SCHOOL OF MINES
AND METALLURGY
STATE COLLEGE

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

# GEOLOGIC ATLAS

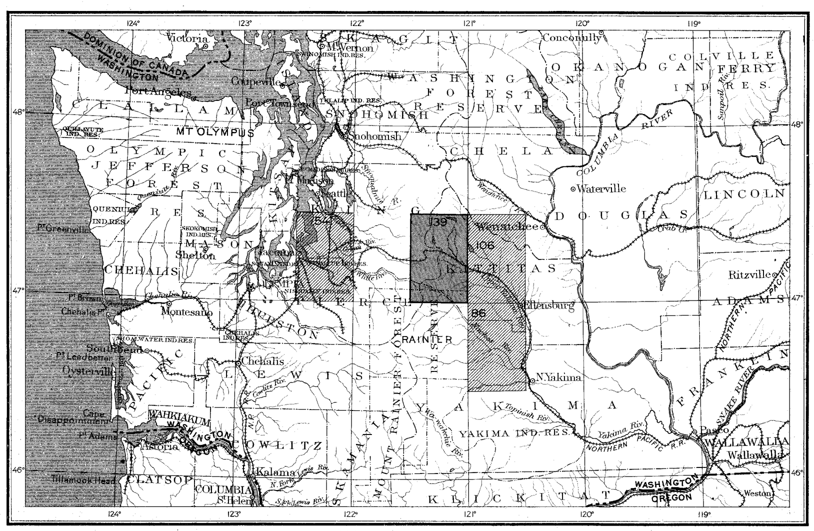
## OF THE

# UNITED STATES

# SNOQUALMIE FOLIO

## WASHINGTON

INDEX MAP




SCALE: 40 MILES=1 INCH

SNOQUALMIE FOLIO

OTHER PUBLISHED FOLIOS

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WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS    S. J. KUBEL, CHIEF ENGRAVER

1906

SCHOOL OF MINES
AND METALLURGY,
STATE COLLEGE, PA.

Case 10
Drawer 125

OHIO STATE UNIVERSITY

# GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic 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 outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal 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).

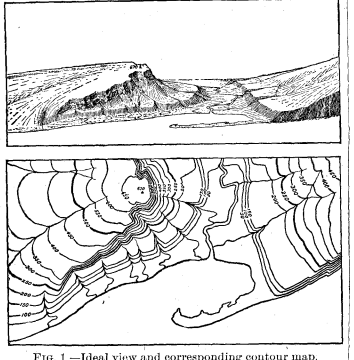

FIG. 1.—Ideal view and corresponding contour map.

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, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. 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 a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found 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 all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These 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 altitudinal 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 serviceable 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 a stream flows the entire year 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, are printed in black.

*Scales.*—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure 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 $\frac{1}{63,360}$.

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 about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles in English inches, by a similar line indicating distance in the metric system, and by a fraction.

*Atlas sheets and quadrangles.*—The map is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas 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-fourth 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.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and 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 map.*—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

## THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land, and the structure sections show their underground relations, as far as known and in such detail as the scale permits.

### KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

*Igneous rocks.*—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

*Sedimentary rocks.*—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. In smaller portion the materials are carried in solution, and the deposits are then called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind; and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in 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, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

*Metamorphic rocks.*—In the course of time, and by a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

### FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

### AGES OF ROCKS.

*Geologic time.*—The time during which the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

(Continued on third page of cover.)

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

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that 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 sedimentary formations are remote from each 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 strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.

Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not of their metamorphism.

*Colors and patterns.*—Each formation is shown on the map by a distinctive combination of color and pattern, and is labeled by a special letter symbol.

*Symbols and colors assigned to the rock systems.*

| | System. | Series. | Symbol. | Color for sedimentary rocks. |
|---|---|---|---|---|
| Cenozoic | Quaternary... | Recent........ Pleistocene.... | Q | Brownish - yellow. |
| | Tertiary...... | Pliocene....... Miocene....... Oligocene...... Eocene........ | T | Yellow ocher. |
| Mesozoic | Cretaceous.... | .................... | K | Olive-green. |
| | Jurassic...... | .................... | J | Blue-green. |
| | Triassic...... | .................... | Ꞧ | Peacock-blue. |
| Paleozoic | Carboniferous. | Permian....... Pennsylvanian Mississippian.. | C | Blue. |
| | Devonian..... | .................... | D | Blue-gray. |
| | Silurian...... | .................... | S | Blue-purple. |
| | Ordovician.... | .................... | O | Red-purple. |
| | Cambrian..... | Saratogan..... Acadian....... Georgian...... | Є | Brick-red. |
| | Algonkian.... | .................... | A | Brownish-red. |
| | Archean...... | .................... | Æ | Gray-brown. |

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin.

The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

Hills and valleys and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 1, is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion, and these are, in origin, independent of the associated material. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterwards partly eroded away. The shaping of a marine or lacustrine plain, is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain*. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

THE VARIOUS GEOLOGIC SHEETS.

*Areal geology map.*—This map 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 colored pattern and its letter symbol 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 formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

*Economic geology map.*—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map 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 mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

*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 term 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 formation of rocks, and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits 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:

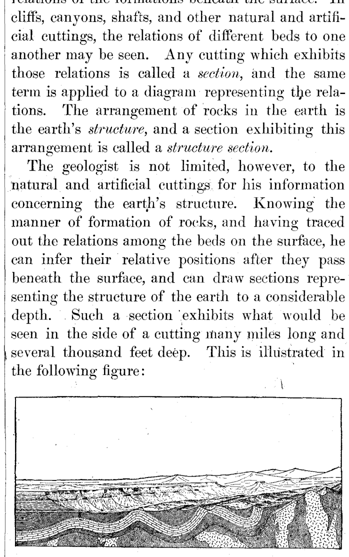

Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated 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:

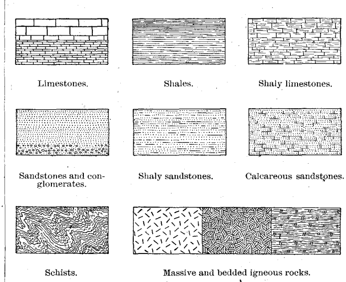


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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 the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

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. The direction that the intersection of a bed with a horizontal plane will take is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines*. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in fig. 4.

On the right of the sketch, fig. 2, 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

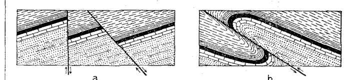


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a 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 been raised 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 rocks thus rest upon an eroded surface of older rocks 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 the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval 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 is another unconformity; it marks a time interval between two periods of rock formation.

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

*Columnar section sheet.*—This sheet contains a concise description of the sedimentary formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures which state the least and greatest measurements, and the average thickness of each 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 at the bottom, the youngest at the top.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

CHARLES D. WALCOTT,

*Director.*

Revised January, 1904.

# DESCRIPTION OF THE SNOQUALMIE QUADRANGLE.

By George Otis Smith and Frank Cathcart Calkins.

## INTRODUCTION.

*Location and area.*—The Snoqualmie quadrangle is bounded by meridians 121° and 121° 30′ west longitude and parallels 47° and 47° 30′ north latitude, and embraces 812.4 square miles. The quadrangle is situated nearly in the center of the State of Washington and includes portions of Kittitas, Yakima, Pierce, and King counties.

*Natural divisions of the State.*—The State of Washington comprises five natural divisions, which are geologically as well as geographically distinct.

The first of these divisions is the Olympic Mountains, which overlook the Pacific. These form apparently the northern extension of the Coast Range of Oregon, and are represented farther north, beyond Juan de Fuca Strait, by the heights of Vancouver Island.

East of the Olympic Mountains is the second division, the Puget Sound basin, a notable depression lying between parallel mountain ranges, and extending beyond the boundaries of the State, southward in the Willamette Valley of Oregon and northward in the sounds of British Columbia. Its characteristic topography and geology are described in the Tacoma folio.

The third division is the Cascade Range, a mountain mass trending north and south and forming the most prominent topographic feature of the State. This line of uplift is a continuation of that of the Cascade Range of Oregon, but the Cascades of Washington deserve further subdivision. From Columbia River northward to the vicinity of Mount Rainier the range resembles the Oregon portion, both in topography and in geology, in that it consists of basaltic and andesitic lavas of Tertiary and later age. A typical portion of the eastern flanks of this part of the Cascade Range is described in the Ellensburg folio. Farther north, however, older rocks appear in the Cascade Mountains and the topography of the range becomes more varied. These geologic and topographic distinctions are sufficiently important to deserve recognition, and on this account the range from the vicinity of Mount Rainier northward to the forty-ninth parallel will be termed the Northern Cascades. The application of this term beyond that latitude is questionable, since there is in this vicinity an abrupt change from rugged peaks to more rounded and lower ridges such as occur north of the international boundary. The areas described in the Mount Stuart folio and in this folio are typical of the Northern Cascades, while the southwestern portion of the Snoqualmie quadrangle presents features resembling those that are characteristic of the Cascade Range of Oregon. Mount Adams, Mount Rainier, Glacier Peak, and Mount Baker, peaks that dominate both portions of the Cascade Range in Washington, are volcanic cones of later date than the range itself, and their presence does not affect the subdivision here proposed.

The fourth important division of Washington is the Great Plain of the Columbia, a plateau that includes approximately one-third of the State and extends southward into Oregon and eastward into Idaho. The Ellensburg quadrangle, described in folio 86, lies in the border land between the Columbia Plain and the Cascade Range.

The mountainous district bordering the Columbia Plain on the north and traversed by the international boundary constitutes the fifth natural division of the State. It includes the Colville Mountains, which apparently represent the southern continuation of higher mountains in British Columbia.

*General geology of the Cascade Mountains.*—The geology of a limited area like the Snoqualmie quadrangle can not be fully understood without some general knowledge of the province of which it is a part. A brief outline of the geologic history of the Cascade province will therefore serve as a proper introduction to the more detailed description of the geology of this quadrangle.

The oldest rocks known in the Northern Cascades are probably of Paleozoic age and represent volcanic products as well as sediments. Their characters indicate that the conditions of volcanism and of sedimentation were remarkably similar to those that prevailed during the same period in the Sierra Nevada and in British Columbia. No early Mesozoic strata are known in this region, but during late Mesozoic time sediments that formed sandstones and other rocks were laid down in portions of the Northern Cascade area. The most important body of Cretaceous rocks lies near the international boundary and represents an extension of the Cretaceous sea southward from the interior region of British Columbia. Toward the south the nearest known area of rocks of similar age is in the John Day basin and the Blue Mountains of Oregon. Thus central Washington may have been in Cretaceous time a land area, with seas both to the north and to the south.

The deposition of the Cretaceous rocks seems to have been followed by an epoch in which these and older rocks were folded and uplifted. Thus was an early Cascade Range outlined, although it may be that the range had an even earlier origin. The post-Cretaceous mountain growth was accompanied by intrusions of granitic and other igneous rocks, which now constitute a large part of the mass of the Northern Cascades. During all the time that any portion of this area was not covered by water the rocks were exposed to the vigorous attacks of atmospheric agencies. Thus at the beginning of the Tertiary the Northern Cascade region appears to have been a comparatively rugged country, although not necessarily at a great elevation above sea level.

During the Eocene epoch an extensive estuary or arm of the sea occupied the Puget Sound area and extended well over toward the present axis of the range. Other large bodies of water, probably fresh, existed in central Washington, and some of these may even have been connected with the Puget estuary. Thousands of feet of arkose sediments were deposited at this time, and in these Eocene strata are included all the coal beds in the State that are of economic importance. In this period also began the volcanism that in later epochs became so characteristic of the province. The more extensive basaltic eruptions, however, occurred in the succeeding epoch, the Miocene, when an area measuring many thousands of square miles was buried deep beneath the flood of lava. In portions of this vast area sedimentation within shallow-water bodies immediately followed the eruption of basalt, and the Miocene epoch closed with slight tilting and folding of these deposits. The erosion that followed the exposure of these beds and the underlying rocks to atmospheric action continued until the whole region was planed down to a lowland surface, possessing only slight relief. This reduction of the area to what may reasonably be termed a peneplain marks the destruction of the earlier Northern Cascades as a mountain range, but toward the close of Tertiary time, probably, this leveled surface was gradually uplifted to form the present Cascade Range. This uplift at its very beginning inaugurated fresh attacks upon the rock masses by the streams, and is so recent that streams and glaciers have as yet succeeded only in giving to the range an extremely rugged relief.

## TOPOGRAPHY.

*Relief.*—The Snoqualmie quadrangle lies in the heart of the Cascade Range and includes about 50 miles of the main divide between the Puget Sound drainage and the streams tributary to the Columbia. Yet this divide is not the most important element in the relief of the quadrangle, since it is to a large extent an inconspicuous feature, and does not form a natural division line separating the eastern and western slopes as distinct topographic regions. A more obvious topographic subdivision of the area is made by the broad valley of Yakima River, which extends southeastward from Snoqualmie Pass to the eastern edge of the quadrangle, separating it into two elevated regions of nearly equal area, which present marked differences in topographic character.

The highest peaks in this quadrangle are in the extreme northern and southern parts. One of the "Needles" north of Glacier Lake has an altitude of 7512 feet, and 15 miles east of this point, at the head of Camp Creek, an elevation of over 7000 feet is reached on Hawkins Peak, the summit of which is a few hundred yards beyond the eastern edge of this quadrangle. The next highest elevations are near the southeast and southwest corners of the quadrangle, where the culminating points on two ridges are 6312 and 6325 feet respectively. This distribution of the most elevated points is noteworthy, since, with the exception of the highest peak, they are not on the main divide and two of them are many miles east of that divide. The topographic map clearly shows that the most prominent mountain ridges in this region trend not north and south but more nearly east and west. The high country in the northern portion of the quadrangle is deeply cut by tributaries of the Yakima, so that, while the range continuity is not apparent, yet the heights bordering these canyons exhibit more or less uniformity in altitude. South of the valley of the Yakima the ridges are more continuous, especially the one between that valley and the Naches basin. The physiographic significance of this distribution of the heights will be discussed under the heading "Historical geology."

The group of mountains in the northern part of the quadrangle forms a part of the important range which extends eastward across the Mount Stuart quadrangle and is known there as the Wenatchee Mountains. This line of heights forms the divide between the Middle Fork and the headwaters of the South Fork of Snoqualmie River and also the divide between Yakima River and the West Fork of Clealum River. Here the topography is of the boldest type, the divides being generally narrow, and in some places having knife-like crests. Extreme examples of relief of this character are afforded by the "Needles" between Burnt Boot Creek and the headwaters of West Fork of Clealum River. Here spires and pinnacles of bare rock overlook a series of small glaciers. Several of these divides are impassable, the precipitous character of the bordering cliffs preventing ascent at any point, while the narrow crest is too sharp and ragged to allow passage along the divide itself. These high peaks and ridges are mostly snow-capped throughout the summer and, together with the cascading streams and small glacial lakes, constitute the most picturesque features of the scenery of the region.

Somewhat in contrast with such ridges are others to the east and southeast. Goat Mountain, and especially the ridges between the Middle and West forks of Clealum River, between Keechelus and the two Kachess lakes, and between the Kachess lakes and Clealum River, are characterized by a somewhat different type of upland topography. Viewed from below these present the same steep slopes, often with bold walls of rock rising 2000 or 3000 feet from the lake or river, and Goat Mountain presents on its southeastern face an almost unbroken rock wall over 3500 feet high. Yet on the summits of these ridges there are level stretches of forest or grassy meadow, and traces of old Indian trails emphasize the contrast between these heights and those of the other type. This northern area, then, can be briefly described as a plateau region in which the larger streams have deeply incised their canyons. In the highest parts of this plateau dissection has attained an extreme degree of maturity, while other portions of the upland surface apparently have to a large extent escaped attack.

In the southern half of the quadrangle the mountains are of a more subdued type. Steep cliffs border some of the streams for short distances, but are exceptional east of the divide. Even in their highest parts the ridges have broad level crests, which are taken advantage of by the principal trails. The southern part of the quadrangle thus lacks the scenic beauty of the northern part, and when viewed from a distance the southern ridges appear to unite in a broad, monotonous plateau that slopes gently eastward and westward from its central portion.

The valley of the upper Yakima, which has been taken as a division line between two topographic provinces, is itself a conspicuous feature of the relief. The Yakima is remarkable in that its low-grade valley extends well back to its headwaters, an easy railroad grade being maintained to within 3 miles of Snoqualmie Pass. For a distance of 10 miles this valley approximately parallels the main Cascade divide, which at Stampede Pass is only about 1 mile distant from the edge of the valley. The divide is here generally low and possesses little importance in the topography of the region.

Yakima Valley is everywhere broad except for a few miles above Easton, and within this quadrangle includes nearly 20 square miles of bottom land. A notable feature on the southwest side of the valley at Easton is a ridge rising 1600 feet above the valley floor, behind which is a well-marked narrow valley, drained by branches of Big, Little, and Cabin creeks, and by an unnamed creek that enters Yakima River near Easton.

The valleys of Clealum River and its several forks have wide, flat bottoms like Yakima Valley, and Naches River is also bordered by broad meadows in portions of its course. Along the upper valleys in the northern part of the quadrangle, topographic features due to glaciation are conspicuous. A noticeable example is seen in the character of the valley floor in the vicinity of Big Salmon Lasac, where numerous channels and basins have been carved in the rock, the county road following one of these side channels at some distance from the river. The valleys of tributary streams in this region commonly show marked differences in grade between their upper and lower portions, the streams passing from broad basins with gentle grade into narrow gorges which extend to the river valley. The best examples of these hanging valleys are on Thorp and French Cabin creeks, which enter Clealum River from the west. These creeks flow through rather broad valleys until they reach the brink of Clealum Valley and then cascade down about 600 feet through deep cuts in the valley wall.

*Drainage.*—As has been stated above, the main Cascade divide crosses this quadrangle, so that the area includes parts of two drainage basins. The streams tributary to the Columbia River are Yakima River and its various branches, the largest of which are Clealum and Naches rivers. The streams tributary to the Puget Sound drainage include the headwaters of four rivers—Snoqualmie, Cedar, Green, and White.

The eastern and western drainage basins exhibit a marked contrast in stream grades. The Yakima and its larger tributaries are as a rule characterized by low grades, but the westward-flowing streams descend much more rapidly. Thus it happens that, although the divide between the two drainage basins lies near the western margin of the quadrangle, the lowest point in the area, 1400 feet, is in the northwest corner. Also, while the descent of the Yakima is only about 1000 feet from its source at Snoqualmie Pass to its junction with Clealum River, a distance of over 25 miles, the

South Fork of the Snoqualmie, flowing westward from the same point, descends 1200 feet in a distance of about 5 miles. A somewhat similar grade is shown on Green River, and this difference between the eastern and western slopes is made even more apparent by the different types of railroad engineering east and west of Stampede tunnel, on the Northern Pacific.

The rivers and streams of this quadrangle all benefit by the heavy annual precipitation of the Cascades. The seasonal character of this precipitation is somewhat counteracted by its storage in the high mountains in the form of snow, banks of which, during ordinary seasons, persist late into the summer and in many places throughout the year. Two small glaciers are included within this quadrangle, and these, together with others immediately north of the quadrangle, are tributary to West and Middle forks of Clealum River, serving to keep up its discharge in the summer months. The larger of these glaciers is directly exposed to the sun, and its existence is therefore the more remarkable. Although small, these glacier remnants present all the characteristics of true glaciers and are traversed by crevasses, on whose walls the banded structure of the ice can be seen. The work of the ice streams of which these are the survivors can be traced along all the valleys in the northern half of the quadrangle.

*Culture.*—The total population of this quadrangle in 1900 was about 600. This is probably nearly evenly divided between King and Kittitas counties, and is practically confined to the immediate vicinity of the line of the Northern Pacific Railway. Easton and Lester are the only villages. Ronald was formerly an important mining town, but is nearly deserted now, the center of the coal-mining industry being at Roslyn, immediately east of the edge of this quadrangle.

Agriculture and the lumber industry support most of the permanent inhabitants. Agriculture is practiced only on a limited scale, and is confined to the valleys of the Yakima and Clealum. During the summer months large bands of sheep graze in the elevated region bordering the lower Clealum Valley and in the southern half of the quadrangle east of the divide.

This quadrangle includes the only wagon road crossing the Cascade Range in Washington, the Snoqualmie Pass road, which is therefore an important route, although in many years it has been blocked with snow except during the summer months. Another county road leading well into the heart of the range follows Clealum River. By these two routes many prospectors reach the Snoqualmie Pass, Gold Creek, and Camp Creek districts, where they work during the summer months and even throughout the greater part of the year.

## DESCRIPTIVE GEOLOGY.

### STRATIGRAPHY.

*General features.*—The Snoqualmie quadrangle is a remunerative field for geologic investigation. Here both the oldest and the youngest rocks thus far discovered in the Northern Cascades are exposed and the structure of the Cascade Range is well exhibited. The formations, which are representative for much larger areas, may be separated for convenience into two classes, the older or pre-Tertiary, and the younger or Tertiary. This classification is natural in view of the great unconformity at the base of the Eocene, although the difference between the rocks of these two groups is not so apparent in this quadrangle as it is farther east, in the Mount Stuart quadrangle. In both groups the rocks are varied in composition and in kind. There has been no definite determination of the age of any pre-Tertiary formation, but several of the Tertiary formations carry fossil plants that afford a basis for fixing their exact age.

Among the pre-Tertiary formations intrusive and metamorphic rocks predominate—that is, rocks which acquired their present character deep below the surface of the earth. The intrusives were consolidated from bodies of molten material forced up from below and the metamorphics were formed by the alteration, through the agency of heat and mountain-making forces, of sedimentary and igneous materials. The Tertiary rocks, on the other hand, are chiefly of the kind formed at the surface, such as sediments and volcanic deposits. These are sandstones and shales, deposited as sands and muds in large inland lakes, or lavas and beds of tuff, erupted from openings in the earth's crust. Associated with these are also intrusive rocks of Tertiary age.

The difference in age between these two groups of rocks is considerable. The older rocks had been long exposed to the influence of the atmosphere and carved by streams into hills and valleys when the first deposits in the Eocene waters were laid down over an uneven surface composed of rocks widely differing in character. This is what is meant by the statement that there is at the base of the Eocene sandstone a marked unconformity representing an erosional interval. In the following portions of this descriptive text all of these formations, both pre-Tertiary and Tertiary, will be described with more detail, and these descriptions will be followed by an outline of the geologic history of the region, which is an interpretation of the record afforded by the rocks.

In the texts of folios of the Geologic Atlas it has been customary to separate the descriptions of the sedimentary from those of the igneous rocks. In the present case, however, the order of treatment will be based upon succession alone. This deviation from the usual practice is considered desirable in view of certain facts that are peculiar to this province. Several of the formations here described are of composite character, being in part of sedimentary and in part of volcanic origin. Most of the sedimentary formations are not widely distributed but rather represent local deposits in a region where igneous activity frequently interrupted sedimentation. The rapidity with which one geologic process succeeded another is the most noteworthy characteristic of the history of the province, and since the rock formations constitute the record of that history, the strict separation of the sedimentary and igneous rocks would tend to obscure the record.

### PRE-TERTIARY ROCKS.

*Age and succession.*—The precise geologic age of the pre-Tertiary rocks can not be determined, owing to lack of paleontologic evidence, but the very marked unconformity by which they are separated from the overlying Eocene strata proves conclusively that they are pre-Tertiary. This unconformity, moreover, represents a very long time interval. The Eocene beds rest not only upon the eroded edges of older sedimentary strata but also upon the granular igneous rocks that were intruded into those sediments. Intrusive rocks of this kind must have consolidated far beneath the surface, so that their presence at the base of the Eocene strata shows that this unconformity records the removal by erosion of a cover of considerable thickness—a process which in turn implies that a long interval of time had elapsed between the igneous intrusions and the beginning of Tertiary time.

The great difference in appearance between the schists and slates and the Eocene sandstones is more striking to the casual observer than the unconformity just described. This contrast is due to a difference in degree of alteration between the rocks of the two groups, and indicates that the time interval between the deposition of the pre-Eocene rocks and that of the Eocene sediments was not only great but eventful. It must have included several momentous episodes of deformation and intrusion as well as one or more periods of long-continued erosion. Thus it may be reasonably supposed that the period of deformation, intrusion, and erosion included all of Mesozoic time and that the oldest rocks in this area are of Paleozoic age. This conjecture is further warranted by the fact that similar rocks in British Columbia, the Blue Mountains of Oregon, and the Sierra Nevada of California are known to be Paleozoic.

The age of the pre-Tertiary intrusives can only be a matter of conjecture. That they are Mesozoic, however, can be considered probable, since in California and Oregon that age has been assigned to granodiorite and serpentine similar to those occurring in this area.

Although the precise geologic age of these pre-Tertiary formations is thus in doubt, their ages with respect to one another may be determined by their obvious geologic relations, which will be described when the formations are discussed. The oldest formations in this region are the Easton schist, the Peshastin slate, and the Hawkins volcanic rocks. Of these the oldest and most altered—the Easton schist—is a metamorphic formation that probably comprises both sedimentary and igneous rocks; the others, although somewhat altered, are plainly sedimentary and volcanic, respectively. The pre-Tertiary igneous rocks that are intrusive in these formations are peridotite (now largely altered to serpentine), the Mount Stuart granodiorite, and a quartz-diorite which is probably older than the granodiorite. All but the last of these formations also occur in the Mount Stuart quadrangle and are described in folio 106.

