
26	Sandstone, thin bedded, with shale in middle.
195	Sandstone, massive.
70	Concealed.

WILKESON FORMATION

Feet.	
10	Shale, sandy.
8	Coal, bony.
12	Sandstone, shaly.
30	Shale, gray, hackly.
75	Concealed.
55	Sandstone, massive.
75	Concealed.
2718	Carried forward.

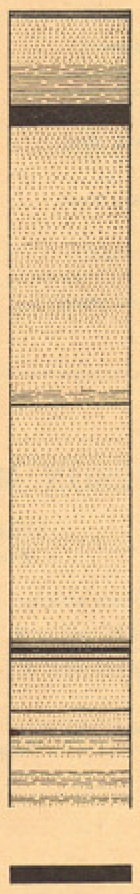


WILKESON FORMATION

Feet.	
2718	Brought forward.
18	Shale, sandy.
6	Coal, bony, and sandy shale.
12	Sandstone, shaly.
100	Concealed.
5	Shale, dark above, gray below.
40	Sandstone, with shale beds.
90	Concealed.
5	Shale, gray.
10	Sandstone and shale, interbedded.
16	Sandstone.
57	Concealed.
20	Shale, gray, hackly, with thin sandstone beds.
4	Sandstone.
18	Shale, dark gray, hackly, coaly at base.
17	Sandstone, massive, gray.
25	Shale, dark; fossil shells, "Clam Bed."
50	Sandstone, massive.
20	Shale, gray, hard.
3	Shale, yellow, soft.
6	Black shale and bone.
30	Sandstone, massive.
21	Concealed
12	Sandstone, massive.
15	Shale and sandstone interbedded.
30	Shale, gray and dark, hackly.
10	Concealed.
30	Shale, concretionary, ferruginous.
21	Shale, black and gray.
18	Sandstone, gray, micaceous and carbonaceous; slabby, becoming massive.
11½	Coal and bone, the Miller vein.
50	Sandstone, massive, homogeneous.
16	Sandstone, shaly, largely covered.
22	Sandstone, thin bedded.
14	Sandstone, massive above.
13	Shale, dark, upper beds crushed.
13	Sandstone, nodular, with thin shale at base.
20	Sandstone, massive.
16	Shale, gray, with sandstone.
10	Shale, brown, hackly.
9½	Slate, black, with bone and clay at top.
23	Sandstone, thin bedded, buff and dark gray, argillaceous and arkose.
4	Black slate, bony coal at top.
19	Sandstone, nodular.
12	Shale, gray, nodular, with black slate at base.
14½	Sandstone. with gray shale and black slate.
2½	Shale, gray, and bone.
20	Sandstone, massive.
11	Shale, buff, nodular.

CARBONADO FORMATION

Feet.	
64	Concealed.
12	Sandstone, massive.
8½	Shale, nodular, and coal.
12	Sandstone, thin bedded.
5½	Coal, No. 6.
10	Sandstone, massive.
28	Concealed.
26	Sandstone, massive, ripple marked; beds 2 to 4 feet thick, with dark shale layers.
44	Shale, nodular, hackly, with gypsum, white efflorescence.
17	Sandstone, massive.
14	Shale, dark, nodular above, fissile below.
1½	Coal. and black slate.
5	Sandstone, massive, ferruginous.
99	Concealed.
60	Shale, dark gray and brown, nodular.
4	Coal, No. 2 or No. 5.
40	Shale, dark gray, nodular.
92	Sandstone, nodular, gray, with massive beds in middle and interbedded shale below.
12	Sandstone, thin bedded.
4	Shale, gray, sandy, fissile.
25	Sandstone, massive.
10	Sandstone, interbedded with thin gray shale.
5	Black slate.
5	Coal, No. 4, south.
35	Sandstone, thin bedded.
3	Shale, sandy.
4369	Carried forward.

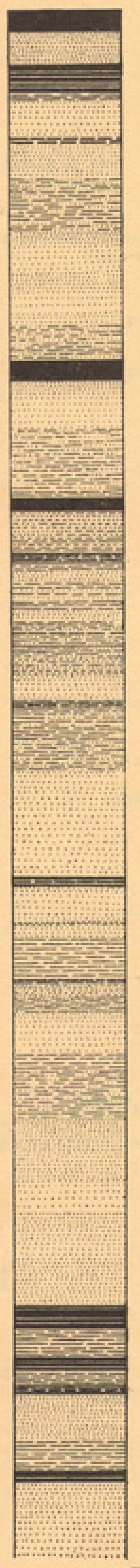


CARBONADO FORMATION

Feet.	
4369	Brought forward.
30	Concealed.
3	Coal, bony.
20	Sandstone, slabby.
16	Shale, gray, hackly, with black slate.
9	Coal, bony.
110	Sandstone.
6	Shale, sandy, coal at base.
90	Sandstone.
8	Coal and sandstone interbedded, No. 5.
20	Sandstone.
1	Coal.
10	Sandstone, with coal and slate at base.
30	Shale and sandstone, partly concealed.
224	Concealed.
7½	Coal, No. 7, south.
4953	Total thickness.