#### EASTON SCHIST.

*General character and occurrence.*—The Easton schist comprises light-green and bluish, banded phyllitic schists and darker green schists rich in hornblende. The name given to the formation is that of a small town in Yakima Valley, close to which it is well exposed. It includes sedimentary and igneous rocks, now highly metamorphosed. A characteristic feature of the formation as a whole is the extreme alteration produced in it by heat and by mountain-making pressure. These agencies have produced new "metamorphic" minerals—as mica and hornblende—and characteristic schistose and crumpled structures, the latter being especially evident in the laminated sedimentary rocks. The bedding and schistosity of these rocks are in general highly inclined, and very frequently vertical. The intense metamorphism of the Easton formation is an indication of its great age and the chief criterion for its distinction from later formations.

The Easton schist is exposed in three zones. The first of these extends southeastward from Easton in a conspicuous ridge which has been carved from the schist. Parallel with this and about 2 miles south of it is a second zone of Easton schist and of other pre-Eocene rocks, from which is carved another prominent ridge. The third zone of this schist comprises three large areas in the north-central part of the quadrangle. All of these zones extend in a northwest-southeast direction.

*Lithology.*—The hard and resistant Easton schist affords extensive exposures, the best of which occur on the escarpment south of the Taneum Creek basin, in the canyon of Little Creek, and on the bold wall east of Little Kachess Lake. The observed exposures, however, constitute only parts of the whole formation, and owing to the impossibility of working out the structure of these intensely deformed rocks no satisfactory correlations can be made, nor can the succession of beds be accurately determined. Therefore only the general character of the formation as seen in the field will be stated.

In the region about the headwaters of Taneum and Manastash creeks the Easton schists are chiefly amphibolitic. The amphibolitic schists are greenish gray to almost black in color and sufficiently coarse grained to enable the hornblende to be easily recognized. They do not show much crumpling and break into flat leaves or slabs. Schist of this character forms the upper part of the cliff south of Taneum Creek, but the lower part is composed of a lighter green, more siliceous rock. Farther east on the same ridge, at the head of the North Fork of Manastash Creek, are some fine-grained, olive-green rocks with small white spots that look like altered porphyritic feldspars.

The zone lying next north is formed in greater part of siliceous and phyllitic schists, gray-green and bluish in color. Such rocks are exposed on the railroad above Easton, on the little island in Kachess Lake, and in the low hills south of Nelson. Some hornblende schists also occur in this zone, especially in its southern part.

In the northernmost zone one of the most abundant rocks is an olive- to blue-green schist, fine grained and tough, which is extensively developed near the head of Little Kachess Lake. In this northern district there is also a large amount of thinly laminated and intensely crumpled bluish schist, which is typically developed in areas northwest of Clealum Lake and north of Little Kachess Lake. Locally these rocks show a considerable proportion of graphite and at one place they have been prospected for coal, which there is, however, no reasonable hope of finding.

As studied under the microscope, the Easton rocks fall into two principal groups—the quartz-mica phyllitic schists and the amphibolitic schists, and the petrographic characters of each will be described in somewhat general terms.

The phyllitic schists have for their chief constituents quartz and muscovite. They are composed of thin laminæ, alternately quartzose and micaceous, along which the rock splits readily. The mica is very finely divided and gives a silvery sheen to the surfaces of the layers. The colors, which, as already noted, vary from blue-black in certain graphitic varieties to blue-gray and grayish green, are dependent upon the presence of graphite and chlorite. The microscope reveals, in addition to the constituents above noted, a little feldspar, with some accessories, as magnetite and zircon, in trifling amounts.

The amphibolitic schists, darker green in color, do not show such marked lamination as the phyllitic schists, but they exhibit distinct cleavage, and a roughly parallel arrangement of amphibole prisms is visible megascopically. Their present texture has evidently been determined by metamorphism, which has obscured their original texture. Their essential constituents, as shown by the microscope, are green hornblende, lime-soda feldspar, usually a little quartz, and more or less epidote and chlorite. The last two are especially abundant in the fine-grained schist at the head of Little Kachess Lake. Magnetite, apatite, and titanite occur as rather abundant accessories.

The Easton schists, like several later formations in the quadrangle, seem originally to have been composed of interbedded sedimentary and volcanic rocks—a conclusion reached chiefly by petrographic study. The phyllitic schists, judging by their lamination and by their chemical composition, which is similar to that of sandy clay, appear to have been derived from sediments. The amphibolitic schists, on the contrary, are chemically related to the basic igneous rocks. In clastic rocks the ferromagnesian constituents are washed away, leaving a dominant proportion of the more resistant minerals, as quartz and the acid feldspars, with more or less argillaceous material, which becomes altered chiefly to mica. Rocks so rich in ferromagnesian constituents as these amphibolites are therefore, in all probability, igneous. As to whether they are volcanic or intrusive, there is no perfectly clear evidence, but since they are fine grained and in the form of layers it seems more probable that they are volcanic.

#### PESHASTIN FORMATION.

*General character and occurrence.*—The Peshastin formation is best exposed on the creek of that name in the northeastern part of the Mount Stuart quadrangle. In the Mount Stuart folio (No. 106), the formation is described as consisting chiefly of dark-colored slate interbedded with subordinate amounts of grit, conglomerate, chert, and limestone, the last forming lenses of very moderate extent.

In the Snoqualmie quadrangle, on the ridge between Taneum Creek and Naches River, there is one main area of dark slate similar to the typical Peshastin, and smaller areas occur between the headwaters of Taneum and Manastash creeks. In the northeast quarter of the quadrangle there are three small areas of rocks which it seems best to refer to this formation. One of these, in the basin of Fortune Creek, is an area of metamorphosed siliceous rock, such as might be derived from some phase of the Peshastin formation, which occurs in force immediately east of the edge of the quadrangle. Another is a small area of impure limestone and calcareous shale northwest of Clealum Lake, but as these rocks are not near any exposure of characteristic Peshastin slate, their reference to that formation is somewhat tentative. The third area is a narrow band of metamorphosed limestone at the head of Boulder Creek.

*Relations.*—The belief that the Peshastin formation is considerably younger than the Easton schist is not supported by such definite evidence as would be afforded by an exposure of typical Peshastin slate resting with distinct unconformity upon the Easton schist. At a point between Taneum and Manastash creeks, where the boundary between these two formations is best seen, the contact plane is a fault, and nowhere is a normal contact of superposition well exposed.

At the occurrence near Clealum Lake the calcareous rock overlies Easton schist but is separated from it by a layer of metamorphosed volcanic rocks. Here there is a distinct unconformity, for the schist is vertical while the limestone and shale have a dip of 45°. Of course the doubt attending the reference of these rocks to the Peshastin formation diminishes the value of this observation. Thus, it follows that the principal evidence as to the relative age of the two formations is almost wholly the low degree of metamorphism shown by the Peshastin slate as compared with that shown by rocks in the Easton schist that are believed to have been of similar original composition. This difference in degree of metamorphism is so marked as practically to demonstrate that the Easton rocks underwent the larger part of their alteration before the Peshastin formation was deposited.

It is evident that exposures which so imperfectly show geologic relations can furnish no grounds for an estimate of the thickness of the formation. This is also true of exposures in the adjoining Mount Stuart quadrangle, where complicated structure and extensive intrusion by igneous rocks prevent any measure of stratigraphic thickness. The lithologic differences between the various areas referred to the Peshastin suggest, however, that these are remnants of a formation whose thickness possibly measured thousands of feet, and that some of the exposures represent the upper part and others the lower part of that formation.

The age of the Peshastin formation and its possible correlation with similar beds in other areas will be discussed later in the description of the Hawkins formation.

*Lithology.*—The dominant rock in the main area of the Peshastin formation in this quadrangle is a dark-gray to black slate, plainly derived by induration and alteration from a somewhat carbonaceous mud. This slate is mostly homogeneous and lacks conspicuous banding, although it contains some thin arenaceous layers. Cleavage, while not very well developed, is generally present, being usually parallel to the bedding, but in some cases inclined to it.

In the small area south of Fortune Creek the rock has been highly altered by the peridotite which surrounds it, and the formation here includes green and bluish siliceous schist, together with some impure quartzite. At the occurrence near Clealum Lake the rock is a thin-bedded and fine-grained gray limestone interbedded with calcareous shale and shaly sandstone. The sandstone, when studied microscopically, appears to be tuffaceous.

One exceptional phase of the Peshastin formation and its mode of occurrence requires special mention. Within the peridotite or serpentine areas or in the areas of Peshastin rocks near the contact with the serpentine, at a number of localities in the Mount Stuart quadrangle, there are ledges, only a few feet across, of a bright-yellow or light-red rock with rough, ragged surfaces. These ledges have a general east-west trend, and are locally known as the "nickle ledge" or "porphyry dike." Owing to their hardness they weather out more prominently than the surrounding rocks, and their characteristic rugged erosion forms and bright colors make them easily recognized at considerable distances.

The principal occurrences of this peculiar rock in the Snoqualmie quadrangle are on the eastern edge in the upper basin of Boulder Creek, but of these only one, which continues eastward into the Mount Stuart quadrangle, is extensive enough for mapping. Near the mouth of this creek large blocks of the typical yellow rock may be seen.

Examined microscopically the rock exhibits no structures that afford any clue to its origin, and the only determinable constituents seen are carbonates and iron oxide. Chemically it is a siliceous dolomitic rock containing considerable iron. A specimen analyzed in the laboratory of the United States Geological Survey contained only .08 per cent of nickel oxide (NiO), which is even less than the percentage of nickel in the serpentine.

Two explanations may be given of the origin of this "nickel ledge:" (1) The bands may represent mineralized zones in both the serpentine and the slate, or (2) they may have been originally calcareous beds or lenses belonging to the Peshastin formation, in part included within the intruded peridotite, in part situated along its contact, and thus in a position to have been subject to alteration by this magnesia-rich igneous rock. The latter hypothesis is the one which is better supported by the relations observed. Limestone lenses such as are called for by this hypothesis occur within the Peshastin areas, though they are not known at the serpentine contact. Here, however, the peculiar magnesian rock does occur, and just beyond the eastern edge of this quadrangle, on the ridge next south of Hawkins Mountain, a ledge of this magnesian rock runs parallel with the bed of limestone within the slate series, the relationships plainly indicating that the altered condition of the former rock is directly dependent on the proximity of the serpentine, with which it is partly in contact. The association of the slate with the magnesian rock is therefore believed to justify the mapping of the latter as also belonging to the Peshastin formation. The enrichment of the calcareous rock with magnesia may have occurred at the time of the intrusion of the peridotite or later.



HAWKINS FORMATION.

*General character and occurrence.*—The Hawkins formation consists of volcanic rocks, mostly basic and dark colored and of the general type often termed greenstones. These rocks include amygdaloidal lavas, breccias, and tuffs, which have been considerably altered but not so much so as to obscure wholly their original character. The most obvious feature of the Hawkins rocks is their tendency to weather into rugged slopes with crest lines marked by pinnacles and spires. This characteristic topography is well exemplified on the upper part of Hawkins Mountain, where the formation is typically displayed.

The distribution of the Hawkins formation in the Snoqualmie quadrangle is similar to that of the Peshastin. Near the northeast corner there are three areas, of which the easternmost, extending into the Mount Stuart quadrangle, includes Hawkins Mountain and affords the most typical exposures. The areas of greenstone in the southeastern part of the quadrangle are referred to this formation from their resemblance to the rocks of the northern areas both in this and the Mount Stuart quadrangles. The small area of volcanic rock northwest of Clealum Lake has been mapped as belonging to the Hawkins formation, but, as will be indicated in a later paragraph, this reference is made with some doubt.

*Lithology.*—Hawkins Mountain is carved from a typical breccia composed of black, reddish, and greenish angular fragments cemented by a red and green matrix. At other localities the rocks composing this formation are dark green, either massive or brecciated, and at some places they are aphanitic, so that their igneous nature is not apparent.

Under the microscope, all these rocks show textures characteristic of lavas or other volcanic deposits. They have been considerably altered, the alteration resulting in the production of secondary minerals, such as hornblende, calcite, epidote, chlorite, and quartz. Yet the character of these alteration products, together with remnants of augite and plagioclase crystals, indicates approximately the original composition of the rocks and, together with abundant traces of ophitic texture, shows that the Hawkins lavas were prevailingly basaltic.

In the area near Clealum Lake, however, the rocks appear to have been more acid in composition. Here there is a green, spotted schist, which might have been derived from a basic tuff or lava, but above this are some porphyritic rocks of andesitic composition and a purple flow breccia, with phenocrysts of quartz and feldspar, which is rhyolitic or dacitic. Locally this material is sheared to a purple, slaty rock that shows no igneous features.

*Relations and age.*—The relations of this formation to the Easton schist are nowhere well exhibited, yet the lesser degree of metamorphism of the Hawkins greenstone is believed to indicate that it is of later ages than the Easton schist. There is a similar lack of direct evidence regarding the relative ages of the Hawkins and Peshastin formations. In the southeastern areas the two formations are intimately associated and so intricately folded together that their areal separation for the purpose of mapping is difficult. The boundaries drawn between them are only approximately correct, for the Peshastin areas include subordinate amounts of infolded Hawkins greenstone, while within the Hawkins areas there are masses of slate too small to be separated on the map. It is evident that such a complex will not yield very definite data as to the relative ages of its members.

On Sheep Mountain, in the Mount Stuart quadrangle, the two formations are in apparently conformable contact, with a low dip, and this relation was interpreted as proving the overlying Hawkins greenstone to be the younger rock. This determination seems to accord with the structural relations suggested by the general distribution of the two rocks in that quadrangle. Inasmuch, however, as all the exposures of these rocks consist of masses surrounded by the large peridotite intrusions, too much dependence should not be placed upon apparent relations. The areal distribution of the two rocks in the southern part of the Snoqualmie quadrangle also somewhat favors the belief that the Hawkins is the younger.

These two pre-Tertiary formations are provisionally assigned to the Carboniferous system. This assignment rests wholly upon their tentative correlation with somewhat similar rocks in other parts of the Pacific province which are known to be of Carboniferous age. The Hawkins and Peshastin formations, taken together, bear a striking resemblance to the "Cache Creek series" of British Columbia, a series which in its eastern development includes argillites with intercalated limestones, sandstones, and conglomerates, together with a large amount of contemporaneous greenstones. Moreover, slates and limestones with associated volcanics supposed to belong to that series extend southward into Washington along Okanogan Valley. Here the altered basic lavas and pyroclastics overlie the limestone and slate, and if the correlation is correct it implies that the Hawkins greenstone is younger than the Peshastin formation.

The relations at the occurrence near Clealum Lake, however, appear to be not in accord with the foregoing evidence, Here the volcanic rock underlies the calcareous shale and the two rest unconformably upon the Easton schist. It has been mentioned above, however, that the lava and breccia here exposed is partly rhyolitic and unlike the typical Hawkins greenstone, so that these may be some earlier volcanic rocks which lie at the base of the Peshastin formation and are distinct from the later eruptives which overlie the sediments. In view of all the evidence this is perhaps the most satisfactory explanation of the occurrence, but provisionally these pre-Tertiary volcanic rocks are mapped as belonging to the Hawkins formation.

PERIDOTITE AND SERPENTINE.

*General character and distribution.*—Peridotite is a dark-colored, granular, intrusive rock whose chief constituent is olivine. Olivine is very susceptible to alteration by hydration to the mineral serpentine, and when this change has proceeded far the altered peridotite is called serpentine. Naturally, rocks showing various degrees of serpentinization grade into one another and are not to be separated in areal mapping. In the Snoqualmie quadrangle there are intrusive masses which were originally peridotite but are now all serpentinized in some degree. An area of these rocks in the northeast corner of the quadrangle has an extent of several square miles, comprising the western portion of two belts that extend nearly across the Mount Stuart quadrangle. The peridotite also continues northward beyond the boundaries of the two quadrangles, covering an area in this region that probably exceeds 100 square miles. In the complex of metamorphic rocks in the southeast corner of the quadrangle there are dikes of serpentine that trend northwest-southeast, eight of which are large enough to be represented on the map.

*Relations.*—In the northern area the peridotite is plainly intrusive in the Peshastin and Hawkins formations, but is in turn intruded by the Mount Stuart granodiorite. These relations, of course, fix its relative age, while the fact that it is directly overlain by Swauk conglomerate with serpentine bowlders shows that it was denuded before the beginning of the Tertiary period. The dikes in the southern part of the quadrangle are likewise intrusive in the Peshastin and Hawkins formations, and although their relation to the granodiorite is not seen they probably belong to the same epoch of intrusion as the peridotite of the main area.

*Lithology.*—The peridotite as seen in the field shows great variability in color and in mode of weathering. Its erosion forms are of two contrasted types. In some localities, as along the south side of Fortune Creek, the rock is carved into bold and massive features and forms a talus of great angular blocks, while elsewhere, as upon the south side of Mount Hawkins, it forms smooth slopes and gently rounded summits covered with fine shingle. The color of the massive rock on fresh fractures is olive-green, but the weathered surfaces are usually dark green or reddish brown, while the shingly serpentine shows paler tints of bluish green.

These different modes of weathering express differences of internal structure. The rock showing the first type of topography has somewhat widely spaced joints, like those common in granite. The rock in which the second type is developed is divided by innumerable fissures, generally curved, intersecting and anastomosing irregularly. Where the fissures are most numerous the rock can be crumbled with the fingers into minute flakes, but embedded in the fissured material are abundant bowlder-like masses of firm and comparatively fresh rock. These masses are not well rounded, but are bounded by facets. Their surfaces are of green translucent serpentine and are usually striated and polished, so that they glisten in the sunlight.

The remarkable schistose structure which is developed in parts of the serpentine, and which appears also in similar rock found elsewhere, has been studied by observers in other fields and shown to be a result of the conversion of the original non-hydrous magnesian silicates, olivine and enstatite, to the hydrous magnesian silicate, serpentine. The process is hydrothermal in its nature, and may have been accomplished in this region by waters heated by the intrusion of the Mount Stuart granodiorite. In contrast to weathering, it is deep seated; and it is attended, moreover, by a considerable increase in volume. Inevitably, therefore, it developed enormous expansive stresses which produced the multitudinous fissures in the rock and the movement of fragments upon one another, shown by the characteristic slickensiding.

The fact that this alteration has proceeded much farther in some areas than in others closely adjacent is strongly impressed upon the observer in the field and calls for explanation. It is likely that before the serpentinization certain zones in the peridotite were fissured by orogenic agencies, and that, numerous passages for the circulating hot waters thus being provided, hydration was far more rapid and complete in these zones than elsewhere.

This extensive serpentinization occurred in pre-Tertiary time, for a peculiar phase of the Eocene basal conglomerate, to be described later, contains faceted and striated bowlders of serpentine exactly similar to those mentioned above as occurring upon the surface today. Inasmuch as these owe their form to shearing within the peridotite mass, this action and the hydration which caused it must have occurred before the accumulation at the Eocene surface of the bowlders and detritus forming the conglomerate.

The freshest specimens of this serpentine, which best show the original character of the rock, are obtained from the massive-jointed phase and the bowlder-like masses of the schistose phase. Such material consists mainly of a dark-green waxy-looking substance, in which are embedded a variable quantity of lighter olive-green crystals with bright satiny lustre. Locally the rock contains many irregular veinlets, composed of greenish-white silky fibers.

Microscopic examination shows that the rock was originally composed essentially of olivine with less enstatite, and that it therefore belongs to the variety saxonite. Remnants of both these minerals are found in the majority of slides, but both are largely replaced by characteristic varieties of serpentine, whose origin generally can be recognized even when the alteration is complete. That derived from olivine has the "mesh structure," and that derived from enstatite has the parallel-fibrous or "bastite structure," both familiar to students of petrography. The amorphous-looking waxy serpentine is of the first variety, and the satiny light-green crystals are chiefly of bastite.

A chemical analysis of the rock by Dr. Hillebrand, published in the Mount Stuart folio, shows a high percentage of magnesia, considerable iron oxide, and a comparatively low silica content. Alumina, lime, and the alkalies occur in very subordinate quantity. The percentage of water is notably high, being nearly 14 per cent.

QUARTZ-DIORITE.

*General character and occurrence.*—The quartz-diorite is lithologically distinct from any other rock that forms a considerable mass in this quadrangle. It is a gray granular rock, composed essentially of plagioclase, quartz, and hornblende, with a distinctly recognizable, though not very marked, secondary foliation. It occurs in but one area, which lies southeast of Easton. It is a resistant rock and for the most part is exposed on elevated ground. Its general characters can be studied fairly well in the field, although it is largely weathered at the surface. The marginal portions of the mass afford more satisfactory exposures of fresh rock than portions of its inner part.

*Relations and age.*—Many exposures show clearly that the quartz-diorite is intrusive into the Easton schist, the only pre-Tertiary formation with which it is in contact. East of Goat Peak it is clearly overlain by fine conglomerate of the Naches formation. There are no other data bearing upon its age, so that the period of its intrusion can be stated only as post-Easton and pre-Tertiary. It is well to note however that the rock may be older than the Peshastin slate. On the other hand, the possibility of correlating it with the Mount Stuart granodiorite might suggest itself to one familiar with that rock and its relations. The reasons for not making this correlation can be presented more clearly after the relation of the Mount Stuart granodiorite and the lithology of both rocks have been discussed.

The irruption of the quartz-diorite into the Easton schist has produced distinct metamorphism. On the south side of Yakima Valley the diorite is in contact with green schists, probably of igneous origin. In these rocks it has produced a coarser crystallization, but apparently no new minerals, the contact rocks being medium-grained hornblende-schists. The intruded rock contains apophyses of the intrusive, which have been sheared subsequently to the intrusion. This fact, combined with the basicity of the diorite near the contact and the chemical relationship of the two rocks, makes it sometimes difficult to determine precisely the position of the contact.

*Lithology.*—The rock forming most of the mass is a rather coarse-grained, light-gray quartz-diorite-gneiss. Its chief constituent is snow-white feldspar, but it contains considerable dark-green hornblende in large prisms having a rudely parallel arrangement. Biotite is absent and quartz is not abundant or conspicuous.

Near the irruptive contacts there is considerable variation from this principal type. Here occur phases very rich in hornblende, in which the gneissic banding is more conspicuous than in the lighter colored rock. There are also some rocks that appear to be sheared diorite-porphyries, showing rounded phenocrysts of feldspar in a schistose hornblendic base.

Under the microscope the feldspars are found to be mainly plagioclase, belonging for the most part to the species labradorite and andesine. Quartz is present in somewhat variable amount. Orthoclase is in all cases very subordinate and inconspicuous. The hornblende is of the common green variety.

The pronounced changes, both structural and mineralogical, which the rock has undergone, are seen better under the microscope than megascopically. The feldspars are partially altered to rather sharply bounded aggregates of secondary minerals, which consist mainly of zoisite, with sericitic mica and scapolite. The hornblende is somewhat altered to epidote and chlorite. The effects of dynamic metamorphism are strikingly illustrated in all the slides. The quartz shows very marked strain shadows, and there is much finely crushed feldspar, quartz, and hornblende between the larger grains. This fine interstitial material in some places appears to "flow" about large rounded individuals of feldspar, as in a typical "augen" gneiss. In the large plagioclase crystals the twin lamellæ are frequently curved and faulted and some of the feldspar shows an extremely minute polysynthetic twinning, which was probably induced by great pressure.

### MOUNT STUART GRANODIORITE.

*General character and occurrence.*—This rock is a granular intrusive, light gray in color and resembling granite in appearance. In the Mount Stuart quadrangle this granodiorite is very extensively developed and forms the peak for which the quadrangle and the formation are named. In the Snoqualmie quadrangle there are correlated with the type occurrence, on the basis of lithologic character and relations, one area near the northeast corner and several in the southeast quarter. In all these areas there are good exposures that clearly show the relations of the granodiorite to the contiguous rocks.

*Relations and age.*—The granodiorite of the mass from which Mount Stuart is carved is intrusive in all the other pre-Tertiary formations, and is overlain by the Eocene. The northern granodiorite area of the Snoqualmie quadrangle shows the same geologic relations, being clearly intrusive in the Hawkins greenstone and in the peridotite, and overlain at the eastern base of Goat Mountain by the Swauk formation, of Eocene age. The relations of the southern masses, which form a definite group and presumably belong to the same epoch of intrusion, define their age less narrowly. They are intrusive in various pre-Tertiary formations, while Eocene rhyolite and Miocene basalt lie upon the eroded surfaces of the masses with which they are in contact. This relation to the Tertiary rocks excludes a correlation with the Snoqualmie granodiorite, which is of Miocene or post-Miocene age. On the other hand, all the relations observed are in harmony with the reference of these masses to the Mount Stuart granodiorite.

The irruption of the granodiorite into the Peshastin clay slates east of the head of Little Creek has resulted in their metamorphism. The sedimentary rocks here have a sparkling crystalline appearance and contain little knots of prismatic form. When the rock is examined in thin section, it is seen to contain developed in it a large proportion of biotite and scattered porphyritic crystals of brownish-yellow andalusite.

*Lithology.*—By Lindgren's definition granodiorite is a granular rock consisting essentially of plagioclase, orthoclase, and quartz, with biotite or hornblende, or, as is usual, both; the plagioclase markedly, although in variable degree, predominating over orthoclase. This rock constitutes a well-defined type, probably the dominant one in the great batholiths of the western Cordilleras.

The masses mapped as Mount Stuart granodiorite are composed mainly of a rock corresponding in all respects to the type as defined, but comprise a small amount of more basic rocks, which are generally developed at the margins of the masses. Megascopic examination of the granodiorite shows that its chief constituent is white feldspar, which is accompanied by quartz in moderate quantity and by moderate and sensibly equal amounts of hornblende and biotite. The quartz is in rather small anhedral grains. Of the feldspar there can be recognized, megascopically, two varieties, (1) plagioclase, which occurs in partly idiomorphic individuals on which striations may be seen, and (2) unstriated orthoclase, which occupies interstices and in some places forms large poikilitic individuals that inclose plagioclase as well as hornblende and biotite, these also approaching idiomorphism. Titanite is an accessory that is visible megascopically in some specimens of the rock.

Under the microscope the additional common accessories—magnetite, apatite, and zircon—are visible in small quantities. The hornblende is of the common green variety, and the biotite is a deep greenish brown. The orthoclase is not perthitic. The plagioclase is mainly andesine, but includes considerable oligoclase.

The more basic modifications of this rock constitute a minor but noticeable proportion of the northern area. Locally the granodiorite passes into a rock that consists of the same minerals combined in different proportions, forming a quartz-mica-diorite. As compared with granodiorite this rock has less quartz, less orthoclase, and more of the ferromagnesian constituents, with the hornblende commonly in excess of the biotite. From granodiorite to quartz-mica-diorite there are, naturally, all gradations. In this graded series a rock in which the orthoclase is unessential may be assigned to diorite. A still more pronounced departure from the prevailing type is seen near the contact with the serpentine on Fortune Creek, where the intrusive rock is a quartz-diorite, free from biotite, in which the hornblende is pale green. Here it is somewhat foliated.

Granodiorite of this type prevails in all the southern areas except the one at the head of Little Creek, where the rock is rather darker and finer grained than typical granodiorite, with a notably large proportion of hornblende. Under the microscope the rock shows profound alteration, the feldspars especially being changed to clear mosaics. Biotite is an essential constituent, which differentiates this rock from the quartz-diorite already described.

*Relation to quartz-diorite.*—The grounds, lithologic in character, for separating the Mount Stuart granodiorite and the quartz-diorite just described may now be concisely indicated. On comparing the dominant types of the two the following important differences appear. First, in the granodiorite orthoclase, though subordinate to plagioclase, is an essential constituent, but it is not essential to the quartz-diorite. Second, biotite constantly occurs in considerable amount in the granodiorite, and even in most of the basic varieties of rock into which it locally passes, but is absent from the quartz-diorite. Third, the quartz-diorite is characterized throughout by a secondary foliation, indicating that it has been subjected to enormous pressure, but such foliation is not shown, except very locally, in the granodiorite of the masses that lie on either side of the quartz-diorite. These differences are so sharp that representative specimens of the rocks would never be confounded by a petrographer.

The geologic relations of the quartz-diorite and the granodiorite do not preclude their correlation, but on the other hand they do not preclude the hypothesis that the two rocks represent intrusions of widely different age. The granodiorite is intrusive in the Peshastin and Hawkins formations, but the quartz-diorite is found in contact only with the older Easton schist, and may be pre-Peshastin. The gneissic structure of the quartz-diorite supports this conjecture, for it may indicate that the rock participated to some extent in the great disturbances which the Easton schist suffered before the Peshastin formation was laid down.

## TERTIARY SYSTEM.

### EOCENE SERIES.

Eocene rocks occupy nearly one-half of the Snoqualmie quadrangle. In order of age, the formations comprised in the Eocene series are the Swauk, the Naches, the Kachess, the Teanaway, the Roslyn, and the Manastash. The Swauk, Roslyn, and Manastash consist of sedimentary rocks alone. The Naches formation includes sandstone and basalt. The Kachess and Teanaway are important volcanic formations, the first consisting chiefly of rhyolite, the second chiefly of basalt. Since the separation of sedimentary and igneous rocks so intimately connected is impracticable, these six formations will be described in the order of age.

#### SWAUK FORMATION.

*General character and distribution.*—The Swauk formation consists of sedimentary strata, chiefly sandstone, with some conglomerate and shale. These rocks are but slightly indurated and are not conspicuously altered. The beds commonly dip at moderate angles, although they are steeply tilted and are even vertical at a few localities. The formation is named for Swauk Creek, in the Mount Stuart quadrangle, where it is extensively exposed.

In the Snoqualmie quadrangle its development is confined to the northeast quarter, and for the most part to a single great area. The formation extends northward a few miles beyond this quadrangle and eastward across the Mount Stuart quadrangle into the valleys of Wenatchee and Columbia rivers. Its total area is therefore many times that included within the Snoqualmie quadrangle, and it is, in fact, one of the most extensive sedimentary formations in the Cascades.

*Relations.*—The relation of the Swauk to the pre-Tertiary rocks is one of strong unconformity. This relation is shown not only by the contrast of the metamorphism and high inclination of the older rocks on the one hand to the relatively slight alteration and open folding of the Eocene on the other, but by the fact that the basal conglomerates of the Swauk contain bowlders of serpentine and granodiorite, the more recent of the pre-Tertiary rocks.

The formation next younger than the Swauk is the Teanaway basalt, which generally overlies it, but in the northern part of the quadrangle it is overlain by the Keechelus, a volcanic formation of Miocene age. It is intruded by late Tertiary granodiorite and diorite.

The Eocene age of the formation has been determined from fossil leaves. The only known locality in the Snoqualmie quadrangle where these may be collected is on the ridge between the Middle Fork of the Teanaway and Clealum River. In the Mount Stuart quadrangle they are most abundant and best preserved in the vicinity of Liberty, on Swauk Creek. Dr. F. H. Knowlton has examined a collection of leaves from this locality and reports that they indicate that the Swauk formation is of Eocene age.

*Thickness.*—The thickness of the Swauk formation is widely different in different parts of its area. Perhaps the best exposure in the Snoqualmie quadrangle, and the one showing the greatest thickness, is seen on the east and southeast sides of Goat Mountain, whose base is traversed by the contact of the Swauk upon the pre-Tertiary rocks and whose summit is formed by Miocene volcanics. The total thickness of the Swauk exposed here is over 5000 feet. It is probable, however, that the volcanics were deposited after a portion of the Swauk was eroded, and its total original thickness at this locality must therefore have exceeded 5000 feet. East of Kachess Lake and north of Little Kachess the thickness of the formation exposed between the Easton schist and the Kachess rhyolite is much less. Since it may have been eroded here, as elsewhere, before the overlying volcanics were laid down it is difficult to determine how far this apparent thinning may be due to erosion. It is probable, however, in view of the absence of strong unconformity with the rhyolite, that no great volume of sediments was ever deposited at these localities, which were therefore, perhaps, near the final shore lines of the basin in which the Swauk was laid down.

*Lithology.*—The Swauk formation consists of conglomerate, sandstone, and shale. Of these rocks the most abundant is sandstone. The conglomerate is confined mostly to the lower part of the formation, and the shale is found interbedded with both conglomerates and sandstones.

The base of the formation is usually conglomeratic, although at a number of localities finer sediments rest directly on the older rocks. In the latter case the sandstone or shale is composed of material derived from the underlying rock; for example, greenish-yellow sandstone containing fragments of serpentine is found in contact with the serpentine. The coarsest phases of the basal conglomerates are likewise very local in their occurrence, and in their composition often bear a definite relation to the underlying formation. The serpentine conglomerate is composed of slickensided bowlders, such as occur abundantly in some parts of the peridotite areas, with a scarcely noticeable admixture of small pebbles of slate and other rocks, the whole cemented by finer detritus derived from the serpentine. Such a phase of the basal conglomerate is found in the valley of the North Fork of Clealum River, where the conglomerate is associated with a shale composed of serpentine and magnetite, representing residual material from the rock directly beneath. These local conglomerates mark the position of shallow bays, the sediments in which were derived from the region immediately bordering the shore, and pebbles of foreign material are therefore rarely found in them.

The sandstone of the Swauk formation is generally a light-gray arkose, which may be seen megascopically to consist mainly of quartz, feldspar, and mica. It is usually distinctly bedded, and cross-bedding is sometimes visible. The prevailing medium-grained sandstone is interstratified with beds of shale and conglomerate. The shale is usually rather dark and carbonaceous, and frequently contains well-preserved leaf impressions.

#### NACHES FORMATION.

*General character and distribution.*—The Naches formation is composed of interbedded sandstone and basalt, the sedimentary rock predominating in the lower, and the volcanic in the upper portion. The formation is named for the river in whose basin it is most extensively developed. The main area, which has a northwest-southeast trend, extends along the northeast side of the Naches basin and continues to Yakima Valley. The only other important areas lie just north of the principal one. No occurrences of the Naches formation are known outside of the Snoqualmie quadrangle.

*Relations and age.*—The base of the Naches formation is exposed at only a few places, where, like the Swauk, it rests directly on highly metamorphosed pre-Tertiary rocks with marked unconformity. This contact is generally covered, however, by the Kachess rhyolite, a rock that bears a peculiar relation to the Naches and is in part contemporaneous with it, so that a heavy flow of Kachess rhyolite is interbedded with the Naches sandstone and basalt. The upper surface of the Naches formation, where it is not in contact with the Kachess, is overlain unconformably by the Keechelus volcanics. The strata of the Naches have been thrown into open folds and usually dip at angles ranging from 30° to 60°.

Since the Naches and Swauk formations are not found in juxtaposition, there is a lack of direct stratigraphic evidence regarding their relative ages. It is noteworthy, however, that they have similar relations to both the older and the later rocks, a fact which suggests that they may be nearly contemporaneous. The evidence afforded by fossil plants confirms this view. The shales of the Naches formation have at two localities yielded fossil leaves, which have been examined by Dr. F. H. Knowlton, who comments upon them as follows:

The plants . . . . belong to unpublished species of *Juglans* and *Ficus* and are the same as those found at the locality west of Liberty [in the Mount Stuart quadrangle]; hence, I assume, are to be referred to the Swauk. The species of *Juglans* is distinct and unmistakable, and neither this nor the *Ficus* have before appeared outside of the Liberty locality.

Although similar relations and similar fauna indicate the contemporaneity of the Swauk and Naches formations, evidence now to be stated seems to justify mapping them as distinct units. According to the hypothesis on which the separation is based, the area of pre-Tertiary rocks extending southeastward from Easton once formed a divide between basins on the north and on the south. In the basin to the north, sediments were deposited without admixture of basaltic material, but in the area south of this ridge basalt flows were intercalated with beds of sand.

West of the Kachess lakes the Swauk sandstone is overlain by volcanic formations, but in its southwesternmost exposures the Swauk formation is notably thinner than elsewhere. In a similar way the Naches formation rapidly thins eastward as it approaches the area of pre-Tertiary schist. The thin bed of sandstone exposed immediately west of Easton connects southward with the main body of Naches sandstone, and this connection is interpreted as showing that the two basins may have been joined during the later part of the Swauk-Naches epoch. Inasmuch as the later formations overlap both the Swauk and Naches on the west, it is possible that a mile or two farther west the connection between the basins was made earlier. However, all that is known regarding the lithologic character and areal relations of the two formations favors the view that they were deposited in basins that were separated during the greater part of the epoch and that the eruption of basalt was confined to the southern basin until the close of this epoch.

*Thickness.*—No very accurate estimate of the thickness of the Naches formation is possible. The maximum is given by a section across the folded strata north of Bear Creek, which indicates a thickness of about 4000 feet. Some allowance should be made, perhaps, for repetition due to structural details not seen, but, on the other hand, some of the Naches formation probably had been removed by erosion before the Keechelus andesites covered it. To the northeast the formation thins out rapidly as the principal mass of Easton schist is approached. There is, however, no evidence that the Naches was extensively eroded before the overlying Kachess rhyolite was poured out, and, indeed, the eruption of this lava began well back in the period of Naches sedimentation. The thinning, therefore, probably indicates not greater erosion in this vicinity but proximity to the shore line of the basin in which the formation was deposited.

*Lithology.*—The Naches formation is composed of interbedded sedimentary and volcanic rocks, the latter of basaltic character. Its lower portion consists principally of sandstone, with which is intercalated a rather subordinate amount of basaltic material representing contemporaneous extrusions. The basalt, however, becomes increasingly important in the higher beds, and is dominant in the uppermost part of the formation.

The sandstone, which is perhaps the most important member of the Naches formation, is similar to the typical sandstone of the Swauk. It is rather light gray, weathering in tawny hues, and the grains, which are not well rounded, are of quartz and feldspar with a subordinate quantity of schistose and slaty material. The rock generally shows distinct bedding, and at some places cross-bedding, although at other localities it is massive and breaks down in great blocks.

The shales, which are interbedded with the sandstone in rather subordinate quantity, are olive to brownish black in color, the darker phases being carbonaceous. These fine-grained beds have yielded the fossil leaves already described.



No conglomerate was seen in the Naches formation except at one point on the southwest side of the ridge of pre-Tertiary rocks in the southeast quarter, where a thin bed of conglomerate containing pebbles of slate and quartz separates the Kachess rhyolite from the Peshastin slate.

The basaltic material occurs in three forms—intrusive dikes and sheets, massive flows, and fragmental beds, or tuffs. Of these three, the flows are the most important.

The basalt of the intrusions and flows is grayish black or dark gray on fresh fracture. It exhibits coarse phases, in which the crystalline texture is evident, and finer ones which appear aphanitic. The flows may be generally distinguished by their highly vesicular upper surfaces, the rock of the intrusive bodies being, on the contrary, almost entirely compact, though sometimes slightly vesicular near the contacts with the sediments. The fragmental volcanics are dark olive-green tuffs, composed of angular, mostly vesicular fragments. They are much more decomposed than the massive basalts, and have a dull, earthy appearance. Their green color is due to the presence of abundant iron-bearing secondary silicates.

The microscopic petrography of the Naches basalt may be omitted here, since the rock is entirely similar to the Teanaway basalt, which will be discussed in greater detail.

### KACHESS RHYOLITE.

*General character and occurrence.*—The Kachess rhyolite is named for Kachess Lake, on whose northeast side it is well exposed. The formation comprises several flows of acidic lava. Throughout a large part of its extent it is separated by interbedded sandstones and basalts into several distinct rhyolitic sheets, but elsewhere these sheets merge together and, owing to their lithologic similarity, can not be distinguished. They must therefore be mapped together as one formation.

The Kachess rhyolite has been observed only in the Snoqualmie quadrangle, where it is developed mainly within a zone extending from the southeast corner northwestward somewhat beyond Little Kachess Lake. An isolated area of rhyolite east of Clealum River is correlated with the Kachess, as well as a larger area at the head of Clealum Lake.

The formation is composed chiefly of rhyolite, which, owing to its hardness and the poor soil it furnishes, is carved into rugged forms that are but scantily covered with vegetation. The rhyolite is in general of lighter color than any other rock of the region, being commonly a creamy white or light yellow. It usually has a platy parting, which causes it to disintegrate into thin slabs that form characteristic talus on the steep slopes. Excellent exposures showing these characteristics are found in the basins of Quartz Creek and Little Creek, and an easily accessible one lies just south of the railroad a short distance west of Easton. A thin bed of brick-red, decomposed rock, apparently andesite, is intercalated with the rhyolite in the area between the two forks of Quartz Creek. A thicker bed of andesite constitutes the base of the formation west of the head of Clealum Lake and is poorly exposed on the eastern side of Kachess Lake. This rock is of light greenish-gray color and is not conspicuously different from the rhyolite.

*Relations.*—The relations of the Kachess to other formations are peculiar. In the southern part of the quadrangle the Kachess rhyolite forms three main bodies; one interbedded with the Naches formation, one between the Naches and the Teanaway basalt, and one above the southern extension of the Teanaway basalt. In the northern part there is one small mass, just south of Howson Creek, interbedded with the Swauk, a main body of rhyolite between the Swauk and Teanaway, and a little rhyolite, in masses too small to map, locally interbedded with the Teanaway basalt. In the southern part of the quadrangle the rhyolite flows extend eastward beyond the limits of the Naches formation and thus lie in places directly upon the pre-Tertiary rocks, these relations indicating transgression by the lava flows beyond the shore line of the Naches basin.

The episode of eruptions which the Kachess rhyolite represents began at some time near the middle of the epoch in which the Naches and Swauk formations were deposited. It continued during the later half of the Naches-Swauk epoch and for some time after its close, and persisted during the early stages of the eruption of the Teanaway basalt. The eruptions which occurred during the deposition of the early Eocene sediments were confined almost entirely to the Naches basin. Later, the rhyolite flows extended farther northward and covered the western part of the Swauk beds as well as the Naches to a considerable depth.

*Thickness.*—The rhyolite shows a maximum thickness of about 4000 feet, an amount which is derived from measurement of sections across the main area and which, being the sum of the maxima for all the sheets, is greater than the thickness actually accumulated at any particular point. The rhyolite thins out in some places, however, with striking abruptness, as is illustrated, for example, by the difference in its thickness on the opposite sides of the ridge east of Kachess Lake, as well as by the flow intercalated with the Naches strata, which thins out abruptly to the west of Quartz Creek. This pronounced variability in thickness is probably due to the viscosity of the lava and not to the fact that the rhyolite was poured out upon a very uneven surface or that subsequent to its extrusion it was deeply eroded. The variations in thickness are indicated in the structure sections as definitely as the scale will permit.

*Petrography.*—In addition to the general characters already noted the details of constitution and texture of these rhyolites may be further described. Although prevailingly creamy white or gray, they sometimes show pale hues of green, purple, pink, or brown. A delicate banding, due to alternation of lighter and darker layers, is common. Their texture is usually stony and in some places completely aphanitic, but generally small phenocrysts of feldspar, sometimes accompanied by quartz, are visible. Rather exceptional are glassy phases, either gray or lustrous coal-black in color. Spherulitic structures are common, the spherulites being small and inconspicuous in some specimens, but in certain exposures on Quartz Creek attaining a diameter of 2 or 3 inches.

Examined microscopically, the rhyolites exhibit a notably constant and simple composition. Their essential constituents are sodic plagioclase, quartz, and orthoclase, accompanied in some cases by glass. Accessories are magnetite, apatite, and zircon, in small quantities. Ferromagnesian constituents are almost completely absent. Considerable alteration is shown in all the specimens, giving rise to kaolin, sericite, and sometimes calcite and a little chloritic matter.

Texturally the majority of specimens are porphyritic and the phenocrysts are mainly of sodic oligoclase or albite. Porphyritic quartz is rarely present, and phenocrysts of orthoclase are not common. The groundmasses, which consist of plagioclase, quartz, and orthoclase, exhibit an interesting variety of textures, of which the leading types are as follows:

(1) *Glassy.* Consisting mainly of glass, with various kinds of crystallites. (2) *Felsitic.* Consisting of minute, irregular grains of feldspar and quartz. This texture is frequently so fine grained that the minerals are not readily distinguished, and there may in some cases be a little glass. (3) *Fibrous.* Feldspar occurs in minute fibrous crystals which may form aggregates of several kinds as (*a*) *spherulitic*, radiating from a point and approximately spherical; (*b*) *longulitic*, radiating from a line and approximately ellipsoidal; (*c*) *sheaf-like*, forming bundles of nearly parallel fibers, divergent at the ends; (*d*) confused irregular aggregates. The groundmasses are in no case composed entirely of fibres, for between the fibrous aggregates there is always some interstitial matter which may be microgranular, vitreous, or micropegmatitic. Some phenocrysts of quartz and feldspar have fibrous borders, of which the main portion extinguishes with the nucleus. (4) *Micropegmatitic.* Composed of intergrown quartz and alkali feldspar. With the micropegmatite may be associated microgranular or fibrous material. (5) *Micropoikilitic.* Minute laths of feldspar lying in various directions are inclosed in much larger irregular grains of quartz. . . .

The nonporphyritic rhyolites exhibit felsitic, glassy, and spherulitic textures, the best development of the last being shown in nonporphyritic specimens. Glassy textures are noticeably rare in these rhyolites. Probably part of the rocks were originally glassy but have undergone devitrification, and, in some specimens, there are clear indications of such a change. It is probable, however, on the other hand, that much of the material solidified in a holocrystalline condition, indicating that it was partly extruded in great flows which cooled slowly.

The chemical composition of a typical specimen is shown in the following analysis by Mr. George Steiger of the United States Geological Survey. The specimen is white in the portion from which the material was taken for analysis, but in other parts is much stained with limonite. Microscopically it is seen to bear small phenocrysts of albite in a groundmass of quartz and alkali feldspar which are mostly in micropegmatitic intergrowth. Unimportant accessories are magnetite, zircon, and apatite. The rock is slightly weathered, the feldspars being somewhat clouded with kaolin and sericite, and limonite occurring in miarolitic cavities.

*Analysis of Kachess rhyolite from near Easton.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 76.17 | $TiO_2$ | .20 |
| $Al_2O_3$ | 12.32 | $ZrO_2$ | .03 |
| $Fe_2O_3$ | 1.47 | $CO_2$ | none. |
| FeO | .20 | $P_2O_5$ | .04 |
| MgO | none. | $SO_3$ | none. |
| CaO | .17 | S | none. |
| $Na_2O$ | 3.94 | NiO | none. |
| $K_2O$ | 4.27 | MnO | none. |
| $H_2O-$ | .23 | BaO | .10 |
| $H_2O+$ | .79 | SrO | not looked for. |
| | | | 99.93 |

The rock is thus composed essentially of silica, alumina, and the alkalies. The considerable amount of ferric oxide is probably for the most part combined with water in limonite and may be largely of extraneous origin. The essential mineralogical composition of the rock as calculated from the analysis is as follows:

*Mineralogical composition of Kachess rhyolite.*

| | | | |
|---|---|---|---|
| Quartz | 35.8 | Ilmenite | .5 |
| Orthoclase | 25.6 | Hematite | 1.4 |
| Albite | 33.6 | Water | 1.0 |
| Anorthite | 1.4 | Excess* of $Al_2O_3$ | .6 |
| | | | 99.9 |

*The excess of alumina probably is in the form of kaolin.

According to the quantitative classification, the rock is a liparose.

The andesite in the areas northwest of Clealum Lake and east of Kachess Lake weathers almost white, but on fresh fracture it is light olive or sage green. It is seen megascopically to consist mainly of an aphanitic groundmass in which are embedded, rather sparingly, small phenocrysts of white feldspar. Microscopically these feldspars are found to be much altered plagioclase. The rock contains pseudomorphs of quartz, chlorite, and calcite that seem to represent phenocrysts of a ferromagnesian mineral. The groundmass has the typical andesitic texture and is impregnated with a secondary chloritic mineral. The rock is thus plainly andesitic, but it can hardly be determined more specifically.

### TEANAWAY BASALT.

*Occurrence and general character.*—The Teanaway basalt has been fully described in the Mount Stuart folio. It was named for the river in whose basin it is most extensively developed. It extends from this river basin westward into the Snoqualmie quadrangle, where there are several large areas, chiefly in the central and northern parts, with some small ones in the southern part.

Although the formation is composed predominantly of basalt, it comprises also some andesite, rhyolite, sandstone, and conglomerate. The basalt and andesite are mainly massive, but partly fragmental. The massive basalt is dark gray or, in some places, greenish to brownish, hard, and resistant to erosion so that it is well exposed and gives rise to prominent ridges with steep slopes sparingly clothed with vegetation. It generally becomes somewhat reddish on weathered surfaces, and decomposes to a rust-red soil. It is everywhere much jointed, in some places irregularly, in others into horizontal plates, but comparatively rarely into the regular vertical columns so characteristic of basalt in general. The andesite is of similar general appearance but is distinguishable chiefly by porphyritic texture, not seen in the basalt. The fragmental rocks are made up of angular pieces of lava, consolidated by secondary cementation into masses more or less firm, the coarser material into agglomerates, and the finer into tuffs. The sedimentary rocks, with an exception to be noted in its place, are arkose sandstones, quite distinct in composition from the basalt tuffs. A small amount of rhyolite tuff, petrographically similar and probably equivalent in age to some of the upper Kachess rhyolite, occurs locally, but in insignificant masses, not large enough to be represented on the scale of the map.

The sections of the Teanaway basalt differ from point to point. No attempt will be made to trace out these variations in detail, but the general character of several exposures will be briefly indicated. The northernmost extensive section, at the head of Clealum River, shows considerable green indurated tuff and breccia in its central part, with basalt above and below, interbedded with a little arkose sandstone. The sections on either side of Clealum Lake have at the very base a peculiar conglomerate consisting of pebbles of Kachess rocks embedded in a matrix composed of ordinary sand and basaltic tuff, and this rock is overlain by several hundred feet of tuff. The tuffs on the eastern side of the valley are green and red, while those on the western side are green. Above the tuffs lie several thousand feet of rocks that are nearly all lava. An excellent and characteristic exposure of the upper part of the great body of the formation appears on the face of Easton Mountain, and this section consists chiefly of lava. The mass interbedded with the Kachess rhyolite south of Yakima Valley is all basalt. The section along Guye Creek contains several beds of leaf-bearing shale and sandstone. This carbonaceous rock has been prospected for coal, but these beds represent simply lenses of sandy mud, of very limited extent, that were deposited in depressions in lava sheets and covered by the later flows.