SECTIONS OF PART OF THE CARBONADA FORMATION MEASURED IN THE WESTERN CROSSCUT TUNNEL OF THE WILKESON MINE.

SCALE: 80 FEET=1 INCH.

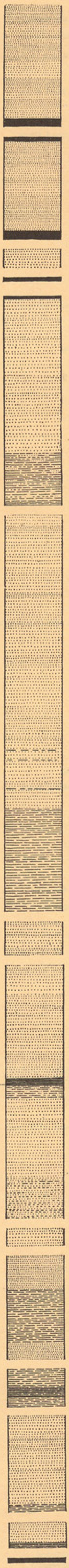


CARBONADO FORMATION

Feet	
10	Coal, No. 3.
15	Sandstone, thin bedded, layers 2 to 3 inches thick.
12	Coal, the Bogus vein.
3	Shale, dark gray, with bony streaks.
17	Sandstone, massive.
1½	Coal, bony.
16	Sandstone, very fine, thin bedded, with homogeneous layers.
23	Shale, sandy, dark gray, homogeneous, no distinct bedding; fracture conchoidal.
42	Sandstone, thin bedded, with leaf fragments; micaceous, with occasional massive, homogeneous beds 1± foot thick.
15	Shale, sandy, dark gray, massively bedded.
9	Coal, No. 2.
21	Sandstone, coarse, massive, thin bedded at top.
31	Shale, dark gray, sandy.
6	Coal, No. 1.
13	Sandstone, argillaceous.
5	Shale, dark gray.
6	Coal and bone; thin shale with leaves at base.
29	Sandstone, fine, argillaceous, interbedded with shale in thin layers.
2	Bone in sandstone, fine, argillaceous.
11	Shale, fine, sandy; conchoidal fracture.
19	Sandstone, thin bedded, shaly above.
3	Coal, bone, and shale.
27	Shale, fine, dark gray, sandy.
48	Sandstone, massive, soft, and friable.
4	Coal, bony.
16	Sandstone, gray, heavy bedded.
7	Sandstone, fine, thin bedded, thin clay at top.
18	Shale, soft, gray.
1	Bone and coal.
13	Sandstone, gray, argillaceous, becoming shale in lower portion.
19	Sandstone, massive, grayish brown, in beds 2 to 4 feet thick.
7	Shale, fine, gray, homogeneous.
21	Shale, sandy, leaf bearing.
28	Sandstone, thin bedded, micaceous, with carbonaceous streaks.
15	Sandstone, massive, gray.
40	Sandstone, thin bedded, micaceous, with leaf impressions and carbonaceous fragments.
10	Coal, No. 7, or Kelly.
13	Shale, with coal streaks.
6	Coal, soft, No. 6.
10½	Shale, bone and coal in lower portion.
21	Sandstone, thin bedded.
13	Shale, gray, with leaf impressions.
4½	Coal, No. 5.
34	Sandstone, massive, gray, in beds 2 to 5 feet thick.
685	Total thickness.

COLUMNAR SECTION OF THE BURNETT AND WILKESON FORMATIONS AS EXPOSED ON SOUTH PRAIRIE CREEK EAST OF BURNETT.

SCALE: 80 FEET=1 INCH.



BURNETT FORMATION

Feet.	
3500	Approximate thickness of strata above measured section, exposed to the eastward.
100	Sandstone, thin bedded.
5±	Coal, the Pittsburg vein.
375	Concealed.
3	Coal, the Acme vein.
80±	Sandstone, thin bedded.
7±	Coal.
1250	Concealed.
15	Sandstone, massive.
82	Concealed.
3	Coal, bony.
80	Concealed.
2	Coal, bony.
135	Sandstone, massive; partings, black, argillaceous; with many brown micaceous streaks.
45	Shale, sandy.
1	Leaf-bearing shale, sandy, black.
519	Concealed.
255	Sandstone, massive, interbedded with gray shale.
92	Shale, gray, arenaceous.
693	Concealed.
30	Sandstone, massive.
20	Concealed.
100	Sandstone, layers 3 inches to 4 feet thick.