*Relations and age.*—The Eocene age of the Teanaway basalt is at once shown by the fact that it is underlain by the Swauk and overlain by the Roslyn, sedimentary formations that bear Eocene flora. The relations of the basalt to the rocks beneath show that its outpouring was immediately preceded by a period of general erosion. Evidence of this is afforded in the Mount Stuart quadrangle by the unevenness of the surface of the underlying Swauk sandstone. In the Snoqualmie quadrangle the unconformity at the base of the Teanaway may be most plainly observed at a point northwest of Clealum Lake, where the formation overlaps the beveled edge of the Kachess rhyolite, from which it is separated by a tuff-conglomerate containing pebbles of the rhyolite. As the time interval between the Swauk and the Teanaway was sufficient not only for this extensive erosion but also for the outpouring of much of the Kachess rhyolite, it must have been very considerable. On the other hand, there is no evidence of a long interval between the Teanaway and the overlying Roslyn sandstone.

Additional evidence regarding the age of the basalt is given by remnants of plants collected on Gale Creek from a bed of sandstone intercalated with the lava flows, and this flora is valuable chiefly as suggesting correlations with formations on the west side of the Cascades. These plant remains have been submitted to Dr. Knowlton, who has reported upon them as follows:

This is a collection consisting of a dozen or more pieces of matrix showing numerous impressions. I note the following genera: *Populus* sp., *Ficus* sp., *Pterospermites* sp., *Ulmus* (?) sp.

I do not recognize any of the species in this collection. The genera are sufficiently clear, but the species are new and are unlike any heretofore obtained. The forms are not similar to those found in either the Roslyn or the Swauk, but appear to find their greatest affinity with material from the west side of the Cascades, at Carbonado and vicinity. For example, no Eocene species of *Populus* has heretofore been found east of the Cascades, while several forms have been found about Carbonado, South Prairie Creek, and Franklin. The species of *Ulmus* is similar to elm leaves from vein 12 at Franklin, but I am not certain that it is absolutely identical.

*Thickness.*—The section that would seem to give most nearly the maximum original thickness of the Teanaway basalt is the one along the ridge east of Clealum Lake, where the thickness exposed between the Swauk and Roslyn formations is about 6000 feet. On the northern border of the quadrangle there is a section of Teanaway rocks, dipping almost vertically, which measures about the same. In the southern part of the quadrangle the Teanaway basalt interbedded with the Kachess rhyolite is only about 500 feet thick. These figures show that the basalt had its maximum development in the northern areas and was relatively thin in its southern extension.

*Petrography.*—Of the rocks constituting the Teanaway formation it seems necessary to give further description of only the dominant lava—the basalt—and the less important andesite.

The basalts are mostly dark gray to black on fresh fracture, usually with a tinge of green. Generally they are fine and even grained, but with crystalline texture more or less developed. Occasionally, however, there occurs a little pitch-black glass, which is sometimes so etched on the weathered surface as to show the existence of alternating layers more or less susceptible to decomposition.

Microscopic study shows that the chief constituent of the massive basalt is plagioclase, mainly labradorite. Augite is second in abundance; its color in thin section is generally pale brown, sometimes with a tinge of violet indicating that it contains titanium. The accessories are abundant magnetite and some apatite. In addition to these minerals, which are invariably present, the rock may contain a little hypersthene. Olivine has not been found in the specimens of Teanaway basalt from this quadrangle, but its original presence in much of the rock is shown by pseudomorphs of characteristic outline. Glass is commonly present, in some specimens in considerable amount, and in many specimens where no glass is found there are indications that it was originally present but has undergone devitrification or replacement.

The textures of the basalts are varied, the most common being the intersertal. Typical ophitic texture has not been noted, although the augite often incloses the plagioclase, which occurs in lath-shaped crystals or microlites. Fluidal arrangement of the feldspar laths is seen in some specimens. A decidedly porphyritic structure is not common, but in some specimens there are phenocrysts of feldspar, augite, and olivine.

An exceptional phase is a quartz-basalt found near the head of the West Fork of Clealum River. This rock contains a few phenocrysts of plagioclase and augite, with possibly some of olivine (replaced by chlorite or serpentine), and corroded grains of quartz surrounded, as in most quartz-basalts, by wreaths of glass and augite. A similar rock occurs in this formation in the eastern part of the Mount Stuart quadrangle.

The Teanaway basalt in general shows much alteration. Of all the minerals, the feldspars show the least decomposition, but are generally somewhat altered, giving rise to kaolin, sericitic mica, and at some places scapolite and zoisite. The ferromagnesian minerals are attacked in different degrees. While the olivine has entirely disappeared, and the hypersthene when present is more or less altered, the augite is often perfectly fresh. The most abundant and most characteristic secondary product derived from the ferromagnesian minerals is a serpentinoid substance of deep olive-green or reddish-brown color and high double refraction, which appears to be iddingsite. Other secondary minerals occurring in the basalt are calcite, uralitic hornblende, epidote, chlorite, and serpentine.

Analysis of a typical specimen of the Teanaway basalt given in folio 106 shows that it belongs, according to the quantitative classification, to vaalose.

The andesites occurring as flows intercalated with the basalt sheets belong to the pyroxene-bearing varieties. Megascopically they are porphyritic rocks showing phenocrysts of feldspar and less conspicuous ones of pyroxene in a dark greenish-gray to black, fine-grained groundmass.

Under the microscope the feldspar phenocrysts are seen to be chiefly labradorite. The phenocrysts of pyroxene include augite and hypersthene, the augite generally fresh, but the hypersthene largely or even completely replaced by the olive-green to reddish micaceous material to which hypersthene so frequently alters. The groundmass contains a second generation of plagioclase and the pyroxenes, together with a little finely granular paste, apparently of quartz and feldspar, and a good deal of the secondary mineral already mentioned, in a finely divided state. A little glass is in some places present. The usual accessories, magnetite and apatite, occur.

### BASIC DIKES AND SHEETS.

*Occurrence.*—The Swauk sandstone and the older rocks are cut by a great number of basic dikes of dark, reddish-weathering rock closely resembling the Teanaway basalt. These dikes extend upward to the Teanaway basalt and in some favorable localities can actually be seen to connect with the lower lava flows of that formation. They evidently represent the conduits through which the lava reached the surface, and show plainly that the Teanaway basalt was erupted through many fissures rather than from a great crater. They are most abundant northeast and northwest of the head of Clealum Lake, being thus, in the Snoqualmie as in the Mount Stuart quadrangle, mainly confined to the belt of Swauk sandstone just beneath the main body of Teanaway basalt. In a part of the Teanaway basin they are almost incredibly numerous, and over considerable areas actually occupy more of the surface than the sedimentary rock which they intrude.

The great majority of the dikes form a definite system, with a trend a little north of east. The dip is almost constantly steep to the west. In addition to the nearly vertical dikes there are a few sheets injected between strata, of which only one, which is situated east of Clealum River above the lake, is large enough to be mapped. In width the dikes vary from a few hundred feet to a few inches. They influence the details of relief considerably, especially on ridge tops, for on slopes the mantle of waste obscures the effects of differential erosion. In a great majority of cases the dikes weather out more prominently than the sandstone on either side, but occasionally the reverse is true, and the position of a dike is marked by a notch in the crest line. The projecting dikes are being reduced mainly by mechanical disintegration and break down into angular rubble which spreads over the sandstone. Therefore in places where the dikes are most crowded the intervening sedimentary rock is completely covered with basalt fragments, so that a general view of a large area might lead to the conclusion that the underlying rock there was all basalt.

The tracing of these dikes is often difficult and their representation on the map is necessarily inadequate. The dikes are generally well exposed on ridge tops and can there be mapped completely, but many dikes seen on the crests can not be traced down the slopes because they are there covered by waste. This explains why so many more dikes are mapped on the crests than on the slopes. Again, in the area where the dikes are most abundant, the task of tracing them is made extremely difficult by the merging of the débris from contiguous dikes, and even where all the dikes are traceable they can not all be represented, on the scale of the map. In this area, then, only the larger and better-exposed dikes are mapped.

*Petrography.*—Petrographically, these dike rocks show a distinct relationship to the Teanaway basalt. In texture they are generally holocrystalline and either porphyritic or typically diabasic. The texture is usually coarser in the wider dikes, but sometimes other factors enter, so that no constant relation exists between the texture and the width of the dike. The porphyritic rocks, which are of subordinate importance, contain abundant phenocrysts of plagioclase and pyroxene and might be classified either as basic augite-andesite-porphyries or as diabase-porphyries.

Microscopically, the plagioclase crystals are found to be mainly labradorite, but they generally show zonal structure and have rims that are more sodic in composition. The pyroxene is chiefly augite, with which hypersthene is in places intergrown; in rare instances the rhombic pyroxene is more abundant than the monoclinic. In the porphyries the groundmasses are of plagioclase and pyroxene, often with ophitic texture. In the ophitic diabases the chief constituents are labradorite and augite. Both hypersthene and olivine may occur in them, together or separately. Greenish-brown hornblende, apparently original, is here and there present in small amounts. Quartz is an essential constituent of a large proportion of the specimens, including many of those that contain olivine. It forms anhedra and is generally intergrown with orthoclase in interstitial masses of micropegmatite. These basic dike rocks are considerably altered, but to a less extent than the surface lavas of the same age. Their most characteristic secondary constituent is iddingsite or a related mineral, which is derived both from olivine and from hypersthene.

A chemical analysis of a typical basic dike rock from the North Fork of Teanaway River has been published in the Mount Stuart folio. The rock is a quartz-bearing olivine diabase containing some hornblende. It is more siliceous than the Teanaway basalt analyzed, and according to the quantitative system it is classified as tonalose. Notwithstanding this difference, however, the basalt and diabase show marked mineralogical and chemical relationship.

### ROSLYN FORMATION.

*Occurrence and general character.*—The Roslyn formation consists of sandstone and shale and contains workable seams of coal which will be described under the heading "Economic geology." Its distribution, so far as known, is restricted to a single basin, lying chiefly in the Mount Stuart quadrangle. The two rather small areas in the Snoqualmie quadrangle form the westernmost part of this basin.

The formation affords numerous exposures, none of them very extensive or conspicuous, since the rocks composing it are soft and generally become covered with soil. Good sections of parts of it are exposed in the coal mines. The name of the formation is that of the principal coal mine developed in it and is also the name of a mining town situated immediately east of this quadrangle. The thickness of the Roslyn formation at a locality just east of the quadrangle, where it reaches its maximum, is approximately 3500 feet.

*Relations and age.*—The Roslyn formation is found in contact only with Quaternary deposits and the Teanaway basalt. It overlies the basalt without observed angular unconformity or distinct evidence of an erosion interval.

The Eocene age of the Roslyn formation has been determined by Dr. F. H. Knowlton from collections of fossil plants made at the Roslyn mine, just east of the edge of this quadrangle. The Roslyn and Swauk floras have no species in common, which is believed to indicate that the plants that grew while the Swauk sandstones were accumulating did not survive to the time in which the Roslyn sandstone was deposited. The conclusions formed from the study of the flora are in accord with the stratigraphic relations already noted. The unconformity between the Swauk formation and the Teanaway basalt indicates a time interval, while the eruption of the basaltic lavas over this region furnishes a further cause for the nonsurvival of species belonging to the Swauk flora and for their absence from the Roslyn flora.

*Lithology.*—The greater part of the Roslyn formation consists of massive sandstone, rather more yellowish in color than the typical Swauk sandstone. With the sandstone occur fine-grained clay shales and coarser arenaceous phases. The stratification of the sandstone is not strongly marked as a rule, and irregularities of bedding and local unconformities can be seen at some localities. Conglomeratic beds are not common, pebble bands in the sandstone being the coarsest material usually found. Although the Roslyn formation appears to overlie conformably the Teanaway basalt, the basal sediments are distinct in essential composition from the basaltic tuffs. The sandstone occurring near the base is a siliceous arkose but is often darker than higher beds, by reason, possibly, of slight admixture of material derived from the basalt series. The portion of the formation containing coal beds will be described more particularly under the heading "Economic geology."

### MANASTASH FORMATION.

*Occurrence and relations.*—The youngest of the Eocene sedimentary formations occurs on the headwaters of Manastash Creek, for which it is named, and on Taneum Creek. At most places where it is seen the Manastash sandstone rests directly upon the Easton schist, and at some places it is accompanied by a well-developed basal conglomerate. On both forks of Taneum Creek the sandstone is exposed beneath the Yakima basalt and the Taneum andesite, both of Miocene age, and in the more northern of these two occurrences, the sandstone rests upon the quartz-diorite. In all of these small areas the Manastash sandstone is poorly exposed, so that the knowledge of the formation has been gained chiefly in the larger area farther east, in the Mount Stuart quadrangle.

*Lithology.*—The Manastash, like the other Eocene sedimentary formations, comprises sandstones and shales. East of Frost Mountain, a peak in the Mount Stuart quadrangle, between the south forks of Taneum and Manastash creeks, the sandstones are well exposed and are massive and quartzose with pebble bands, white quartz being most abundant among the pebbles. The shale is fine grained and in the Mount Stuart quadrangle is associated with seams of bone and impure coal. No coaly beds were seen within the Snoqualmie quadrangle, although the lower area of the Manastash formation on North Fork of Taneum Creek is the western extension of the sandstone in which a coal seam has been prospected at a point in the Mount Stuart quadrangle about 2 miles east of its western boundary. The small area north of B. M. 5695 contains some reddish, decomposed andesitic tuff.

*Age.*—The age of the Manastash formation has been determined chiefly from a small collection of fossil plants obtained near the head of North Fork of Manastash Creek, which indicate that it is upper Eocene, probably later than the Roslyn.

### MIOCENE SERIES.

The Miocene rocks of the Snoqualmie quadrangle are nearly all included in one great area, which occupies most of the western half and extends to the southeastern corner. They are almost entirely igneous and mostly volcanic, including the Taneum andesite, the Guye formation (sediments with some basalt and rhyolite), the Yakima basalt and associated diabase, the Keechelus volcanic series (mainly andesitic), the pyroxene-diorite associated with this series, the Ellensburg formation (composed of volcanic sediments), and the intrusive Snoqualmie granodiorite. The order in which these formations have been mentioned is thought to be approximately that of age, but our knowledge of their succession is incomplete. The Guye formation is not found in contact with the other Miocene sedimentary formation, and the paleontological evidence upon which it is determined as Miocene does not fix its age precisely. The Keechelus series includes some very fresh lavas that may be of Pliocene or possibly Quaternary age. The Snoqualmie granodiorite is intrusive in and therefore younger than the Guye strata, but no other precise data have been obtained regarding its age.

### TANEUM ANDESITE.

*Occurrence and relations.*—In the southeastern portion of the quadrangle, in the drainage basins of Taneum Creek and Little Creek, several square miles of andesitic rocks are exposed. These lie stratigraphically between the Manastash sandstone and the Yakima basalt, and are, therefore, probably of early Miocene age. To distinguish them from other andesites in this region that are of similar composition but different age, these rocks have been called the Taneum andesite, from the creek in whose basin they are chiefly found. This volcanic formation has only a very local occurrence. It occupies a small area in the Mount Stuart quadrangle, but is not known outside this immediate vicinity. Some of the best exposures of the formation occur along the south side of the North Fork of Taneum Creek. On Frost Mountain the lava is less than 300 feet thick, but in the Taneum basin it may measure several times that thickness.

*Lithology.*—The Taneum andesite comprises tuffs and tuff-breccias as well as lavas. These rocks vary greatly in megascopic appearance. The lavas in the main area are generally rather light colored, exhibiting shades of gray, brown, pink, and green, and are in large part rough textured and porous. The small mass north of the Manastash drainage area is a compact, dark-green rock showing a few phenocrysts of feldspar, and is not very readily distinguished from the overlying basalt. A very little rhyolitic material is also associated with the andesite.

By microscopic examination it is found that notwithstanding its variable appearance, most of the rock of this formation belongs to the single species hypersthene-andesite. The phenocrysts are of zoned plagioclase and a somewhat decomposed ferromagnesian mineral, which in some slides has been entirely replaced. The plagioclase is mostly sodic labradorite. The principal original ferromagnesian constituent is hypersthene. When this is present, it is always partly altered to a lamellar mineral of high double refraction, which seems to be iddingsite. In many specimens the original ferromagnesian mineral is not found, but is represented by iddingsite pseudomorphs with the characteristic forms of hypersthene.

### GUYE FORMATION.

*General character and occurrence.*—The Guye formation consists of detrital rocks with some chert and limestone and interbedded basalts and rhyolites. It occurs, so far as is known, only in the northwest quarter of the Snoqualmie quadrangle, where it is rather extensively exposed. The formation is much folded, and its structure can not be worked out in detail, nor can any general section of it be compiled. Its base is nowhere exposed, and its top has been removed by erosion, so that its limits and its thickness are unknown. The general character of the formation may be indicated, however, by brief descriptions of its principal exposures.

The southernmost occurrence of the Guye formation lies northwest of the head of Lake Keechelus. On the creek draining Silver Peak are rather poor exposures of dark shale and gray sandstone dipping to the north. Upon these sedimentary rocks rests a great thickness of light-colored rhyolite, indicated on the map. In the vicinity of Snoqualmie Pass there are exposures of shale and sandstone mingled with prominent beds of conglomerate. Kendall Peak is carved from steeply inclined beds of Guye rocks, its sharp spurs and pinnacles being formed of the harder beds. In this vicinity the formation is represented chiefly by sandstones, with some shale, and interbedded with these are considerable basalt and a little rhyolite, both occurring in massive and in fragmental form. Commonwealth and Guye creeks also afford good exposures, which show mainly greenish-gray to blue-gray indurated shales, with some rather coarse grit. Near Chair Peak there is exposed a considerable mass of chert, with rhyolite in too small amount for mapping. At the Guye iron prospect the formation includes one or two beds of limestone whose aggregate thickness is only a few feet.

*Relations and age.*—The Guye formation has been found in contact only with two later ones. The Snoqualmie granodiorite is intrusive in it, and the Keechelus andesitic series overlies it with marked unconformity.

The intrusive relation of the granodiorite is clearly shown at several localities, perhaps best at the head of Snow Creek, where the contact of the two formations is well exposed. Here the Guye rocks are penetrated by apophyses of the granodiorite, which contains angular inclusions of the rocks invaded.

The strong unconformity separating the Guye from the Keechelus is shown both on the ridge between Denny and Guye creeks and at a point southeast of Silver Peak. At both these localities the Keechelus strata, dipping very gently, form the summits and upper slopes, while lower down the Guye is exposed with dips near 60°. The actual contacts, unfortunately, are obscured by talus.

The age of the formation is determined by a small collection of fossil leaves which have been examined by Dr. F. H. Knowlton, and reported upon as follows:

*Platanus dissecta* Lesq.
*Acer æquidentatum* Lesq.
*Ficus* n. sp., cf. *F. artocarpoides* Lesq.
*Cinnamomum* n. sp.

The first two species are without question Miocene. The *Ficus* approaches quite clearly *F. artocarpoides*, which is from the Fort Union group (Eocene) of Montana. The specimen is not perfect and can not therefore be positively determined. If it differs at all from the Fort Union species the difference must be very slight. Yet the species may prove to be new.

The *Cinnamomum* is undoubtedly new and is a fine characteristic species. It does not approach any described species very closely, yet appears to be of a Tertiary type.

The two species that can be determined are Miocene and the other two are of Tertiary, probably Miocene, facies.

Thus the age of the Guye formation is fixed as Miocene. Stratigraphic evidence shows that it belongs in the early part of that epoch, for it is overlain, with marked unconformity, by thousands of feet of the Keechelus volcanics, which are in turn overlain by the Ellensburg sandstone, of known Miocene age. Yet the stratigraphic relations to the overlying rocks, added to the lithologic resemblance of the Guye formation (composed of interbedded sediments, basalt, and rhyolite) to the Eocene formations, would have led to its reference to the Eocene were it not for the paleobotanic evidence just cited.

*Lithology.*—The Guye formation presents an interesting variety of lithologic types, both sedimentary and volcanic, and of these the sediments will be described first.

The shaly rocks, which contain fossil leaves, are probably the most abundant. They are partly grayish green and partly black and carbonaceous. In the southernmost area the fine sediment has the ordinary aspect of shale, being rather soft and fissile. In places these shales are somewhat carbonaceous and have been prospected for coal. In areas farther north the shale is commonly harder, more compact, and much more resistant to erosion, and breaks under the hammer with conchoidal fracture rather than along bedding planes, resembling slate in its induration but differing from it in being free from secondary cleavage. The induration is probably due to the intrusion of the Snoqualmie granodiorite, the nature of whose action will be discussed further on.

The sandstone contains rock fragments and approaches an arkose. Its grains comprise, in addition to quartz, much feldspar and some mica. In color it varies according to composition from light gray or olive to dark grayish or purplish brown. Like the shale, the sandstone exhibits various degrees of induration. At considerable distances from the granodiorite it is but moderately hard and somewhat porous, but in the exposures on Kendall Peak it is closely cemented, taking on the character of tough quartzite, and breaks with conchoidal fracture. Some of the lighter arkose phases resemble fine-grained granite. On microscopic examination it is found that the cement is composed essentially of quartz and sericite.

The conglomerate exposed near Snoqualmie Pass and on Guye Creek is made up of angular to subangular fragments, mostly of black chert or indurated slate much veined with quartz. Associated with these are pebbles of vein quartz. The material of this general composition varies in grain from conglomerate or breccia, with fragments 2 or 3 inches in diameter, to fine grit. It is extremely characteristic of the Guye formation, and glacial erratics of the conglomerate, found many miles down the Yakima Valley, are easily recognizable, since no similar rock occurs in any other formation of this region.

The chert is light gray in color and is distinctly bedded in layers a few inches thick. It is minutely fissured and veined with quartz. The limestone found at the Guye prospect is a light-gray crystalline rock, somewhat marble-like in character.

The rhyolites in the Guye formation are in the main very similar to the Kachess rhyolite, already described. They are light colored and without ferromagnesian constituents, but carry quartz phenocrysts rather more frequently than the Kachess rhyolite. A very peculiar apparently rhyolitic rock is found on the southwest shoulder of Kendall Peak. It consists mainly of a rather hard, aphanitic groundmass, dull coal-black in color, which contains abundant small angular grains and crystals of quartz. Its texture and composition, studied microscopically, indicate that it is tuffaceous. Its black color is due partly to an abundance of finely divided scaly material resembling green biotite and numerous black opaque particles of undetermined character.

The basalt included in the Guye formation near Kendall Peak is mostly a greenish black, compact, aphanitic rock, not very readily distinguished from the indurated black shale. Its true character was first recognized by the finding of amygdaloidal phases, with cavities full of quartz, hornblende, and other secondary minerals. A little indurated tuff was also found. The microscopic study of these rocks demonstrates that they are basalts, resembling in original constitution the Teanaway basalts, already described. Their original nature is masked, however, by changes due to the action of the Snoqualmie granodiorite.

### YAKIMA BASALT.

*Distribution and general character.*—In Washington, Oregon, and Idaho a vast area, probably more than 200,000 square miles, is underlain by basalt. The larger part of this great accumulation, in the sections where it is best known, is of Miocene age. In the Mount Stuart and Ellensburg quadrangles this Miocene basalt forms a perfectly definite unit, which is called, from its excellent exposures along the Yakima River, the Yakima basalt. That the Yakima basalt is coextensive with the great expanse first mentioned is not certain but is probable, and if this is so it is undoubtedly the most widely distributed volcanic formation on this continent.

In the southern part of the Snoqualmie quadrangle, a few small remnants of the western portion of this great basalt sheet occur. They are mainly of black, compact lava, with hardly any of the fragmental material that forms a considerable part of the formation as exposed in the Ellensburg quadrangle.

One of the best exposures of the Yakima basalt in the Snoqualmie quadrangle may be seen at the head of Quartz Creek, where a great landslide has produced an escarpment of the black rock overlooking a broad expanse of crumbling hummocks and loose angular rubble. The tendency to form cliff and talus is characteristic, owing to the readiness with which the rock is broken down in large fragments, combined with its slowness in disintegration. It decomposes to a rust-red soil, which in this area is generally very thin.

*Relations.*—The correlation of the largest areas of the basalt here described with the Yakima basalt is made confidently, since they are practically continuous with the type areas of the formation. The rock of the other areas is similar and agrees in relations, so far as those are known, with the typical Yakima basalt. The rock of the northern areas overlies various formations, ranging from the Easton schist to the Taneum andesite, in such a way as to indicate that its eruption was preceded by an erosion period. The southern masses have not their bases exposed, but, like the basalt of the Ellensburg quadrangle, are overlain by the Ellensburg formation, although the Keechelus andesite usually intervenes.

*Lithology.*—The Yakima basalt comprises massive lava and fragmental rocks, the lava greatly preponderating. It is well exposed along the high ridge in the extreme southeast corner of the quadrangle, where its characteristic features are well displayed, especially in certain landslide areas where the rock may be seen in fresh escarpments. The massive basalt is nearly black and is generally much jointed. The prevailing type of jointing is the columnar, but nowhere in the Snoqualmie quadrangle are the columns of very regular form. Usually the basalt is divided into rudely prismatic masses, standing nearly vertical and cut across by horizontal joints at irregular intervals. Less frequently there is no conspicuous vertical jointing, but only the nearly horizontal platy parting. These characteristic partings were produced by the contraction of the basalt on cooling. The crevicing of the rock determines the manner of its disintegration, and it breaks down into very angular fragments that accumulate as talus at the base of steep slopes.

Examined in natural exposures or hand specimens, the basalt usually appears somewhat crystalline, but is so fine grained that the constituent minerals can not be identified megascopically. By microscopic examination, it is found that it is all normal feldspar basalt. The chief constituents are plagioclase and augite. Olivine is usually present, although in very variable amount, and there is nearly always some glassy base. Accessories are apatite and magnetite, the latter frequently being so abundant that it almost deserves to be ranked as an essential constituent.

The plagioclase forms lath-shaped crystals and shows more regular crystallographic development than any of the other constituents. It is nearly all labradorite and exhibits little zonal structure. The augite, which may form stout prisms or irregular grains, is generally pale brown, often with a tinge of purple. The olivine forms crystals or rounded grains. It is always subordinate in amount to the augite, and in some specimens is altogether lacking.

The texture of the basalts is more variable than their composition. They are hardly ever truly porphyritic, their typical texture being the intersertal. All degrees of crystallinity are to be observed. Holocrystalline phases occur in which the fabric is generally ophitic, and the rapidly cooled upper and lower surfaces of the flows often contain a large proportion of glass. Generally, however, crystalline matter forms the greater portion of the rock.

A chemical analysis has been published in the Mount Stuart folio of a representative specimen from that quadrangle. The rock is less basic than typical basalts. It shows close chemical relationship to the Teanaway basalt, and according to the quantitative classification belongs in the same subrang, vaalose.

### DIABASE.

*Occurrence.*—In the southeastern corner of the Snoqualmie quadrangle there are several small, irregular masses and dikes of diabase which, like similar intrusive bodies in the Mount Stuart quadrangle, have been correlated with the Yakima basalt. This diabase is a dark-brownish to grayish-black rock, distinguished lithologically from the extrusive basalt by its coarser grain and its lack of amygdaloidal structure. It is resistant, and the masses stand in relief above the surrounding sandstones and basalts. A very prominent feature carved from this rock is a crag on the south side of the Taneum basin, marked with nearly vertical parallel bands about a foot wide, slightly darker or lighter according to their mineral composition. The crag and its peculiar banding are visible for many miles.

The diabase is found in irruptive contact with the pre-Tertiary rocks—the Taneum andesite, the Manastash sandstone, and the Yakima basalt. Since no extrusive basalts later than the Yakima are known in the vicinity of these occurrences, these relations of the diabase—observed in both the Snoqualmie and Mount Stuart quadrangles—as well as its petrographic character, indicate that it originated from the same magma as the Yakima basalt and represents in part the reservoirs or conduits from which the Miocene lavas were extruded.

The question arises here whether the irregular masses represent underground chambers from which the basalt escaped to the surface through fissures, or chimney-like vents which themselves extended to the surface. Evidence on this point is to be looked for in the character of the adjacent volcanic deposits. Lavas may emanate from craters or from fissures, and some of the greatest lava floods, such as those of the Columbia Plain, are known to have originated by fissure eruption. It is a generally accepted belief on the other hand that tuffs, which represent explosive eruptions, are usually erupted from craters. If these irregular diabase masses are volcanic necks, we should expect to find accumulations of tuff in their vicinity. Although no considerable masses of basaltic tuff occur in this immediate neighborhood, there are included in the Yakima basalt series as exposed near the northwest corner of the Ellensburg quadrangle, at a point about 5 miles distant from the diabase areas, several hundred feet of such material, the greatest thickness thus far found in this formation. The presence of these tuffs would naturally lead one to look for traces of volcanic vents which had been opened through the older rocks. Therefore the occurrence of these diabase masses and of heavy layers of tuff within a few miles of each other supports the hypothesis that the diabase masses represent the roots of basalt volcanoes, and that the absence of tuffs in immediate proximity to the diabase may be explained as the result of erosion.

*Petrography.*—The typical Miocene diabase is a dark-brown or gray crystalline rock of medium grain. It has an ophitic texture, best seen on weathered surfaces, where the dull-white lath-shaped feldspars are contrasted with the dark interstitial ferromagnesian material. In a typical specimen of fresh rock from the Taneum basin this texture is illustrated in an even more striking manner. By turning the specimen about in a good light, reflections from the cleavage faces of the pyroxene may be observed, and the rock is then seen to be composed of interlocking grains of pyroxene, about 1 centimeter in average diameter, with abundant inclosed lath-shaped feldspars and grains of olivine, inconspicuous because of their freshness and transparency. Small cavities into which the crystals project may be seen in some specimens of the diabase, and an exceptionally coarse gabbroitic phase occurs at one place in the largest area.

In microscopic sections these rocks are all seen to have plagioclase (labradorite) as their chief constituent, with augite generally second in importance. The other essential constituents are olivine and hypersthene, of which either one or both may be present. As accessories there occur abundant iron oxide and more or less apatite, and in some slides a little hornblende is seen, which is possibly original, but, on the other hand, may be paramorphic after augite. The augite is of different colors, some being greenish, some brownish, and some tinged with violet, indicating its titaniferous character. The general order of crystallization is apatite, plagioclase, olivine, magnetite, hypersthene, and augite.

The diabase is never quite free from alteration. The feldspars are commonly somewhat clouded and the olivine is always altered in some degree to iddingsite, which appears also as an alteration product of hypersthene, and may fill cracks and irregular spaces in the rock. The Miocene diabase is on the average distinctly fresher than the rock of the Teanaway dikes.

### KEECHELUS ANDESITIC SERIES.

*General character and occurrence.*—The Keechelus series occupies most of the western half of the Snoqualmie quadrangle, and is probably the most voluminous assemblage of rocks in the Cascade Range for some distance to the west and south. It consists mainly of andesitic material, with some basalt and rhyolite and a small amount of sedimentary rock. The volcanic rocks comprise lavas, agglomerates, and tuffs, the fragmental rocks probably predominating on the whole, although the proportion varies in different localities. In the northern part of the quadrangle and about Stampede Pass tuff and breccia predominate, but to the south lavas are the more abundant.

Classified according to composition, the Keechelus volcanics are pyroxene-andesite, dacite, rhyolite, and basalt, the first two species greatly preponderating.

The exposures of the Keechelus series are extensive and fairly satisfactory. They will be briefly described, beginning with those on the south. About the headwaters of Naches and Greenwater rivers there are excellent exposures of the porphyritic lava, mostly grayish black, but in part light gray, red, and green. Near the head of the South Fork of Naches River is a great cliff exhibiting a flow of dull-black andesite with columnar structure. Tuffs occur, on the whole, in the southern areas in subordinate quantity, but they are extensively displayed near Arch Rock and farther south. They are red, green, and yellow in color, and contain many fragments of the porphyritic lava. Pyramid Peak is carved from a conspicuous porphyritic andesite, but toward the north, along the main divide, the lavas become rather less abundant than the tuffs. A mass of white porphyritic rhyolite, the largest observed in the Keechelus series, forms a hill southeast of Pyramid Peak. About Green Pass the rocks are chiefly the characteristic green andesitic tuffs, with some lighter colored ones, some dark-gray and pinkish andesite, and considerable basalt. Many cuts along the Northern Pacific Railway afford good exposures of Keechelus rocks, here chiefly red and green andesitic tuffs, with some basaltic and andesitic lava, which is partly dacite. A few miles east of Martin there is a gully eroded in shales and sandstones which form a lens in the Keechelus series several hundred feet thick but of limited horizontal extent. Accounts of the cutting of the Stampede tunnel record the presence of both hard lava and shale-like rock, the swelling of which upon exposure necessitated a masonry lining.

North of Yakima Valley the exposures of this formation are on the whole even better than to the south. The eastern shore of Lake Keechelus is in part a steep bluff of hard dark-green dacite-breccia, in which the road could be cut only by blasting. West and north of this lake there are many high and rugged peaks carved from Keechelus lavas and tuff-breccias, the latter predominating. The lavas are mostly porphyritic pyroxene-andesites and dacites of different shades of gray, but sometimes drab or olive green. In this region there are also small areas of greenish-black basalt and cream-white rhyolite, the rhyolite appearing on the ridge south of Alta Mountain. The fragmental rocks of the northern exposures are chiefly andesitic tuffs and breccias which have in large part been indurated by the action of secondary agencies, so that they are as compact and hard as the massive lavas. The most common of these rocks is a gray breccia, rather dark on fresh fracture but lighter colored on the weathered surfaces, in which the internal structure, obscure in unweathered rock, is revealed by etching. In their larger exposures the tuffs and lavas display distinct bedding, and some of the finer layers show the effect of water sorting and resemble ordinary shale or sandstone.

*Relations and age.*—The Keechelus series is a lithologic unit, composed mainly of andesites from which the subordinate amounts of other rocks can not consistently be separated. In age, however, it has not the unity generally required in a formation, for while it is mainly Miocene it contains some material that is almost certainly post-Miocene. The reasons for not separating these should therefore be stated.

The lower part of the series, comprising by far its greater portion, consists of a succession of volcanic rocks that show considerable alteration. The Keechelus rocks of the northern part of the quadrangle and most of those exposed in the southern part are of this character. In the basins of Greenwater and Naches rivers, however, there are some fresh lavas and tuffs, which are lithologically distinct from the more widely distributed decomposed rocks.

The lower and altered portion of the Keechelus series may without doubt be considered a true geologic unit, and its Miocene age is evident from its relations. In the northwestern part of the quadrangle it overlies the Swauk, Teanaway, and Guye formations, and its unconformable relation to all of these has been determined by the field work, the Keechelus beds generally lying much more nearly horizontal than the older rocks beneath them. Seen from a distance it is at some places apparently a capping, and in certain areas the summits carved from it are rather flat, their form evidently being determined by the nearly horizontal attitude of the tuff and lava beds. In the southern part of the quadrangle the Keechelus lavas are overlain by beds of the Ellensburg formation, of late Miocene age, while in the same vicinity the Keechelus lava overlies the Miocene Yakima basalt. Thus the main portion of the Keechelus series underlies one Miocene formation and is underlain by others, so that its Miocene age is well determined.

The discrimination of the younger lavas, based primarily on lithologic grounds, is supported also by structural and topographical data and one bit of doubtful stratigraphic evidence. It is necessary to give these data and to specify the lithologic evidence.

Lithologically, some of the lava in the Naches and Greenwater basins appears as fresh as any that might be collected from the slopes of the recently extinct volcanoes of the Cascade Range, and in the vicinity of Arch Rock there are great volumes of yellow fresh-looking tuff. The difference in alteration between the older and the younger lavas is made still more evident by microscopic study.

As regards structure, the older portion has been somewhat tilted and gently folded, as shown in the structure sections, while the younger rocks display only such gentle dips as might be considered the initial slope of the lava flows.

The topographic evidence is clear in the area about Naches Pass, and, although more striking in the field, may also be made out by inspection of the map. The summit of the ridge here is broad and flat, in contrast with the rugged topography to the north, and has every appearance of being near the original surface of the flow and but slightly modified by erosion. The lava forming this ridge appears to have been poured out after the extensive erosion which the Cascade Mountains suffered in Pliocene time. At other localities, however, lava showing a plateau-like upper surface is believed for other reasons to belong to the older portion of the series. The only stratigraphic evidence available is afforded by a locality on the ridge north of Crow Creek, where a little andesite apparently overlies the Ellensburg sandstone, but the contact is not well enough exposed to prove this relation.

The conditions above described convinced the authors that the area mapped as Keechelus comprises lavas of two distinct ages. The two divisions in their typical development, the younger as illustrated by the tuffs of Arch Rock and the lavas just south of Naches Pass, and the older as illustrated by the lava of Pyramid Peak and the tuffs along the ridge to the north, could hardly be confused. Along the north side of Greenwater Valley, the boundary between the older and the younger rocks could be traced with passable accuracy. In areas farther south, however, the separation was found to be impracticable. Some black andesite quite similar to that of the upper flows was seen, plainly overlain by the Ellensburg formation. The effort to draw a boundary between this rock and the supposed post-Miocene lava was unsuccessful, since the older rock is less altered than usual, probably because it consists of massive lava.

In short, the criteria, while sufficient to establish the presence of two distinct groups of these volcanics, fail, except locally, to serve as a basis for the determination of boundaries between them. On the average, the later andesite is much fresher, less tilted, and less dissected than the earlier, but in contiguous areas certain phases of the two are so similar that they can not be discriminated with certainty, and the endeavor to map them separately was therefore abandoned.

Lower in the Naches Valley, in the Ellensburg quadrangle, late andesitic lavas occur and have been mapped, since there they are in contact with basalt rather than with lava of similar composition. Moreover, the field evidence supports the belief that in this area there was little interruption of volcanic activity, so that the necessary grouping together of the late Miocene and subsequent lavas is not wholly unnatural.

*Petrography.*—The volcanic rocks of the series will be described in order of acidity. The rhyolite of the Keechelus series resembles in its essential characters that of the Kachess formation. It occurs in the form of breccias and tuffs as well as in flows. Of the massive rock a specimen from the knob east of Pyramid Peak may be considered typical. Megascopically, it shows abundant phenocrysts of quartz and feldspar with a few small ones of biotite, in a dull-white, compact groundmass. On microscopic examination it is found that the feldspar phenocrysts are of sodic plagioclase, while the groundmass is of quartz and feldspar, showing in the same slide micropoikilitic, microspherulitic and micropegmatitic textures.

The dacites are greenish rocks containing abundant megascopic crystals of quartz and feldspar. Most of the specimens collected are tuffs rich in crystals. The feldspars are found on microscopic examination to be mostly andesine, and the quartz shows the usual phenomena of corrosion. In addition, the dacites all contain vestiges of phenocrysts of ferromagnesian minerals, but these are completely replaced by calcite, chlorite, iddingsite, quartz, chalcedony, and epidote, in pseudomorphs whose forms suggest hornblende and hypersthene.

The original petrographic characters of the pyroxene-andesites are well illustrated by a specimen collected from the Naches Valley, near B. M. 3119. It is perfectly fresh, and therefore probably belongs to one of the later post-Miocene flows. Megascopically it shows abundant phenocrysts of glassy striated feldspar, and less numerous ones of black pyroxene, which are not prominent in the black, dense aphanitic groundmass.

Microscopically the rock shows the character of a typical pyroxene-andesite. The phenocrysts are, in order of abundance, labradorite, hypersthene, and augite; the two pyroxenes are frequently intergrown. The groundmass is hyalopilitic, containing plagioclase and both the pyroxenes, of a second generation, embedded in an abundant brown glassy base. As accessories, there occur much magnetite and some apatite. The chemical character of the rock is shown by the following analysis, made by Mr. George Steiger of the U. S. Geological Survey:

*Analysis of Keechelus hypersthene-andesite.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 62.77 | $TiO_2$ | .79 |
| $Al_2O_3$ | 14.96 | $ZrO_2$ | .03 |
| $Fe_2O_3$ | 1.62 | $CO_2$ | none. |
| FeO | 4.36 | $P_2O_5$ | .22 |
| MgO | 1.48 | $SO_3$ | none. |
| CaO | 3.90 | S | none. |
| $Na_2O$ | 4.31 | NiO | none. |
| $K_2O$ | 2.13 | MnO | .10 |
| $H_2O-$ | .51 | BaO | .10 |
| $H_2O+$ | 2.49 | SrO | none. |
| | | | 99.77 |

The rock contains an unexpectedly high percentage of silica, and the analysis as a whole bears a strong resemblance to that of the Tertiary granodiorite, to be described later, but the andesite is more siliceous. According to the new quantitative classification, it falls in the same division, tonalose. It is evident that the glass is rich in silica and potash, and that, if it were completely crystallized, it would contain much quartz and considerable orthoclase, both of which are essential constituents of the granodiorite. It is clear that this analysis does not represent the average composition of the Keechelus andesites, many specimens of which, though nearly holocrystalline, contain little quartz and orthoclase.

The other fresh specimens of andesite resemble this specimen more or less closely. The feldspars are zoned and are chiefly labradorite. The pyroxenes vary in relative amount, the predominant species being in some cases augite, in others hypersthene. The groundmass is in some places almost holocrystalline and is there composed chiefly of well-formed prisms of feldspar and of pyroxene in grains or prisms, which generally appear to have crystallized later than the plagioclase. In some slides a little interstitial quartz and alkali feldspar are visible. The mineralogical composition of some of these specimens shows that they are more basic than the specimen analyzed.

The pyroclastic pyroxene-andesites are composed of fragments that range from less than an inch to several inches in diameter, the smaller predominating. In the southern part of the quadrangle the rocks are generally greenish, massive bedded, more or less compacted, but not generally hard, and in some places show pseudocolumnar parting. The larger fragments, most of which are green, though some are red or brown, show the porphyritic structure of andesite, but are more decomposed than the material of the lava flows, the feldspars being dull white and the groundmass rather dull and earthy. Microscopically, there is seen, in addition to the porphyritic fragments, much finer material, some of the particles showing the characteristic cuspate forms of glass fragments.

The alteration of the older Keechelus andesites is interesting, chiefly because its extent varies significantly in different areas. In areas at a distance from the intrusive granodiorite the alteration of these rocks presents familiar features. Changes peculiar to the belt of cementation are somewhat extensively displayed, and most specimens show in addition considerable effects of true weathering. In the northern areas, however, within 2 or 3 miles of the Tertiary granodiorite, where, owing to conditions of vigorous erosion, weathering is little manifested, the alterations characteristic of the belt of cementation have proceeded to a remarkable extent.

Under the conditions of decomposition obtaining in the southern part of the quadrangle the hypersthene is most readily attacked of all the minerals, and alters to a material having the optical properties of iddingsite. This material here and there partly replaces augite also, but in some specimens the monoclinic pyroxene is perfectly fresh while the hypersthene is almost completely decomposed. In a few instances the augite is altering to hornblende. The feldspars are commonly more or less clouded with the usual decomposition products. The glass of the groundmass is frequently more or less devitrified, the process giving rise to minute irregular granules of quartz and feldspar, and the micropoikilitic structure which in some places occurs may also be secondary. The andesite tuffs are much more altered than the associated lavas, and the glassy matter once abundant in them has become clouded and largely devitrified. The original ferromagnesian minerals in specimens of the tuff examined have been completely replaced, except that in some a little augite remains.

The alterations produced near the granodiorite in the northern part of the quadrangle are made apparent chiefly by a general induration, which makes the Keechelus rocks here appear fresher than the really less altered andesites farther south. Their original pores have been filled in, which makes them more resistant to superficial weathering and disintegration. This is especially well illustrated in the tuffs and breccias, which are generally indurated and compact. It is believed that this type of alteration is directly dependent upon the intrusion of the Snoqualmie granodiorite, and the microscopic characters which show the exact nature of the changes undergone by the Keechelus rocks will therefore be considered in connection with the description of the granodiorite.

The basalts of the Keechelus series are mostly similar to rocks of the Yakima and Teanaway basalt formations, already described, and therefore may be passed over without further notice, with the exception of one type, which possesses especial interest. This is a basaltic rock collected about 2 miles south-southeast of Naches Pass. It occupies a comparatively small area, and overlies a great flow of fresh-appearing andesite. It is a rather light-gray rock containing numerous phenocrysts of olivine in a nearly holocrystalline feldspathic groundmass.

Under the microscope, the essential minerals are seen to be plagioclase, olivine, and augite, and the accessories magnetite and apatite, while there is very little glass. The olivine, which forms the only phenocrysts, shows characteristic crystal form, modified by corrosion. It has a pale-green tint, somewhat deeper on the peripheries and the borders of cracks, which suggests that the color may be partly due to secondary agencies. It is faintly pleochroic. A very little red and green iddingsite has formed at the expense of this mineral, and this alteration is the only one which has taken place in the rock. The groundmass contains a second generation of olivine and augite in roundish grains, but its chief constituent is plagioclase. The centers of the roughly lath-shaped plagioclase crystals are of labradorite, while the rims are more sodic. The magnetite is noticeably less abundant than in most basalts.

The rock has been analyzed chemically by Mr. Steiger, with the following result:

*Analysis of Keechelus basalt.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 50.36 | $TiO_2$ | 1.33 |
| $Al_2O_3$ | 15.83 | $ZrO_2$ | none. |
| $Fe_2O_3$ | 2.29 | $CO_2$ | none. |
| FeO | 8.11 | $P_2O_5$ | .21 |
| MgO | 7.90 | $SO_3$ | none. |
| CaO | 9.25 | S | none. |
| $Na_2O$ | 3.05 | Nio | none. |
| $K_2O$ | .86 | MnO | .24 |
| $H_2O-$ | .05 | BaO | trace. |
| $H_2O+$ | .27 | SrO | trace. |
| | | | 99.75 |

The rock differs considerably from the other basalts of this region already analyzed, being somewhat lower in silica, higher in lime, and, as the large amount of olivine indicates, much higher in magnesia. In the quantitative classification it falls into the subrang auvergnose.

A peculiar rock found in the Keechelus series at several localities is similar to the "labrador porphyrites" of Rosenbusch and the "diabase porphyrites" described by Turner for the Sierra Nevada, and is probably allied to basalt in composition. Megascopically, it has a striking appearance. It is characterized by abundant phenocrysts of feldspar, tabular in form, with a length often exceeding half an inch, embedded in a black aphanitic groundmass. The phenocrysts are commonly assembled in groups, and in some places intersect so as to form peculiar aster-like figures.

Microscopically, the phenocrysts are found to be labradorite. The groundmass has an intersertal texture, without flow structure, and consists of plagioclase laths with secondary ferromagnesian material—an olive micaceous mineral (iddingsite?) and a pale-green amphibole. A similar but much fresher rock was found in association with the Naches sediments in Big Creek basin. This may be either a flow or a dike of the same age as the Keechelus series. In the groundmass of this rock, which is probably essentially the same as the one already described, there is much augite as well as much iddingsite, some of which may have been derived from olivine.

PYROXENE-DIORITE.

*Distribution and relations.*—Within or adjacent to the Keechelus series, there are several masses of granular igneous rock which have for their chief constituents plagioclase, pyroxene, and quartz, and thus fall within the diorite family as defined by Rosenbusch. The largest of these masses is on the main divide near Meadow Pass. Two others lie between Tacoma Pass and Green Pass, and Silver Peak is carved from a fourth. These bodies of diorite are believed to represent the roots of the volcanoes from which the Keechelus volcanics were erupted, the belief being founded upon relations observed in the field and upon the petrographical similarity between the diorite and the Keechelus andesite.

West of the head of Lake Keechelus are two dikes of hypersthene-diabase which are somewhat more basic than the pyroxene-diorite, but whose relations indicate that they are of Keechelus age, and these may have been derived from the same magma reservoir as the diorite.

The Meadow Pass area, besides being the most extensive, is the best exposed. The intrusive mass, harder than the surrounding volcanic rock, rises like a ruined amphitheater opening to the south, with its outer walls descending steeply on all sides. The inner part of the mass is granular, and the granular rock passes gradually into a light-gray holocrystalline diorite-porphyry, and this in turn, at some points near the periphery, into a darker, fine-grained porphyry. On the north side of the butte, a short distance from its base, are exposures of a rock which is very similar to the gray diorite-porphyry in tint and composition, but which shows a nearly horizontal lamellar parting and a brecciated structure and has the appearance of an extrusive rock. No sharp contact could be found between this rock and that which is clearly plutonic. The mass near Green Pass grades from a light-gray and coarse-grained to a dark-gray and finer grained porphyry. At one point andesite tuff was seen within a few feet of this rock, but the relations were not made out with certainty. In the other areas, the contacts are much obscured by soil and talus.

To sum up, the form of the diorite masses and their relations, so far as observed, are in harmony with the hypothesis proposed above, although they do not prove it. The evidence derived from the petrographic study is therefore the more valuable.

*Petrography.*—The granular diorite is medium grained and consists mainly of feldspar and dark-green prismatic minerals, the general color of the rock being greenish gray. The typical porphyry is of similar color and contains abundant phenocrysts of feldspar and the ferromagnesian minerals in a finely crystalline groundmass. Some finer grained phases are darker and resemble basalt.

The best material for microscopic study was taken from the Meadow Pass area, but even the freshest material is considerably altered. The essential constituents of both the granular and porphyritic rocks originally were plagioclase, monoclinic and orthorhombic pyroxenes, perhaps a little hornblende, and a little interstitial quartz and orthoclase. As accessories there are moderate quantities of magnetite and apatite. The general order of crystallization has been (1) accessories, (2) plagioclase, (3) pyroxene, and (4) quartz and orthoclase.