WILKESON FORMATION

Feet.	
6	Bone and coal.
10	Shale, gray, sandy.
70	Sandstone, massive.
36	Sandstone, gray, shaly.
122	Concealed.
15	Sandstone.
122	Concealed.
30	Sandstone, thin bedded.
45	Shale, brown and black.
16	Sandstone, thin bedded.
4	Concealed.
15	Shale.
10	Shale and bone.
8	Shale.
13	Concealed.
21	Sandstone.
58	Sandstone.
7	Shale.
165	Concealed.
18	Sandstone.
4	Bone.
80	Concealed.
4±	Coal, the Burnett vein No. 1.
8271	Total thickness.

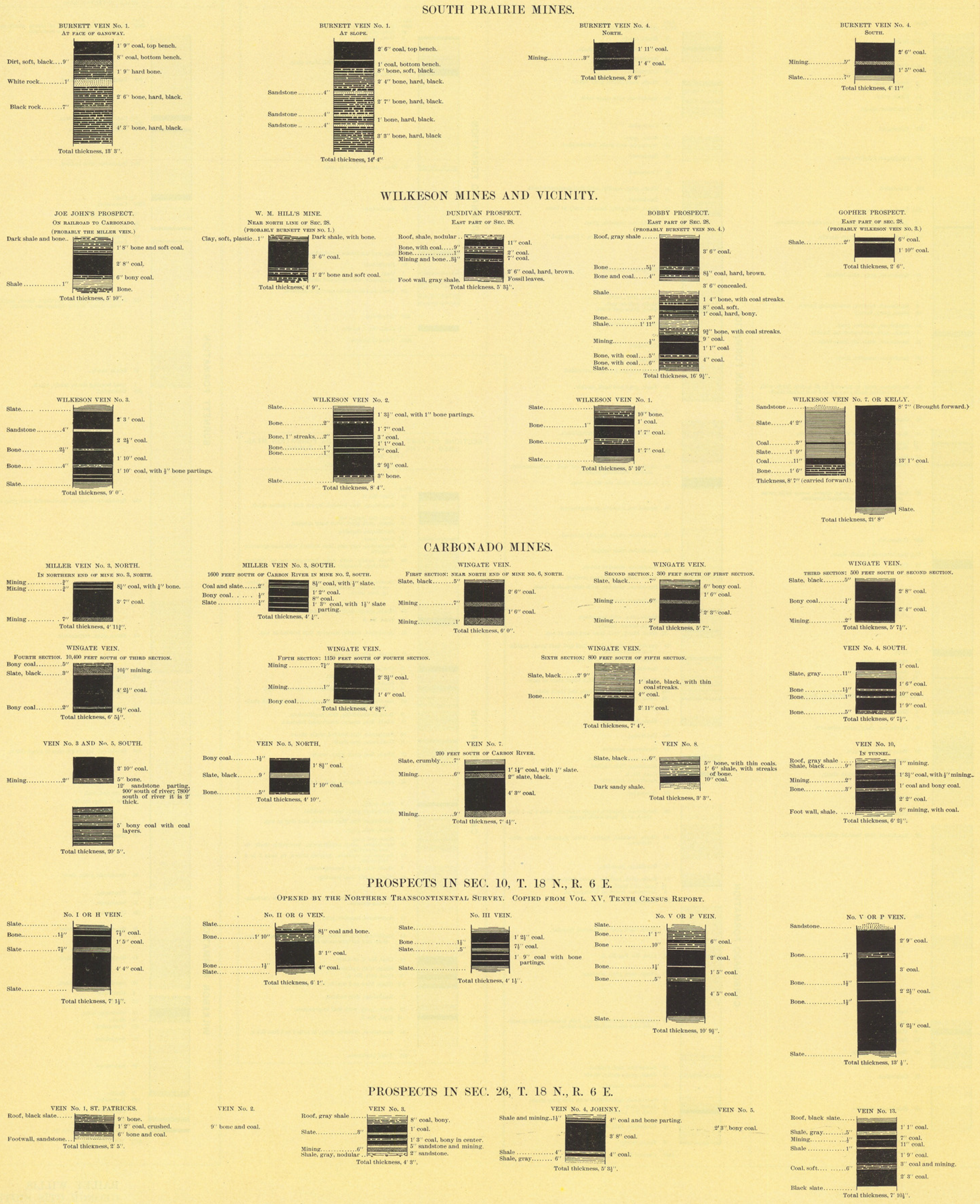
BAILEY WILLIS,
GEORGE OTIS SMITH,
Geologists.

U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

SECTIONS OF COAL VEINS, WILKESON-CARBONADO COAL FIELD.

SCALE: 8 FEET = 1 INCH.