The plagioclase, which shows well-developed crystal form, is characterized by extremely marked zonal structure, the central and larger portions of the crystals being of labradorite, and the rims often of sodic oligoclase. It is clouded to some extent with kaolin, sericite, and calcite. The quartz and orthoclase form anhedral grains in the granular rock and constitute in the porphyries an allotriomorphic granular mixture between the microlites of plagioclase and pyroxene in the groundmass. The magnetite is largely altered to an opaque white "leucoxene," which indicates that it is titaniferous.

The pyroxenes, which have a tendency to idiomorphism, especially well marked in the porphyries, are extremely altered, the augite indeed being mostly and the hypersthene entirely replaced by secondary minerals. In the less altered specimens the resulting pseudomorphs are homogeneous and characteristic. The augite remnants in all slides exhibit the process of uralitization in a very typical manner, and there are abundant pseudomorphs of pale-green amphibole which in many specimens especially of the porphyries, exhibit the characteristic cross section of augite. In places, however, there is intergrown with this secondary amphibole some more massive, pale-brownish hornblende, which may be original. Quite distinct from the uralite pseudomorphs are others, noted in many specimens, of a mineral having the parallel fibrous structure of bastite, but more deeply colored and of higher double refraction. Since the alteration of hypersthene to entirely similar pseudomorphs has been observed very often, there can be no doubt that these represent original hypersthene.

In the more altered specimens, however, the ferromagnesian minerals have given rise to more heterogeneous aggregates, which, besides amphibole, and iddingsite, contain epidote, calcite, chlorite, and quartz. These secondary minerals also form irregular masses, and sometimes replace portions of the feldspars.

The close petrographic relationship of these dioritic rocks to the typical pyroxene-andesites of the Keechelus series is evident. Even after laboratory study of the rocks it is difficult to distinguish some specimens of the peripheral phases of the intrusive Meadow Pass stock from specimens of the gray extrusive andesites found north and west.

ELLENSBURG FORMATION.

*General character and occurrence.*—The Ellensburg formation consists of volcanic materials worked over and laid down by water. In the foothill valleys and plains east of the Cascades it attains considerable thickness and covers great areas, and it is developed extensively throughout central and southeastern Washington, where it generally rests upon Yakima basalt. Its age has been satisfactorily fixed by fossil leaves as late Miocene, and it is probably equivalent to the "Mascall" formation of the John Day basin in Oregon. Among its best exposures are those in the Mount Stuart and Ellensburg quadrangles, and in folios 86 and 106 it has been fully described.

In the southern part of the Snoqualmie quadrangle there are a few small areas of conglomerate that lack fossils to prove their exact age but are correlated upon lithologic grounds with the Ellensburg, which is well developed only a few miles away, in the Ellensburg quadrangle. The material lies in comparatively thin patches upon gently sloping surfaces of the Keechelus andesite, with which it is apparently conformable. The formation is not well exposed and is mapped largely from loose bowlders upon the surface. Wherever seen in place it consists of an imperfectly consolidated conglomerate of andesite bowlders in a light-colored tuffaceous matrix. The bowlders, which are generally but a few inches in diameter, are well rounded. They are mostly of pink or gray hypersthene-andesite and include some white pumice. All these rocks are abundant in typical exposures of the Ellensburg formation.

SNOQUALMIE GRANODIORITE.

*General character and occurrence.*—Some genetically related masses of granular igneous rocks belonging for the most part to the granodiorite type, but including more acid as well as more basic modifications, are exposed in the northern part of the quadrangle, mostly about the headwaters of Snoqualmie River, whose name is therefore adopted for the formation. A small area of this granodiorite also occurs south of Howson Creek. The basic modifications are of very local occurrence, and grade into normal granodiorite. There is included in this formation, on the other hand, a mass of more siliceous biotite-granite, which forms Guye Peak, the spur to the west of it, and part of Snoqualmie Mountain. Its relation to the granodiorite was not definitely determined, but it is supposed to be derived from the same magma and nearly contemporaneous with it, since granodiorite and granite show the same relation to the adjacent sediments. Porphyritic modifications of the granular rocks are found on the margins of the large masses, and in dikes.

These granitic rocks are resistant to erosion, and therefore form the summits of several prominent peaks, as Chair Peak, Granite Mountain, and Snoqualmie Mountain. Dikes are found near the great masses and the connection between the two can in a few cases be directly traced. In other cases this connection is inferred from the close petrographic relationship of the dike and stock rocks.

*Relations and age.*—The Snoqualmie granodiorite is intrusive in both the Guye and Keechelus formations, this relation being abundantly proved by observation of actual contacts. Since the Guye formation contains Miocene fossils and is overlain unconformably by the Keechelus lavas, the age of the intrusive granodiorite must be late Miocene or post-Miocene. In view of the denudation required to expose this acid granular rock, which could have attained its holocrystalline texture only under cover, it appears more plausible to suppose that the intrusion did not occur much later than the close of the Miocene.

*Petrography.*—The essential constituents of the granodiorite of the prevailing type are feldspar, quartz, hornblende, and biotite, all of which can be identified in hand specimens with the unaided eye. The feldspar, generally white and semi-transparent, forms the greater part of the rock. The quartz, colorless and glassy, is much less abundant and rather inconspicuous. In prominent contrast against these white minerals appear the black prisms of hornblende and the dark lustrous brown foils of biotite, which occur in moderate and about equal quantity.

Microscopic study of the granodiorites shows that the feldspars include both plagioclase and orthoclase. The plagioclase, which greatly predominates, generally has more or less distinct zonal structure, the cores usually belonging to andesine, and the outer shells to oligoclase. It shows a strong tendency to idiomorphism. The orthoclase, on the contrary, is interstitial, and often constitutes some individuals of considerable size penetrated by numerous crystals of the other minerals, except quartz, which forms anhedra and is in places intergrown with the orthoclase. The hornblende and biotite show no unusual features, the hornblende being of the common deep-green variety, and the biotite deep greenish brown. Both show partial idiomorphism. The accessories include apatite, zircon, magnetite, and titanite, which occur in all specimens, and in a few a little allanite appears.

The more basic rocks into which the typical granodiorite locally grades should probably be classed with the quartz-diorites, but it would be difficult to fix the line between these two species, which are composed of the same essential minerals. As compared with the granodiorites, the quartz-diorites contain more basic plagioclase, the cores of the zoned crystals being sometimes of calcic labradorite. The quartz and orthoclase are even more subordinate in quantity in the quartz-diorite than in the granodiorite. The ferromagnesian constituents are in larger proportion; the hornblende in some specimens, but not in all, is more abundant than the biotite, and some specimens contain augite, which is generally much uralitized.

The granodiorite porphyries show a distinct relationship to the granodiorites, but, as might be expected, are considerably more variable in mineralogical composition than the corresponding granular rocks. In all, plagioclase is the dominant constituent, quartz occurs in rather subordinate amount, and orthoclase is generally identifiable, though often very inconspicuous. Hornblende and biotite are in many specimens both present, but some phases contain only biotite. The texture is as a rule not quite typically porphyritic, for the grains range in size from phenocrysts to the smallest particles of the groundmass. Of the phenocrysts, the most abundant and largest are of plagioclase, idiomorphic and distinctly zoned, with cores varying from sodic labradorite to calcic oligoclase, and more sodic rims. Biotite and hornblende when present generally occur as phenocrysts, usually of irregular outline, and frequently poikilitic. In exceptional cases, quartz also occurs among the phenocrysts. The groundmass usually comprises all the minerals of the first generation with the addition of orthoclase, though hornblende in places occurs only as a porphyritic constituent. Its texture is usually micrograniti c and of moderately fine grain, but occasionally the quartz forms comparatively large grains poikilitically inclosing crystals of plagioclase. Like the granular rocks most of the dikes have the composition of granodiorite, but some probably approach diorite. The quantitative composition of the porphyritic rocks is still more difficult to determine by microscopic study.

The biotite-granite forming Snoqualmie Mountain and some of the adjacent heights is more siliceous than granodiorite, much richer in quartz, and free from hornblende. The porphyritic modifications of these rocks are more or less similar in mineral composition to the granular phases, but show comparatively large phenocrysts embedded in a finely crystalline groundmass. The phenocrysts in the granite porphyry are of feldspar, biotite, and quartz, the last often noticeably rounded by corrosion.

The biotite-granite, when examined in thin section, is found to contain a large percentage of quartz, about an equal amount of alkali feldspar, somewhat less oligoclase, and a little biotite, largely replaced by chlorite. The alkali feldspar is microperthitic, in contrast with the orthoclase of the granodiorite, which is usually not notably perthitic. The accessories are magnetite, titanite, zircon, and apatite.

The granite porphyries contain the same minerals as the granular rocks, the phenocrysts including comparatively large crystals of quartz and of both the feldspars, with smaller ones of biotite. The microgranitic groundmass contains quartz and both the feldspars in a second generation.

These late Tertiary intrusives, contrary to what might be expected, are everywhere somewhat decomposed. The feldspars are uniformly at least a little clouded, kaolin and sericite being the commonest alteration products, though the basic plagioclase, which is more susceptible to alteration than the more alkaline feldspar, sometimes gives rise to complex aggregates of "saussuritic" character. The biotite is in nearly all specimens more or less altered to chlorite, with which epidote often occurs. Augite, when present, is commonly altered in part to uralite. The hornblende, on the contrary, is but little altered. Pyrite, supposedly secondary, is of not infrequent occurrence.

The chemical character of the Snoqualmie granodiorite of the type first described is illustrated by the following analysis, by Mr. George Steiger, of a typical and fairly fresh specimen from the head of Gold Creek:

*Analysis of Snoqualmie granodiorite.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 60.49 | $TiO_2$ | .69 |
| $Al_2O_3$ | 17.77 | $ZrO_2$ | .02 |
| $Fe_2O_3$ | 1.98 | $CO_2$ | none. |
| FeO | 3.29 | $P_2O_5$ | .08 |
| MgO | 2.94 | $SO_3$ | none. |
| CaO | 6.20 | S | none. |
| $Na_2O$ | 3.67 | MnO | .09 |
| $K_2O$ | 1.37 | BaO | .04 |
| $H_2O$ at 110° | .27 | SrO | .02 |
| $H_2O$ above 110° | 1.13 | CoO (NiO?) | trace. |
| | | | 100.05 |

This analysis shows a fairly close resemblance to two analyses of the Mount Stuart granodiorite, published in folio 106. As compared with those, it shows about 3 per cent less silica, about 2 per cent more of alumina, the same increase in lime, and a smaller percentage of both the alkalies, but according to the quantitative classification it falls in the same subrang, tonalose. This is in agreement with the similarity, already noted, of the two rocks as regards mineralogical composition. The pre-Eocene and late Tertiary granodiorites of this region are thus practically identical in petrographic character.

*Metamorphic effects.*—The intrusion of the Snoqualmie granodiorite has produced extensive changes in the intruded rocks. The effects have been of several different kinds, those most intimately related to the intrusion having the characters generally recognized as belonging to contact metamorphism, while there have been indirect effects much more widespread and on the whole far greater in amount.

True contact metamorphism is exemplified most strikingly at the Denny and Guye iron prospects, where mineralized zones occur near the contact of the granodiorite with the Guye rocks, Magnetite, garnet, hornblende, quartz, calcite, and pyrite are the minerals occurring here, with relations indicating that they owe their origin to the presence of the hot intrusive magma in close proximity to the Guye strata, which here included local beds of limestone. The presence of the calcareous rock doubtless determined the formation of these contact deposits, which have not been found elsewhere along the border of the granodiorite. A quartz-tourmaline contact rock was observed on the South Fork of the Snoqualmie.

The direct effect of heat conducted from the magma to contiguous rocks, combined in greater or less degree with the effects of heated waters, is shown by both sedimentary and igneous rocks within a few yards of the contact. The effects thus produced are of familiar kinds, and need not be dwelt upon at length. The sedimentary rocks have assumed a crystalline structure, and have developed considerable mica, mostly biotite. They do not, however, exhibit any of the minerals that characterize more intense contact metamorphism, such as garnet, andalusite, or chiastolite. The alteration of the igneous rocks is illustrated by a specimen taken near the contact. It consists of amphibole, feldspar, and dark mica, and although it shows no longer the texture of a volcanic rock, its composition suggests derivation from a basalt or basic andesite. Another illustration is afforded by a specimen of altered rhyolite collected near the contact on the South Fork of Snoqualmie River. It is mainly purplish drab in color, but contains numerous flat, white lenses which might represent filled-in steam cavities. Under the microscope the groundmass proves to be a felsitic mixture of quartz and feldspar, while the lenses, coarser grained, are of quartz, muscovite, and andalusite, the last two intergrown.

The remoter effects of the granodiorite intrusion are recognized in the field by the induration of the invaded rocks for a considerable distance from the contact. This phenomenon has necessarily already been referred to in describing the Keechelus and Guye rocks. It is difficult to ascertain the areal extent of the alteration, as the rocks affected by it grade insensibly into those which are unaltered. Indurated rocks of this type are to be seen in typical development on Alta Mountain, on the north side of Kendall Peak, along the rim of the amphitheater at the head of Gold Creek, and on the summit south of Silver Peak, while the dacite breccia along the shore of Lake Keechelus shows effects also attributed to the indirect agency of the granodiorite. Approximately it may be stated that the changes have reached almost complete development as far as half a mile from the contact, and are perceptible 2 or 3 miles from it. The nature of the alteration will be shown in the following general descriptions, which are based chiefly on microscopic study and which may be considered as applying to rocks a quarter of a mile from the contact.

In the sedimentary rocks, the alteration has nearly all consisted in the filling of spaces with quartz and sericite, probably attended by some rearrangement of the original materials of the rock. The latter effect, however, has not been conspicuous. This cementation is a familiar phenomenon and need not be further described.

The alteration of the Keechelus and Guye volcanics has been more extensive than that of the sedimentary rocks, and the metamorphism of volcanic rocks so recent as these is believed to be of peculiar interest. In this alteration there has been both cementation and metasomatism, the latter having been the more active process in the lavas, while the two have been, in the fragmental rocks, of coordinate importance.

The rhyolites generally have suffered less conspicuous alteration than the other volcanic rocks. They are everywhere thoroughly devitrified, and considerable sericite is usually found in them. Both these features have been noted in specimens gathered at a distance from the granodiorite. The dacites are all considerably altered, the ferromagnesian minerals having been replaced by secondary minerals and the glass completely devitrified, while the tuffs have been compactly cemented by secondary material into fairly hard rocks. In one specimen from the ridge south of Silver Peak, calcite is developed abundantly in irregular masses, evidently replacing portions of the original substance of the rock. In the rock from the side of Lake Keechelus quartz is developed in a similar manner, but in some cases it surrounds a phenocryst of quartz and has the same orientation as the nucleus, thus showing a mode of growth analogous to the well-known secondary enlargement of clastic grains in quartzite. All of the alteration processes seen in the dacites, except those just mentioned, are illustrated in the pyroxene-andesites, where, owing to the greater areal importance of this rock type, they have been more thoroughly studied.

The general characters of the altered pyroxene-andesites as seen under the microscope are as follows: The feldspars have suffered more alteration than in the areas remote from the granodiorite, though they are generally determinable and often fairly fresh. They contain secondary inclusions of various kinds, comprising kaolin, sericite, calcite, epidote, quartz, and scapolite. The phenocrysts of the ferromagnesian minerals are usually represented by pseudomorphs, which present much variety of composition and structure. Occasionally one finds regular paramorphs of uralite after augite, and the process of uralitization is clearly exhibited in some specimens, but none of the bastite-like pseudomorphs of iddingsite, common in other altered andesites, were observed. Generally the pseudomorphs are composed of a number of minerals, including quartz, epidote, amphibole, iddingsite, calcite, chlorite, and serpentine. In the groundmasses, no remnants of the original ferromagnesian minerals are found; they have given rise by alteration to the secondary minerals enumerated above, finely disseminated in irregular particles, the form of the original groundmass crystals not being preserved in pseudomorphs. In some cases, indeed, the material has in the process of decomposition been so rearranged that even the porphyritic ferromagnesian minerals have been replaced by formless aggregates.

Perhaps the most interesting change in these altered andesites consists in the universal devitrification of the glassy base. The devitrification gives rise to two distinct types of groundmass texture, both of which doubtless often arise by cooling from a magma, but since both occur more frequently in the more altered andesites than in the fresher ones, it is considered that both are also produced by secondary agencies. First may be mentioned the *micropoikilitic* texture, which has been described in connection with the Kachess rhyolites. In this type of groundmass, the plagioclase microlites and the ferromagnesian constituents are embedded in comparatively large irregular interlocking grains, probably mostly of quartz, but probably in part also of orthoclase. In the second and perhaps more usual type, the interstices between the plagioclase microlites are filled with a microgranular mixture of quartz and anhedral feldspar—the latter probably for the most part orthoclase.

The tuffs of the northern Keechelus areas have undergone alteration similar in character to that seen in the massive lavas but greater in amount. No glass is found in these tuffs, although microcrystalline areas with cuspate outlines are abundant, and evidently represent glass particles. The original porosity of the rock has facilitated the action of the heated waters that were probably the principal agent in the process of decomposition, and the material has been more thoroughly rearranged than in the lavas. The interstices between the fragments, as well as the vesicles of the lapilli, have been filled with secondary materials, as quartz, hornblende, and chlorite, and this cementation has transformed the original soft, porous ash beds to hard and compact rocks.

Metamorphosed basalts have been collected on the north slope of Kendall Peak and along the stream which drains the Park Lakes. The original basaltic texture is fairly well preserved. The lath-shaped feldspars are not much altered, though always somewhat clouded. The most striking change produced in the rocks is the generally advanced and often complete uralitization of the augite, a phenomenon rarely noticed in the basalts collected far from the granodiorite. In the more altered specimens the interstices between the feldspars are filled in with green amphibole and a finely divided greenish-brown mineral resembling biotite. The amphibole in some places forms ophitic plates and in others fine-grained aggregates. Olivine is not present, nor is it represented by recognizable pseudomorphs. Epidote, zoisite, and pyrite are less common secondary constituents. The amygdules of the basalt near Kendall Peak contain quartz, amphibole, the micaceous mineral referred to, and granular apatite.

The genetic relation of these changes to the granodiorite intrusion has been up to this point largely assumed, since it could not be satisfactorily discussed before the exact nature of the changes was shown. To sum up, these consist chiefly in the complete devitrification of the glass, the nearly complete alteration of the ferromagnesian constituents, and the more or less complete filling of supercapillary pore spaces. On comparing the rocks just described with similar rocks of the Keechelus series remote from the granodiorite, it is found that in most of the latter the same changes have taken place, but to a smaller extent. The difference is one of degree rather than of kind.

The agent that has been at work throughout the region is circulating water, and the alterations above described are such as are produced by that agent below the belt of weathering, in the belt of cementation. It is easy to understand how the activity of the water in surrounding rocks would be enormously intensified by the intrusion of a huge mass of igneous rock. The heat given off from the magma would greatly increase not only the solvent power of this water, but also the rapidity of its circulation, and thus intensify in a two-fold manner its efficiency as a metamorphic agent. Van Hise has pointed out that this indirect effect of intrusion is in general vastly greater than the direct effect of heat conducted into the adjacent rocks. There is possibly no clearer or more striking example of this species of metamorphism than this alteration of Miocene rocks by the intrusion of the Snoqualmie granodiorite.

PLIOCENE (?) SERIES.

HOWSON ANDESITE.

*Occurrence.*—North and northeast of the head of Howson Creek are two small areas of hornblende-andesite which can not be correlated with any other formation in the quadrangle. This lava was poured out upon an eroded surface of Swauk sandstone cut by basalt dikes of Teanaway age. The relations evidently prove that the andesite is much younger than the Teanaway, but there is nothing to indicate definitely an upper limit to its age. It is much fresher than the lower Keechelus andesites, and probably is not older than Pliocene or late Miocene. It is noteworthy that the Howson andesite resembles the rock forming a large proportion of the bowlders in the Ellensburg formation, a fact which suggests that the two formations may be of the same age, since the Ellensburg sediments were plainly derived from the products of contemporaneous volcanism.

*Lithology.*—These volcanic areas include no tuffs, but consist entirely of lava which shows well-developed columnar parting and breaks down to form extensive talus slopes. The rock shows black hornblende prisms and small phenocrysts of feldspar in a dull fine-grained groundmass, which is usually light gray but sometimes pink.

With the aid of the microscope the chief constituent of the rock is seen to be plagioclase, which seems to belong to three distinct generations. The larger crystals are of stouter habit and are more strongly zoned than the smaller, and have abundant glass inclusions. In addition to the hornblende there are in the gray andesite phenocrysts of hypersthene, smaller and less abundant. Interstitial between the plagioclase microlites of the groundmass are minute granules which appear to be of quartz and orthoclase, and a little glass. The hornblende is the most interesting of the minerals. In the gray andesite it is green, with moderate double refraction and an extinction angle of about 15°. It has the familiar resorption borders of magnetite and augite. In the red andesite the hornblende is of a markedly different variety, with a very small extinction angle, very strong double refraction, and a striking pleochroism (𝔞, deep reddish brown; 𝔟, lighter reddish brown; 𝔠, light yellowish green). The crystals generally show narrow borders of hematite, which in a finely divided state is thickly disseminated through the groundmass and gives the rock its color. Magnetite also occurs, however, as in the gray andesite. Since neither the gray nor the red andesite show any marks of decomposition the hematite of the latter is doubtless primary. The iron oxide was probably in considerable part peroxidized while the lava was at the surface and still fluid. The abundance of the sesquioxide doubtless determined the formation of brown hornblende rich in ferric iron.

QUATERNARY SYSTEM.

The Quaternary deposits are classified for purposes of description as glacial and alluvial. They are unconsolidated materials, confined mainly to the valley bottoms but usually not well exposed, and therefore not readily distinguished from one another. These two classes of deposits are not, indeed, sharply divided in nature, for they are in some places mingled, and, furthermore, much material loosened and carried a distance by ice has been again taken up and brought to its present position by water. On the map, where the more extensive of the Quaternary areas are shown, only the material evidently owing its present position and arrangement to ice transportation is mapped as glacial.

GLACIAL DEPOSITS.

Typical moraines are found just below Lake Keechelus in Yakima Valley, having the form of ridges slightly convex downstream, as is shown on the map by the topographic contours. These ridges are strewn with more or less angular bowlders of various sizes, many too large for transport by water. Lake Keechelus and the other large valley lakes are held back by moraines, so that the indirect effects of these glacial deposits are more apparent than the small ridges themselves. Two small moraines at the head of Gold Creek that were deposited by cirque glaciers are also indicated on the map. They have been undercut by the torrential streams on either side and the angular unsorted material composing them is well exposed.

A series of short morainal ridges border the western side of the swampy area in Snoqualmie Pass. The county road traverses several of these. The deposition of glacial gravels in this vicinity caused the diversion of Guye and Commonwealth creeks from their old course tributary to the Yakima, so that now they flow precipitously through a freshly cut canyon to join Denny Creek and other branches of the South Fork of Snoqualmie River. The divide between the head of Coal Creek and these creeks that in pre-Glacial times formed a part of the Yakima drainage system is so slight that the intervening space is largely covered by a swamp.

In addition to these morainal ridges there are other glacial deposits which are too ill defined or too small to map, but which nevertheless afford indications of the length and depth of the extinct glaciers. There are suggestions of morainal topography near the mouths of Kachess and Clealum valleys, on Naches River near the forks, and in Yakima Valley near the eastern edge of the quadrangle. Bowlders stranded on the sides of the once glacier-filled valleys are found at many places. East of Lake Keechelus they were noted about 1200 feet above the water level, west of Little Kachess Lake and south of Howson Creek they occur about 1700 feet above the nearest points in the valley bottoms, and some were observed about 1200 feet above Yakima Valley, on the knob south of the mouth of Big Creek. These figures, of course, give minimum values for the depth of the valley glaciers at the various points.

ALLUVIAL DEPOSITS.

The larger valleys have broad floors covered with stream deposits, the most extensive alluvial areas being in the northern and eastern parts of the quadrangle, along Yakima River and its tributaries. Along Clealum River and the Yakima below Easton the stream deposits are well exposed in steep bluffs and consist mainly of clean, well-rounded gravel. In a railroad cut below Nelson, and another 2½ miles above Easton, silts and sands are more abundant. Gravel terraces are well developed in the lower valleys, especially along the lower Clealum and the Yakima near the point where it leaves the quadrangle.

The gravel deposits in the eastern part of the quadrangle, as shown by borings just east of the boundary, are of great depth, the bed-rock floor being lower there than where the river flows over basalt, several miles down the valley. This is possibly due to over-deepening by the great valley glacier. Isolated areas of alluvium in the tributary valleys, especially along several branches of Clealum River, indicate similar irregularities in the bed-rock channel. A most striking instance of such erosion is seen above Easton, where a barrier of rock cut by the narrow gorge of the river separates the broad gravel-covered portions of the valley above and below.

The important gravel deposits of the large valleys were doubtless formed during and after the retreat of the valley glaciers, by streams overloaded with glacial débris. The process is illustrated in miniature at the head of the West Fork of Clealum River, where the turbid stream draining the glacier on the "7512" peak is forming, in the first gently sloping portion of its canyon, a long delta of subangular glacial wash, over which it flows turbulently, with frequent shiftings of its channel.

WIND-BLOWN VOLCANIC SAND.

Surface material of another type consists of thin layers of volcanic sand found at many localities in this and other parts of the Cascade Range. Most of these deposits occur on the flat tops of the highest peaks or in hollows on the slopes, where they have been protected from erosion. The sand is composed largely of crystals of feldspar and pyroxene, and its character suggests that it is the finer portion of material ejected from some volcano of the Rainier type and carried by the wind to its present position.

STRUCTURE.

*Areal distribution of formations.*—In a broad way the geologic structure of the area is indicated by the surface distribution of the rocks of the different periods, as shown on the areal geology map, a fuller interpretation of these areal relations being exhibited in the structure sections. A brief statement of the areal relations of the formations will therefore fitly serve as an introduction to the discussion of the structure.

The pre-Tertiary formations reach the surface in four belts. The most northern is in the extreme northeast corner of the quadrangle, and the rocks here exposed extend 20 miles farther east, forming the Mount Stuart massif. The next area of old rocks forms ridges north and east of the Kachess lakes. Another belt of the pre-Eocene rocks composes the bold ridge extending southeastward from Easton, and it is interesting to note that a tiny island of schist in the middle of Kachess Lake serves to connect, in a way, this belt with the area next north. The fourth belt forms the core of the high ridge northeast of Naches Valley, and is notable as containing exposures of all the pre-Eocene formations.

Throughout the eastern half of the quadrangle, Eocene formations cover the areas intervening between these belts of pre-Tertiary rocks, except for a few cappings of Miocene lavas. It may be noted that the youngest of these Eocene formations, namely, the Roslyn and Manastash sandstones, occupy areas on the extreme eastern margin of the quadrangle.

Nearly the whole of the western half of the quadrangle is occupied by the Miocene formations, the Keechelus lavas alone covering probably one-third of the quadrangle. Outliers of the Keechelus lava and Yakima basalt farther east have already been mentioned. This distribution of the youngest rocks, taken with the areal relations already determined on the adjacent Mount Stuart quadrangle, amounts to a roughly semicircular disposition around Mount Stuart as a center. This arrangement should be interpreted as indicating a dome structure only in a broad way, but since the older rocks of this region constitute, in the Mount Stuart massif, the very highest peaks of the region, the dome conception is of value as a simplified expression of the complex structure to be described below.

*Pre-Tertiary rocks.*—These formations have been subjected to severe dynamic action. So complex has been the folding of the three principal formations that their true stratigraphic relations can not be surely determined. The supposition that the Easton schist is the oldest formation in the region is based primarily upon the contrast between its intensely crumpled and thoroughly crystalline condition and the comparatively slight alteration of some of the clay slate in the Peshastin formation. The relative age of the Hawkins and Peshastin formations is somewhat in doubt, as has been stated above.

The schistosity, joint, and bedding structures in the pre-Eocene formations commonly show high dips, which are often vertical. Over large areas the strike of these will likewise be fairly constant, the northwest-southeast trend prevailing. The influence of these structures upon the older intrusives can be seen in the rectilinear boundaries of the quartz-diorite mass intrusive in the schist southeast of Easton, as well as in the direction of the serpentine dikes intrusive in the different pre-Eocene rocks on the next ridge south.

On the geologic map the pre-Tertiary formations of the southeastern area, although represented in different colors, are not separated by definite boundaries. This convention is made necessary by the difficulties encountered in attempting to delimit these formations in the field. In some portions of the Manastash and Taneum basins the thick mantle of soil contains small fragments of slate, serpentine, and green schist, indicating that these rocks underlie the surface in complex relations. In the absence of data for drawing even rough boundaries the areas have been colored on the map with the tint appropriate to the rock predominating in the soil.

*Eocene formations.*—In considering the structure of the Eocene rocks, it is of prime importance to realize the influence of preexisting structure and the topography determined by it. Study of the varying sections of the Swauk sediments clearly indicates that the areas of schist which extend into the area of Swauk sandstone not only represent anticlinal axes, but mark as well the position of old Eocene ridges which outlined and separated the different Eocene basins. So too, the ridge of schist and diorite south of Yakima Valley formed the boundary between the Swauk and Naches basins in early Eocene time and also the southern limit of Roslyn sedimentation in the late Eocene, and finally, at the close of the Eocene, it became the southern limb of the Roslyn syncline. In short, these east-west and northwest-southeast Eocene ridges of older rock became the axes of some of the larger post-Eocene anticlines.

The folds in the Eocene rocks are mostly of the type of gentle flexures. Several anticlinal axes can be traced in the large area of Swauk sandstone, so that the structure is in no case a simple monocline dipping to the southwest, but is rather a succession of open folds whose axes show a general southeast trend. The area of Roslyn sandstone in this quadrangle represents simply the end of the large syncline which pitches to the southeast. This Roslyn syncline also involves the Teanaway basalt. At Kachess Lake the end of the synclinal axis is roughly paralleled by an anticlinal axis, the position of which is indicated by the small island of schist, and farther west, the mountain of basalt, bordered both east and west by the underlying rhyolite, marks another synclinal axis. The latter syncline can be traced southeastward nearly to the corner of the quadrangle and as a structural feature is well exhibited in the vicinity of the peak "6261," where two sheets of Kachess rhyolite, with the intercalated sheet of Teanaway basalt, form an open syncline which passes into a U-shaped fold both to the north and to the southeast.

One important structural feature of Eocene date, but affecting Eocene rocks principally, should be mentioned. The dikes that represent the conduits for the Teanaway basalt flow present a striking parallelism, due to the preexisting joint system in the sandstone. As studied in this and the Mount Stuart quadrangles these dikes not only possess this uniformity of trend, but also seem to be wholly independent of the folds in the Swauk sandstone. Other noticeable characters in this dike system are the extremely rare occurrence of intrusive sheets and the almost universal absence of local deformation or displacement of the sandstone or shale forming the walls of the dikes. When the large mass of intrusive material added to the region in the form of these dikes is considered, this absence of disturbance of the walls is remarkable. These facts bear upon the structural conditions at the time of this intrusion. There must have been tension or at least so little lateral pressure that the molten magma could freely open the joints in the rock, and notwithstanding the introduction of great quantities of the basalt as well as the accumulation of several thousand feet of lava at the surface, no vertical adjustment along these dike walls was necessary.

*Miocene formations.*—The Miocene rocks, with the exception of the Guye formation, have been but moderately deformed. The strata in the vicinity of Snoqualmie Pass are closely folded, and this deformation apparently took place during Miocene time, since the Keechelus lavas overlying the Guye formation do not show at all the same amount of folding. In the large area of the Keechelus series dips of 30° and 50° are observed, but, as has been mentioned before, it is difficult to know how much of this inclination may be due to initial slope of the lavas.

The axes of post-Miocene uplift will be described under the heading "Historical geology." It is sufficient here simply to note the identity of these with the axes of Eocene and earlier folding, especially with that marked by the high ridge north of Naches River. The persistence of this structural axis is noteworthy.

*Faults.*—A few small faults can be detected in the Swauk formation, especially near its contact with the older rocks in the northeast corner of the quadrangle. More important faults occur on the high ridge north of Naches River. Two of these border the syncline already described, while another is of sufficient throw to bring the Miocene basalt against the pre-Eocene rocks, the basalt at the base of the slope dipping 35° toward the older formation.

At its southeast end, near the edge of the quadrangle, this last-mentioned fault appears to be of recent date. The freshness of the scarp and its relation to what appears to represent the old lowland surface strongly support the conclusion that this faulting occurred during the uplift of the range. The position of the fault and its direction suggest a possible connection with the axis of the uplift, indicating that the uplift was too great to be effected by a gentle upwarp of the peneplain, so that local adjustment by dislocation became necessary.

In conclusion, it must be pointed out that the numerous unconformities in this region show that the structure is not simple but complex, and its true interpretation must therefore distinguish between the work of distinct periods of deformation and recognize that the observed structure is the resultant of all the movements. There is not only a striking uniformity in the trend of all structural features but there has been throughout the Eocene and later periods a persistence in the structural axes. These relations are the more noteworthy in that these axes, which control both pre-Eocene schistosity and postpeneplain warping, are transverse to the general trend of the Cascade Range.

### HISTORICAL GEOLOGY.

The geologic history of the area described in this folio is largely the interpretation of the facts already presented. Three main divisions will be made in this geologic history—the pre-Tertiary, the Tertiary, and the Quaternary, all well-differentiated time divisions in the Cascade province. For the first two of these divisions the available history is contained in the rocks, but for the third the record of events is mainly physiographic.

#### PRE-TERTIARY TIME.

*Formation of the oldest rocks.*—The oldest rocks in the area are probably of Paleozoic age, judging from their lithologic similarity to those of known Paleozoic formations. As has been shown, these rocks are in large part metamorphic—that is, they have been altered from their original condition—yet sufficient remains of their original characters to show that the schists, slates, and greenstones of the Easton, Peshastin, and Hawkins formations represent both sediments and products of volcanic activity. Paleozoic rocks strikingly similar to those of the Snoqualmie area are found in California, in the Blue Mountains of Oregon, and in the Okanogan Valley in Washington, south of the international boundary. The inference from this distribution is that during a portion of the Paleozoic time the Pacific Coast region, from British Columbia to California, constituted a single geologic province.

The absence of Mesozoic sediments in this central Washington region suggests that it became a land area during Mesozoic time. The existence of a thick mass of Cretaceous rocks in the Northern Cascades immediately south of the international boundary shows the extension of the Cretaceous sea southward from British Columbia, while rocks of similar age in the John Day basin and Blue Mountains of Oregon mark the southern limit of this central land. Later formations conceal these older rocks over large areas, but future geologic study may furnish data for a description of the Paleozoic and Mesozoic geography, which can only be touched upon now.

*Igneous intrusions.*—The next recognized event in the geologic history of the region was the injection of large masses of molten rock into these older rocks. The schists, slates, and greenstones of the Easton, Peshastin, and Hawkins formations had been folded and uplifted from their original positions when the intrusions of igneous rock began. The earliest of these was that of the extremely basic magma which crystallized to form the peridotite, now largely altered to serpentine. In the northeastern part of this area this intrusive rock cut across the older rocks and so divided the complex of sedimentary and volcanic rocks that their original disposition can not be determined. In the southern region the basic intrusive simply filled small fissures so that the dikes of serpentine now observed are narrow and relatively unimportant.

The next intrusions were of a different character. A large body of dioritic magma was forced into the Easton schist, its boundaries being largely determined by the structural planes in that metamorphic rock. To the north, in the area closely adjacent to this quadrangle, the Mount Stuart batholith of granodiorite represents an intrusion on a large scale, its main mass measuring many square miles in area and being represented in this quadrangle by smaller masses, the intrusion of which is believed to have followed that of the quartz-diorite.

*Erosion.*—Nothing definite can be stated regarding the age of these igneous intrusions. The nearest date that is fixed is the beginning of the Eocene, but at that time the granodiorite, serpentine, and older rocks had suffered a large amount of erosion. The cover under which the granular rock masses had consolidated had been removed and the rocks of varying hardness had been carved so as to form a region of bold relief. This interval of time, during which atmospheric agencies accomplished so much, is measured by the great unconformity between the older rocks and the earliest of the Tertiary sediments.

#### TERTIARY PERIOD.

*Early Eocene sedimentation.*—Conditions favoring the deposition of the waste from the eroded rock masses began early in the Eocene epoch. Coarse bowlders of granodiorite, serpentine, and other rocks accumulated near their parent ledges and were successively covered with finer sediments. Since these contain no marine fossils, it is believed that these sands and muds were deposited in the rising waters of a large Eocene lake. The rugged topography caused the coast line to be extremely irregular, so that inclosed lagoons and narrow inlets doubtless occurred in close proximity to bold headlands. The sediments of this epoch were therefore extremely varied in character, and fine muds and coarse granitic sands may have been laid down contemporaneously in adjoining areas. The relief of the region is indicated also by the fact that the larger part of the Swauk formation is composed of fresh arkose, plainly derived from the Mount Stuart granodiorite under conditions of active disintegration of the granitic rock, with little alteration of the mineral fragments. In a larger way the topographic character of the region in early Eocene time is shown by the distribution of the Swauk formation. The absence of this sandstone at several places where the younger formations overlap upon the pre-Eocene rocks, as well as the conspicuous thinning of the Swauk strata in the southwestern portion of the area of that formation, may well be considered as suggesting the limits of the Swauk lake at the time of its greatest extent and the location of prominent ridges that determined the shore lines at earlier stages.

In the southern half of the area here described it seems that there existed, in early Miocene time, a body of water that was separated from the Swauk lake until near the close of this epoch of sedimentation. Here the conditions of sedimentation were different, since in the Naches lake not only were sands and muds deposited, but basaltic lava flows were poured over these sediments from time to time in increasing amount, so that toward the last the lavas became thicker than the intercalated sediments. This was the beginning of the volcanic activity that characterized the whole of the Tertiary. The boundaries of the basin in which the Naches formation accumulated can not be determined, but, although the Naches strata contain a few of the same species of plants that are carried in the shales of the Swauk formation, yet it is noteworthy that the two basins, though closely adjacent, were the scenes of very different geologic activities. In the Swauk lake there was apparently no interruption of quiet sedimentation until near the very close of the epoch, while in the Naches basin during the same time there were successive eruptions of basaltic lava.

The result of the deposition of these sediments and the accompanying lava flows would have been to efface the earlier topographic diversity had not other geologic forces been active. The erosion unconformity at the base of the overlying Teanaway basalt makes it probable, however, that local elevation and gentle flexing of the rocks terminated the epoch represented by the rocks of the Swauk and Naches formations.

*Volcanic eruptions.*—Erosion had commenced the work of truncating certain of the folds in the Swauk and Naches strata when volcanic activity began on a larger scale. Even before the basaltic eruptions in the Naches basin ceased, flows of rhyolitic lava were poured forth in the same area, with the result that the lowest sheets of Kachess rhyolite are intercalated with the Naches sandstone and basalt. Later flows of the same lava, probably from a southern center of eruption, extended farther north and covered the Swauk sediments along their western edge. Owing to its high melting point, the rhyolitic lava became viscous soon after reaching the surface, so that the rhyolite did not spread out like the basalt in horizontal flows, but appears to have consolidated into thicker masses, even taking the form of low ridges or mounds with moderately steep sides.

Before the rhyolitic eruptions ceased, basaltic lavas again spread over a large area. In the southern part of this quadrangle these flows were less important and the sheet of basalt associated with the rhyolite flows probably represents the thin margin of the Teanaway basalt which was erupted from the fissures to the northeast. In the northern region, however, these eruptions were on a large scale, the whole area being covered with successive lava flows, which in places reached a total thickness of over a mile.

This volcanic material reached the surface through hundreds of cracks in the sandstone, serpentine, slate, and other rocks. For the most part the lava spread out in great sheets, while in certain localities the presence of steam in the molten rock appears to have caused explosive eruptions, thick beds of basaltic tuff being intercalated with the lava sheets.

*Later Eocene sedimentation.*—The violent volcanism was generally succeeded by quiet sedimentation in the later part of the Eocene. Sedimentation began in the western parts of the area before the last flows of Teanaway basalt were erupted and in the sandstones and shales thus intercalated in the basalt fossil leaves are found that afford evidence that farther west the conditions favored forest growth. A land area must have existed, therefore, between this and the Puget basin, the sediments of which contain the same flora.

The sands and muds deposited in this later Eocene epoch appear to have been better sorted than the materials composing the earlier Eocene sediments. Vegetal matter, like that present in the earlier formations, now became prominent, and during the later part of the epoch represented by the Roslyn formation the conditions of sedimentation were such as to allow the deposition of several beds of carbonaceous material, which now furnish workable seams of coal.

Sedimentation during Eocene time appears to have taken place in basins that were neither extensive nor permanent. The relation of the Swauk and Naches lake basins has already been referred to; and in the latter part of Eocene time the Roslyn waters did not extend far to the south, since the basal sediments of the Manastash formation, which is of later Eocene age, rest directly upon the pre-Tertiary schists. The deposition of the sands and muds, which have now become indurated and form the rocks of the Manastash formation, closed the Eocene sedimentation so far as the record is known.

*Earlier Miocene eruptions.*—The stratigraphic break between the Eocene and Miocene epochs indicates a time of erosion in this area. Only in the southeast corner of the quadrangle is the record at all complete. Here the rocks of the Manastash formation were somewhat folded after their deposition late in the Eocene. Erosion followed, and this was continued for a considerable time, to be terminated by a recurrence of volcanic activity, the eruptions of the Eocene being only a prelude to the volcanism of Miocene time.

The Miocene volcanic activity opened with the eruption of the Taneum andesite, a relatively unimportant formation. Immediately after this, however, came the eruption of the Yakima basalt, which was poured forth over a vast area, the western margin of which comes within the Snoqualmie quadrangle. The basaltic eruption during the Miocene epoch constitutes one of the greatest of known volcanic phenomena. The mass of these basalt flows, which extend beyond the boundaries of the State of Washington, is measured in terms of thousands of cubic miles, and the transfer of so great an amount of material from the earth's interior to the surface ranks as one of the greatest geologic events. However, these eruptions were for the most part unmarked by violence, being of the nature of a quiet upwelling of fluid lava from a number of vents. Dikes and intrusive bodies of diabase representing the old conduits can be seen where the older rocks underlying the basalt are exposed. The dikes, however, are not so numerous as those which fed the Eocene basalt flows.

These lava flows were poured forth over a region having considerable relief, but the surface inequalities were soon obliterated by the floods of molten rock which filled the deepest depressions and lapped over the higher portions of the old surface. Eventually the region, which before had been diversified with verdure-covered hills and valleys, became a monotonous waste of black rock.

*Miocene sedimentation.*—Possibly contemporaneous with the basalt eruptions there was sedimentation in the northwestern part of the area here described. The Guye formation includes grits, sandstones, shales, chert, and limestone, sediments deposited in a basin whose extent is not known, since these strata have not been recognized except in the vicinity of Snoqualmie Pass. Associated with the sediments are flows of both basalt and rhyolite, again affording striking evidence as to the constant recurrence of eruptive activity, even at a distance from what seemed to be the main centers of volcanism.

The Guye strata were soon subjected to extreme dynamic action and closely folded. The marked alteration of these rocks is not due wholly to this folding, since later intrusions were probably more effective in their metamorphism.

*Later Miocene eruptions.*—Erosion had begun to attack the rocks of the Guye and other Miocene formations when another epoch of widespread volcanism was inaugurated. This differed from earlier eruptions in that the lavas were largely andesitic, although both basaltic and rhyolitic phases occur. The eruption of the Keechelus andesitic series was on a large scale, possibly exceeding in importance that of the Teanaway basalt, and even in some degree comparable with that of the Yakima basalt. Dikes leading up to these flows, similar to those associated with the Eocene basalt, are not common, but the lavas and tuffs of the Keechelus series appear to have been erupted from volcanoes whose sites are marked by the areas of pyroxene-diorite. Although the lavas and tuffs of this series cover nearly a third of this quadrangle, this area represents only a small part of their extent to the south and west. These volcanic rocks accumulated over this area to a thickness of several thousand feet, and the volcanoes from which the material issued may have been active throughout the rest of Tertiary time, or, indeed, into the Quaternary, when the neighboring cone of Mount Rainier began to be built up.

At one locality a lens of sedimentary material occurs in this Keechelus series, showing that the volcanism was not continuous, and the fossil leaves found in the shale indicate that these interludes were long enough to permit vegetation to become established in the vicinity.

The occurrence of several small areas of typical Ellensburg gravels upon the surface of the Keechelus lava affords evidence that in late Miocene time the streams that distributed fluviatile material over the lower country to the southeast deposited a part of their burden here. It seems, indeed, probable that the volcanic material of the Ellensburg sediments may have been in part derived, by erosion, from portions of the Keechelus lavas.

*Intrusion of granodiorite.*—No exact date can be assigned to the granitic intrusion in the northwestern part of the quadrangle. The Snoqualmie granodiorite plainly intruded the Guye formation and Keechelus series, both of which are of Miocene age. The intrusive mass contains many cubic miles of material, the area covered by it extending far beyond the Snoqualmie quadrangle. The transfer of this large amount of molten rock into strata of Miocene age must have produced orographic results that were much more important than the local metamorphism of the intruded formations. The amount and kind of the contact action can be directly observed, and has been described in an earlier part of this folio, but the broader influence of the batholithic intrusion upon the structure of the Cascade Range can only be surmised. Its occurrence so late in the Tertiary period, which probably closed with the uplift of the mountain range is suggestive, although the statement that this intrusion had a causal relation to that uplift would hardly be justified. The Cascade uplift was effective over a much larger area than that in which there is reason to suspect the presence of intrusions of this age, so that it is more probable that the localized intrusions and the broad mountain uplift are simply concomitant manifestations of the same earth forces.

More definite statements can be made regarding the depth at which this granular rock crystallized than are usually possible. Apparently only two formations constituted the cover of the batholith over most of the area that has been mapped. In the portion of the granodiorite mass at the head of Gold Creek the Keechelus andesitic series alone is present as the intruded rock, and since, so far as can be determined, no other formation has overlain this volcanic series in this portion of its area, a close approximation to the depth of the intrusion in this locality seems possible. Here the peaks composed of the horizontal lavas rise not over 2000 feet above the highest contact with the granular granodiorite, which is 2000 feet above the base of the Keechelus series in this vicinity, and an additional 2000 feet would seem, with all the observations in mind, a very reasonable estimate of the amount eroded from such peaks, inasmuch as this allows an original thickness of 6000 feet for the Keechelus series in this part of the area. The intrusive mass therefore reached within 4000 feet of the upper surface of the volcanic rock. The intrusive rock in this vicinity retains its uniform granular texture close to the contact, although dikes extending upward into the overlying rock exhibit the usual change in texture. The slow consolidation of the intrusive magma must have been favored by the presence of residual heat in this mass of late Miocene lavas.

*Uplift and erosion.*—The presence of local unconformities between the various Tertiary formations is proof of uplift and erosion at different times. The latest events in this period were doubtless of the same character, differential uplift producing gentle folds, on the arches of which the rocks were exposed to erosion. In the Ellensburg quadrangle, which is immediately southeast of the Snoqualmie quadrangle, there is conclusive evidence of moderate flexing of the Miocene formations and their reduction to an approximately level plain, or peneplain, to which a Pliocene age has been assigned.

The absolute identification of this Pliocene lowland surface is difficult outside of the region bordering the valley of the lower Yakima River. In the heart of the range it can not be recognized, and the only places in the Snoqualmie quadrangle where the old surface may possibly remain are in the southeastern corner. On the high ridge north of Naches River, near the head of the South Fork of Manastash Creek, there are level tops, which are eroded on rocks of different formations, and are strikingly different from the surrounding topography. These exceptional topographic forms are strongly suggestive of the Pliocene peneplain, recognized 10 or 15 miles to the southeast.

*Résumé.*—In the Cascade province, the Tertiary period was essentially a time of volcanism. Eruption closely followed eruption, the basaltic floods in the Naches basin continuing even while the flows of rhyolite were poured forth over the same area, and the lava streams being in turn quickly covered by molten basalt in the northern area. Thus the lavas erupted in Eocene time from different centers united to form a thick mantle of volcanic rocks over the larger part of the region here described. Between these eruptions sediments were deposited in local basins, but often the processes of sedimentation were interrupted by the encroachments of lava flows. During the Miocene, andesitic lavas alternated with basalt outflows, while beneath the surface large masses of magma were intruded. In adjacent areas and probably in this quadrangle as well, this volcanic activity extended into the Quaternary.

### QUATERNARY PERIOD.

*Main uplift of the Cascades.*—The later uplift of the lowland surface just referred to was undoubtedly connected with the birth of the present Cascade Range. This was perhaps the closing event of the Tertiary period, but present knowledge of the later history of this area is too incomplete to warrant a sharp separation between Tertiary and Quaternary time. The uplift of the Cascade Range inaugurated the present cycle of topographic development, and it may be said that the commencement of this widespread deformation marked the end of the Tertiary, or with equal probability it may be stated that this warping and uplift were events of late Pliocene time which continued into the Pleistocene.

The character of this mountain uplift can be determined by a consideration of the physiography of the region. The distribution of the high peaks in the Snoqualmie quadrangle is believed to give a clue to the nature of the uplift of this portion of the range. If only elevations of 5000 feet and over are considered, it will be noted that these fall into three groups. The southernmost of these groups lies on both sides of the main divide and extends both east and west beyond the boundaries of the quadrangle; the group next northward composes the high ridge forming the divide between Yakima and Naches rivers; while the third line of heights is near the northern edge of the quadrangle. The trend of these elevated regions is slightly north of west, or nearly at a right angle to the main drainage divide of the range. Since uplift has outstripped general degradation in the development of the mountain range, this arrangement of the areas of topographic prominence may be taken as indicating the positions of the areas of uplift.