WASHINGTON
TACOMA QUADRANGLE



BAILEY WILLIS,
Geologist.

forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be discovered by observing their relative positions. This relationship holds except in regions of intense disturbance; sometimes in such regions the disturbance of the beds has been so great that their position is reversed, and it is often difficult to determine the relative ages of the beds from their positions; then *fossils*, or the remains of plants and animals, are guides to show which of two or more formations is the oldest.

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are characteristic types, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present.

When two formations are remote one from the other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first.

Fossil remains found in the rocks of different areas, provinces, and continents, afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the color or colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions of the periods, frequently used in geologic writings, are bracketed against the appropriate period name.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the first (Pleistocene) and the last (Archean). The formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint (the underprint) is printed evenly over the whole surface representing the period; a dark tint (the overprint) brings out the different patterns representing formations.

Period.	Symbol.	Color.
Pleistocene	P	Any colors.
Neocene { Pliocene / Miocene }	N	Buffs.
Eocene (including Oligocene)	E	Olive-browns.
Cretaceous	K	Olive-greens
Juratrias { Jurassic / Triassic }	J	Blue-greens.
Carboniferous (including Permian)	C	Blues.
Devonian	D	Blue-purples.
Silurian (including Ordovician)	S	Red-purples.
Cambrian	Є	Pinks.
Algonkian	A	Orange-browns.
Archean	Æ	Any colors

Each formation is furthermore given a letter-symbol of the period. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations of the Pleistocene render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the metamorphic rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Historical geology sheet.—This sheet shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any particular colored pattern and its letter-symbol on the map the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet by fainter color-patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

Structure-section sheet.—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same name is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

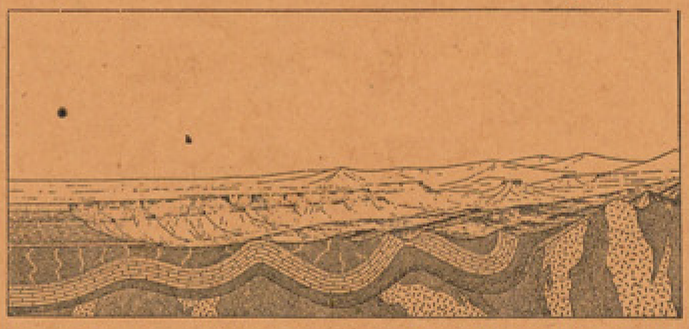


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane that cuts a section so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

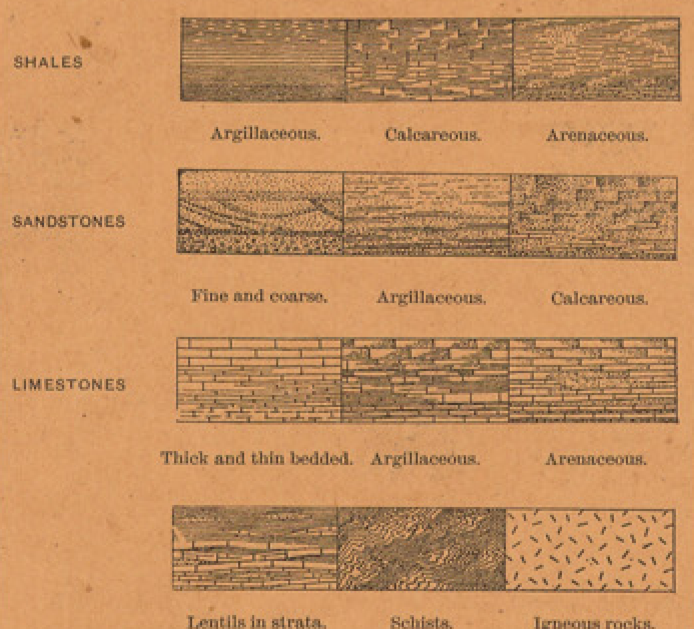


Fig. 3.—Symbols used to represent different kinds of rock.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section.

The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. But these sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which have from time to time caused the earth's surface to wrinkle along certain zones.

On the right of the sketch the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has swelled upward from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger strata thus rest upon an eroded surface of older strata the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond to the actual slopes of the ground along the section line, and the depth of any mineral-producing or water-bearing stratum which appears in the section may be measured from the surface by using the scale of the map.

Columnar-section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. The diagrams and verbal statements form a summary of the facts relating to the character of the rocks, to the thicknesses of the formations, and to the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given under the heading "Thickness in feet," in figures which state the least and greatest measurements. The average thickness of each formation is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement: the oldest formation is placed at the bottom of the column, the youngest at the top, and igneous rocks or other formations, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition of sediments may be indicated graphically or by the word "unconformity," printed in the columnar section.

Each formation shown in the columnar section is accompanied by its name, a description of its character, and its letter-symbol as used in the maps and their legends.

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Director.

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