The possibility that the prominence of the three lines of heights is due to selective erosion rather than to differential uplift is opposed by the fact that both stream and glacial erosion have been and are most active in their attacks upon the northern heights, while along the lower part of the north-south divide the common occurrence of a thick mantle of soil shows how much less effective are the agents of transportation there than on the slopes of the higher east-west ridges. Although the highest peak in the area—the "Needles," 7512 feet—is made up of the resistant metamorphosed Keechelus lavas, yet the next highest peaks, in the northeast corner of the quadrangle, are composed of relatively soft serpentine; and again, the low part of the main divide at Stampede Pass is in exactly the same rock as the high country farther south. From these relations it would appear that rock character has not been a controlling factor in determining the location of the heights. The conclusion appears warranted that the uplift of this portion of the Cascade Range took the form of three well-defined upwarps, transverse to the axis or trend of the range, considered in its whole extent. Two of these axial uplifts extend eastward and connect with similar elevated regions. The northernmost line of heights is thus continuous with the prominent Mount Stuart massif, which forms the axial portion of the supposed Wenatchee Mountain upwarp of the peneplain; and the ridge between the Naches and the Yakima finds its topographic continuation in the Manastash and Umptanum ridges in the Ellensburg quadrangle, which are known to represent upwarps of the old lowland surface, the evidence being cited in detail in the Ellensburg folio. To the east these upwarps die out in the Columbia Plain, so that the transverse uplifts may be considered as details in the broad uplift of the Cascade Range, which trends approximately north-south.

*Development of present topography.*—The broad configuration of the Cascade Mountains is the direct result of the uplift just described, and it is further argued that this direct relation of topographic prominence to uplift extends even to many of the minor features, yet the relief as we see it to-day is the result of the active work of degradation that was inaugurated when the uplift of the peneplain began. This work of sculpturing the elevated rock masses into the present land forms has continued throughout Quaternary time. Owing to the heavy precipitation in the area here considered, erosive processes have been very efficient, and the relatively young range, which owes its origin to so recent an uplift, is already characterized by maturity of topography.

The processes of rock disintegration and of detritus transportation have been so energetic over most of this area, especially its more mountainous portions, that in a broad way the varying resistance of different rocks appears to have been an inefficient factor in determining the general topographic form. Rugged and high peaks of sandstone or serpentine may overtop ridges of basalt, while broad, glaciated valleys cut across the hardest as well as the softest formations. Yet, in the development of topographic detail, rock character is a modifying if not a controlling factor.

*Stream history.*—In outlining the part played by the streams of this area in the development of the topography, little can be said of the streams tributary to Puget Sound, as their history has not been worked out. The master eastward-flowing streams, Yakima and Naches rivers, have been studied in their lower courses. The Yakima established its lower course before the uplift of the peneplain and maintained it, while Naches River is believed to be antecedent in a part if not in the whole of its lower course. In the Snoqualmie quadrangle the drainage appears to have a mixed character as regards its relationship to the uplift of the region. The Naches is for the most part consequent, in that it follows the line of depression between the two axes of uplift mentioned above. The upper Yakima likewise occupies an area of relative depression, and this position may explain the notable fact that its broad low-grade valley extends so far back into the heart of the range. The history of the most important tributary of the Yakima, Clealum River, is less simple. This river appears to head somewhat north of the northern or Wenatchee Mountain axis of uplift, and has deeply dissected the elevated region in the northeast corner of this quadrangle. This position of the Clealum must have been antecedent to the uplift, which was so gradual that the stream has maintained its course with no essential change since the time it flowed across the Pliocene lowland.

The drainage of this area therefore appears to be in part dependent upon the position of the axes of uplift and in part independent of it, the canyons cutting directly across the regions of maximum elevation. This variation in the amount of agreement between drainage and deformation may be due to the fact that the later or post-Pliocene warping followed to some extent lines of earlier deformation, so that streams which previous to the peneplanation had adjusted themselves to the earlier structure might appear to be consequent upon the warped surface, although in reality they are antecedent to this later warping.

Drainage modification has been effected to some extent within this quadrangle. The most noticeable example of capture of the headwaters of one stream by another is at Snoqualmie Pass. Commonwealth and Guye creeks were evidently once tributary to Coal Creek and thus formed a part of the headwaters of Yakima River. Glacial obstructions at the Pass, however, caused the diversion of their waters westward into the South Fork of Snoqualmie River. So low is the divide in the swampy area of the Pass that it would require very little engineering work to divert these waters again into their original course.

*Glaciation.*—Evidences of glacial action are confined to the northern half of the Snoqualmie quadrangle. The existing glaciers near the northern edge of the quadrangle have already been mentioned. These are remnants of large glaciers for which the high mountains in this region formed the center. The longest lobes of this ice mass extended southward as three ice streams, which from their approximate relations to present drainage lines may be called the Keechelus, Kachess, and Clealum glaciers. These were glaciers of the alpine type and were important agents in modifying the preexisting topography, widening and deepening the upper valleys considerably. The topographic features due to glaciation have already been mentioned under the heading "Relief." The four large lakes in this quadrangle, as well as scores of smaller ones, owe their existence either to glacial excavation or to damming by glacial deposits, most of them to both. Probably all three of these glaciers reached the main Yakima Valley at some time in their history. South of Easton a ridge about 1000 feet high immediately borders the valley and back of this ridge there is a well-defined valley, parts of which are now tributary to several streams. The most plausible explanation of this exceptional feature seems to be that this side valley was eroded when ice occupied the main valley, and it thus marks the line of escape to the southeast for the waters which accumulated along the side of the glacier.

Connected with this epoch of glaciation was the deposition of the gravels and silts of the valleys. The increased precipitation which is believed to have characterized this epoch greatly augmented the general degradation of the region, and large quantities of rock detritus were then contributed to the streams. This loading of the transporting waters was so complete that when the gentler grades of the lower valleys were reached the streams were unable to move the whole of their load and thus began to aggrade their beds. These gravel deposits are much more extensive along the main Yakima Valley, where their thickness must reach hundreds of feet. Since these glacial gravels were deposited the principal stream work has been the reexcavation of the valleys. This has been effected only to a slight degree, and along with this has gone the deposition of sediment at the upper ends of the lakes. The silting up of the large lakes from this cause has been sufficient to be noticeable, especially at the place where the deposits of two streams have caused the separation of Kachess and Little Kachess lakes.

## ECONOMIC GEOLOGY.

### COAL.

The most valuable mineral resource of Kittitas County is coal. The Roslyn basin, the western end of which lies within this quadrangle, is one of the most productive coal basins on the Pacific Coast. The coal occurs in the upper part of the Roslyn formation, and the extent of this productive portion, together with the location of mines, is shown on the economic geology map. The upper beds of the formation have been eroded except in the center of the basin, so that the coal field is limited to the vicinity of Ronald and thence extends eastward into the Mount Stuart quadrangle. The outcrop of the Roslyn coal can be traced along the northern side of the basin, but on the southern side the deep gravel filling conceals the rocks beneath and the mapping of this boundary of the basin is based wholly upon data derived from general observations of the structure made elsewhere. As shown on the map there are about 4 square miles of possible coal lands in the Snoqualmie quadrangle.

The structure of the Roslyn basin is simple. The dip of the coal beds is low, 10° to 20°, and no faults have been discovered in the basin as studied in this and the Mount Stuart quadrangles. As can be seen from the geologic map, which shows the areal distribution of the Roslyn and underlying Teanaway basalt, the axis of this basin pitches to the southeast, and since the fold is somewhat unsymmetrical, with lower dips on its northern side, the axis of the basin is nearer the southern edge. Thus the deepest portion of the shallow basin in this quadrangle is probably along the line of the Northern Pacific Railway between Ronald and Roslyn.

Several beds of coal are known in the Roslyn basin. The principal one of these is the Roslyn seam, which is most extensively mined at the town of that name, half a mile east of the edge of this quadrangle. In fact, many of the workings of the Roslyn mine, the largest in the State, are within the Snoqualmie quadrangle, although the shaft and principal works are at Roslyn. The Roslyn seam was earlier mined from works at Ronald, but now this place is almost deserted. The annual product of the Roslyn and Clealum mines, which are operated by the same company, is about 1,000,000 tons.

The Roslyn coal is a coking bituminous coal, well adapted for steam raising and gas making. It is an excellent fuel for locomotives, and over one-half of the product of this field is sold for railroad consumption. The cleanness of the coal and its high percentage of lump fit it well for shipment. Naval tests have shown that the Roslyn coal ignites quickly, combustion being rapid and thorough, the coal swelling slightly on the surface of the fire. The percentage of ash is moderate, and the clinkers formed do not cling to the grate bars, except with forced draft. The amount of soot formed and the high temperature in the uptake are the only objectionable features of this coal.

Analyses have been made of samples of the Roslyn coal from a series of openings extending from the Clealum mine through the Roslyn mine to the northwestern extremity of the basin. These analyses, which were furnished by L. S. Storrs and are given below, show the variation in this seam from a lignitic, noncoking coal to a fairly good coking coal. The samples are numbered in an order that represents the localities at which they were taken, beginning with the open part of the fold, beyond the edge of the Snoqualmie quadrangle and continuing toward its more steeply inclined portion within the area described here. The change in the coal is therefore considered as an expression of the increase in the amount of dynamic action as the heart of the Cascade Range is approached. The coking tests show that the best coking coal comes from the portion of the field included within the Snoqualmie quadrangle. The coal from the western part of the field is also reported to be much better adapted for gas making than that from any of the other localities.

*Analyses of Roslyn coal samples arranged numerically from east to west through the basin.*

| Sample. | Moisture. | Volatile matter. | Fixed carbon. | Ash. | Character of coke. |
|---|---|---|---|---|---|
| 1 | 4.69 | 38.89 | 44.27 | 12.15 | Sinter. |
| 2 | 4.39 | 38.61 | 47.28 | 9.72 | Strong sinter. |
| 3 | 3.50 | 40.35 | 49.08 | 7.07 | Cokes. |
| 4 | 2.12 | 37.64 | 48.13 | 12.11 | Fair coke. |
| 5 | 2.02 | 38.17 | 47.25 | 11.56 | Fair coke. |
| 6 | 2.13 | 36.77 | 46.48 | 14.62 | Good coke. |
| 7 | 1.87 | 32.19 | 44.55 | 21.39 | Very strong coke. |

Two small mines are operated at the western end of the Roslyn basin. The coal mined here is of good thickness, but contains a heavy clay parting in the middle of the seam. The product of these mines is mostly shipped by rail to points in eastern Washington.

Prospecting for coal has been carried on in the vicinity of Coal Creek near Snoqualmie Pass, where the Guye formation includes some dark, carbonaceous shales. At several points on the mountain between Keechelus and Kachess lakes the sandstones and shales interbedded with the Teanaway basalt have also attracted prospectors for coal, but here also, while the rock is leaf bearing and black, the indications of coal are very slight. The other dark leaf-bearing shales in the Eocene and Miocene formations, other than the Roslyn, contain little to justify prospecting for coal. The conditions under which these sediments were deposited were not favorable to the accumulation of carbonaceous material in sufficient amount to form coal seams.

### IRON.

The absence of any large deposits of iron ore on the Pacific Coast has stimulated prospecting for iron in Washington. Among the localities in which deposits of iron minerals have been found, two of the more promising are within the area of the Snoqualmie quadrangle. The only magnetite deposits in the State occur in the vicinity of Snoqualmie Pass, while the iron ores on Clealum River are of poorer quality, but occur in larger bodies.

*Snoqualmie Pass area.*—The magnetite deposits near Snoqualmie Pass show many of the characters of contact deposits. The location of these deposits at or near an intrusive contact and the characteristic contact minerals associated with the ore favor this view as to their origin. The Denny prospect is located on the western slope of Denny Mountain, about 2 miles west of Snoqualmie Pass. The country rock here is the Snoqualmie granodiorite near its contact with the intruded Guye formation. The mineral deposits which have been prospected as iron ore constitute a mineralized band rather than a distinct vein. The granodiorite is much jointed and the joint planes are coated with hornblende and garnet crystals. In the gulch, where some exploration work has been done, a complete section of the ore-bearing band can be seen. The band is parallel to one of the principal joint planes, trending a little west of north, and has on its west side a bed of massive garnet, in places 10 feet wide. Next to this are garnet, quartz, green hornblende, and calcite, all well crystallized. The magnetite occurs as nodules 1 foot or less in diameter and associated with it are masses of pyrite crystals. Through oxidation of the pyrite the rock forming the sides of the gulch is coated with iron oxide, which makes the indications of the extent of the iron ore somewhat deceptive. At another opening on this property, pure magnetite forms a vein-like body with parallel bands of massive garnet and of calcite. The magnetite appears to be the oldest and the calcite the youngest of these crystallizations. Surface workings on the mountain slope expose what are apparently large bodies of this magnetite, but these bodies are found to be oval lenses, 20 feet or more across, which lie approximately parallel to the surface and thus exhibit maximum exposures of the ore.

The Guye iron prospect is due north of Snoqualmie Pass, on the west side of the shoulder connecting Guye Peak with Snoqualmie Mountain. The magnetite deposit here is near the contact between the granodiorite and the Guye formation. The intruded rock here is limestone, and similar limestone or marble also occurs near the Denny prospects, so that the general relations are essentially the same at the two occurrences of magnetite. At the Guye prospect garnet is associated with the magnetite, stringers being seen extending through the ore band, which is much wider and more constant than in the occurrence on Denny Mountain. Large blocks of fairly pure ore can be taken out here.

Analyses of these magnetites, made by Professors Shedd and Fulmer, show that the ore is high in iron—62 to 68 per cent—and low in silica and sulphur, with phosphorus practically absent. The presence of pyrite in some of this ore would doubtless make much of it carry a considerable content of sulphur. Notwithstanding this the ore is of satisfactory quality, but so far these two properties have not been developed, owing, no doubt, to the uncertainty whether the magnetite occurs in sufficient quantity.

The origin of this magnetite at the contact of the intrusive granodiorite is undoubtedly more or less directly connected with the intrusion. The association of minerals and the position of the deposits strongly favor this view. The relations observed at the Guye tunnel suggest replacement of the limestone by the magnetite and the garnet, and the date of this mineralization may very plausibly be referred to the later stages of the granodiorite intrusion. At the Denny prospect the abundance of pyrite may indicate that the sulphide was deposited along with the oxide. In one specimen of metamorphosed wall rock both pyrite and magnetite occur, and under the microscope the magnetite can be seen in small grains along cracks in the rock and in finer grains bordering the larger grains of pyrite. It seems doubtful, however, whether the most of the magnetite could have been derived from the sulphide, since sulphur is wholly lacking in the analyses of the Guye ore and no pyrite was noted there. That there has been a slight amount of subsequent concentration of the ore is shown by one case of brecciation of the massive garnet with impregnation by the magnetite.

*Clealum River area.*—The Clealum iron ores are different, both in character and origin, from those of the Snoqualmie Pass localities. They outcrop in low hills or "iron buttes" along Clealum River between Camp and Boulder creeks and on the ridge south of Boulder Creek. The ore bodies occur as lenses at the basal contact of the Swauk sandstone on the serpentine. The field relations as well as the character of the ore indicate that it is of sedimentary origin, being a peculiar basal phase of the Swauk formation.

The iron ore is a greenish-black, dull rock of amorphous appearance. It is characterized by the occurrence of numerous oölites in the structureless matrix. It contains both magnetite and hematite, associated with more or less weathered serpentine, and the ore lenses are composed of masses which vary from concentrated ore, containing 55 per cent or more of metallic iron, to the clayey waste of serpentine.

Analyses of ore from six different properties in this area indicate an iron content ranging from 46 to 58 per cent, but average samples would doubtless run lower. A large sample was collected by Mr. Bailey Willis, for the purpose of procuring material for a representative analysis. This sample was taken to represent an exposure of 350 square yards, and its analysis by Dr. Hillebrand follows:

*Analysis of iron ores from "iron buttes" along Clealum River.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 7.50 | NiO | .20 |
| $TiO_2$ | .70 | MgO | 2.30 |
| $Al_2O_3$ | 21.90 | $H_2O$ | 6.80 |
| $Cr_2O_3$ | 2.20 | $P_2O_5$ | .09 |
| $Fe_2O_3$ | 37.10 | S | .03 |
| FeO | 21.30 | $CO_2$ | .15 |
| MnO | | | Undetermined, a little. |
| | | | 100.27 |
| Metallic iron | | | 42.51 |

The Clealum iron ore is thus seen to be of low grade and its high percentage of alumina indicates that it would also prove refractory.

These ferruginous bodies originated as residual deposits on the surface of the serpentine, which was exposed to weathering before the Swauk epoch. Conglomerates of either granodiorite or serpentine bowlders occur elsewhere at the base of the Swauk formation and represent simply local phases that are somewhat coarser than these deposits. Where inclosed basins were formed in serpentine rocks, the residual material covering the surface would receive drainage charged with iron and decaying vegetation, thus furnishing solutions of such character that the work of concentration may have begun early in the Eocene epoch.

The analysis given above supports this explanation of the ore as the product of decay of the serpentine. On comparing the analysis of the ore with the analysis of the serpentine of this area it is found that the ore is simply a rearranged but chemically little modified residual product. The presence of chromium and nickel shows its relationship to the serpentine. The occurrence of alumina in this ore in excess of silica indicates that a free oxide or hydrate must be present. This chemical resemblance to the ferruginous bauxite ores is in accord with a certain physical similarity, seen in the presence of the oölitic structure. Other analyses have shown also that the oölitic phases of the ore are much richer in alumina than are the more massive portions of the ore.

Considerable exploration work has been done in this area to test the extent of these ores. If followed by underground workings the ore stratum exposed in the valley would be fonnd to dip under Goat Mountain at angles ranging from 30° to 60°, but the nature and origin of the deposit indicate that this stratum could not be expected to be very thick or as continuous as a coal bed. The ridge ore deposits would dip south at a higher angle.

### OTHER METALLIFEROUS DEPOSITS.

The greater part of the area of this quadrangle has been thoroughly explored by the prospector. In a few localities development work on veins containing ores of gold, silver, and copper has been sufficient to secure some recognition of these local areas as mining districts. This exploration work is still being prosecuted, yet little can be stated regarding the future value of these prospects. In describing these developments, the subject must be treated largely by areas, for none of the ores are distinctively of a single metal.

The vein deposits of the Snoqualmie quadrangle occur both in the pre-Eocene greenstone and granodiorite and in the Eocene and Miocene lavas and granodiorite. In all of the localities where these veins occur there is evidence of crushing and fracturing of the rocks as well as of igneous intrusion in the vicinity. In view of the small amount of exploration of the veins the observations are necessarily too limited to warrant definite statements as to the relative importance of the different agencies in the deposition of the vein minerals. It may be noted that the veins are confined to the compact igneous rocks, and it seems probable that the fractured nature of the rock has been the determining condition of mineralization. This relation is commonly recognized by the prospector.

*Camp Creek district.*—The most important and thoroughly prospected district is the northeast corner of the quadrangle. In 1899 and 1902, when the survey of this quadrangle was made, active development work was being done at several small mines in the vicinity of Camp Creek. Three of these, the Maud O., the Ida Elmore, and the Clealum tunnel, are located on veins in the Hawkins greenstone, and another, the Edna R., is in the granodiorite. In all these mines the veins are near the contact with the serpentine, and at the Maud O. there appears to be a zone of crushed Hawkins greenstone into which the pyroxenite has been intricately intruded. At the Ida Elmore, a serpentine dike cuts the greenstone, while at the Clealum there is a dike of granodiorite-porphyry.

The veins are not as a rule regular, and even where the walls are well defined the vein may be badly pinched in places. The veins show such a variety in trend that no system can be made out for the group. The ore minerals are pyrite, and arsenopyrite in rusty quartz. Some good values in gold have been reported, but when the district was visited none of the properties had become producers.

Cinnabar has been found in a prospect on the eastern edge of the quadrangle at the head of Boulder Creek, where it occurs along a joint plane in the altered rock of the Peshastin formation. The richness of the ore is evident, but the thinness of such bands of cinnabar may prevent the deposit from being of economic importance.

Near the northern edge of the quadrangle a prospect located on the fault contact of the Keechelus lava with the serpentine shows mineralization of the crushed rock with stibnite present as the principal ore mineral.

*Gold Creek district.*—Although the Gold Creek basin lies in a region that is accessible for only a few months in the year, several small mines have been opened in it. At the Esther and Louisa claims, on the eastern side of the amphitheater at the head of Gold Creek, two tunnels have been driven. These are near the wide granodiorite dike that cuts the Keechelus series. The vein contains pyrite, ruby silver, galena, and sphalerite, but even the sphalerite contains some admixture of the silver minerals. The pay ore occupies only a portion of the width of the vein, and the best ore shipped is reported to have carried 240 ounces of silver and $10 in gold.

Below the prominent bench in this amphitheater is another property on which considerable work has been done. This belongs to the Cascade Mining Company, and the principal development consists of a tunnel that crosscuts the granodiorite to intersect the vein, which is also developed above by a shaft. This vein, like the vein on the other property, has a north-south trend. The values are in lead, silver, gold, and copper, and a wide zone of mineralized granodiorite exposed in the tunnel also shows a small percentage of copper.

*Other prospects.*—Copper prospects have been opened along the canyon of the Middle Fork of Snoqualmie River. Here bornite and chalcopyrite occur with quartz crystals in pockets in the Snoqualmie granodiorite.

Several prospect mines have been worked at different times on the creek northwest of Little Kachess Lake. These are on veins, many of which are poorly defined, in the schist, the sandstone and slate, and the granodiorite. Pyrite, chalcopyrite, bornite, and arsenopyrite occur as the ore minerals, associated with quartz and epidote.

### WATER SUPPLY.

Since the annual precipitation in this region everywhere exceeds 40 inches and probably reaches 100 inches in the higher part of the range, this quadrangle is well supplied with perennial streams. A slight amount of irrigation is practiced at a few points along the Yakima Valley, but the value of the water supply of this area concerns a wider territory. This quadrangle includes the most important portion of the headwaters of Yakima River, and the economic value of this river in its relation to irrigation in the lower valleys can not be overestimated. The fact that the waters of the Yakima are at present wholly utilized for irrigation purposes shows that further development of the fertile lands in Yakima County must depend upon improvements in water storage. The many lakes of the Snoqualmie area constitute a natural storage basin for the Yakima. The three large lakes, Keechelus, Kachess, and Clealum, are well adapted for future utilization and have been surveyed as possible sites for storage improvement.

In the elevated portions of this area the snow banks remain until late in the summer, and thus help to maintain the summer flow of the streams. On this account it is essential that the mountainous tracts that have no other value be protected especially from the sheep-grazing industry, which has already seriously injured the region. Desolate tracts of burnt timber and rocky slopes where sharp hoofs have cut up the turf, allowing the soil to be washed away, mark the track of the sheep herder. Such conditions can not fail to affect the natural storage of the water in the mountains, and thus to diminish the supply available in midsummer for irrigation along the lower valleys.

### SOILS AND FORESTS.

Agriculture within the Snoqualmie quadrangle is confined chiefly to the alluvial soils. These areas of alluvium are outlined on the areal geology map. They include the terraces and bottom lands bordering the larger streams and rivers. In such tracts the alluvial soils exhibit considerable variation in texture. Fine silts, easily cultivated and very fertile, cover the bottom lands, but coarse, well-washed gravels occur in other localities, and these are comparatively barren.

All of this quadrangle was originally wooded except some of the highest and most rugged peaks. Even these bear scattered trees having the stunted and gnarled forms that are characteristic of forest growth in localities where the struggle with snow and wind is severe. The lower valleys, however, once contained the finest specimens of forest trees. The red fir and white cedar attained here their perfection of growth, and the stand of timber in these valleys was originally very heavy. Most of this timber, however, has been cut to supply the mills along Yakima and Green rivers, and fire has devastated other tracts, so that little remains to indicate the former extent and magnificence of these forests. Over much of the area of this quadrangle the rugged relief and the distance from the railroad would prevent any use of the timber for lumbering, so that the forest might be preserved without difficulty if fires could be prevented. Over 50 square miles in the southern part of the quadrangle is included within the Mount Rainier Forest Reserve.

May, 1905.

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

# TOPOGRAPHY

WASHINGTON
SNOQUALMIE QUADRANGLE


## LEGEND

**RELIEF** (printed in brown)

Figures (showing heights above mean sea level instrumentally determined)

Contours (showing height above sea, horizontal form, and steepness of slope of the surface)

**DRAINAGE** (printed in blue)

Streams

Lakes and ponds

Glaciers

Marshes

**CULTURE** (printed in black)

Roads and buildings

Churches and school houses

Private and secondary roads

Trails

Railroads

Tunnels

Bridges

U.S. township and section lines

County lines

Reservation lines

Triangulation stations

Bench marks

R. U. Goode, Geographer in charge.
Triangulation by A. H. Sylvester.
Topography by A. E. Murlin.
Surveyed in 1900-1901.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.

*Datum is mean sea level.*

DIAGRAM OF TOWNSHIP

| | | | | | |
|---|---|---|---|---|---|
| 6 | 5 | 4 | 3 | 2 | 1 |
| 7 | 8 | 9 | 10 | 11 | 12 |
| 18 | 17 | 16 | 15 | 14 | 13 |
| 19 | 20 | 21 | 22 | 23 | 24 |
| 30 | 29 | 28 | 27 | 26 | 25 |
| 31 | 32 | 33 | 34 | 35 | 36 |

Edition of Sept. 1903, reprinted April 1906.

U. S. GEOLOGICAL SURVEY
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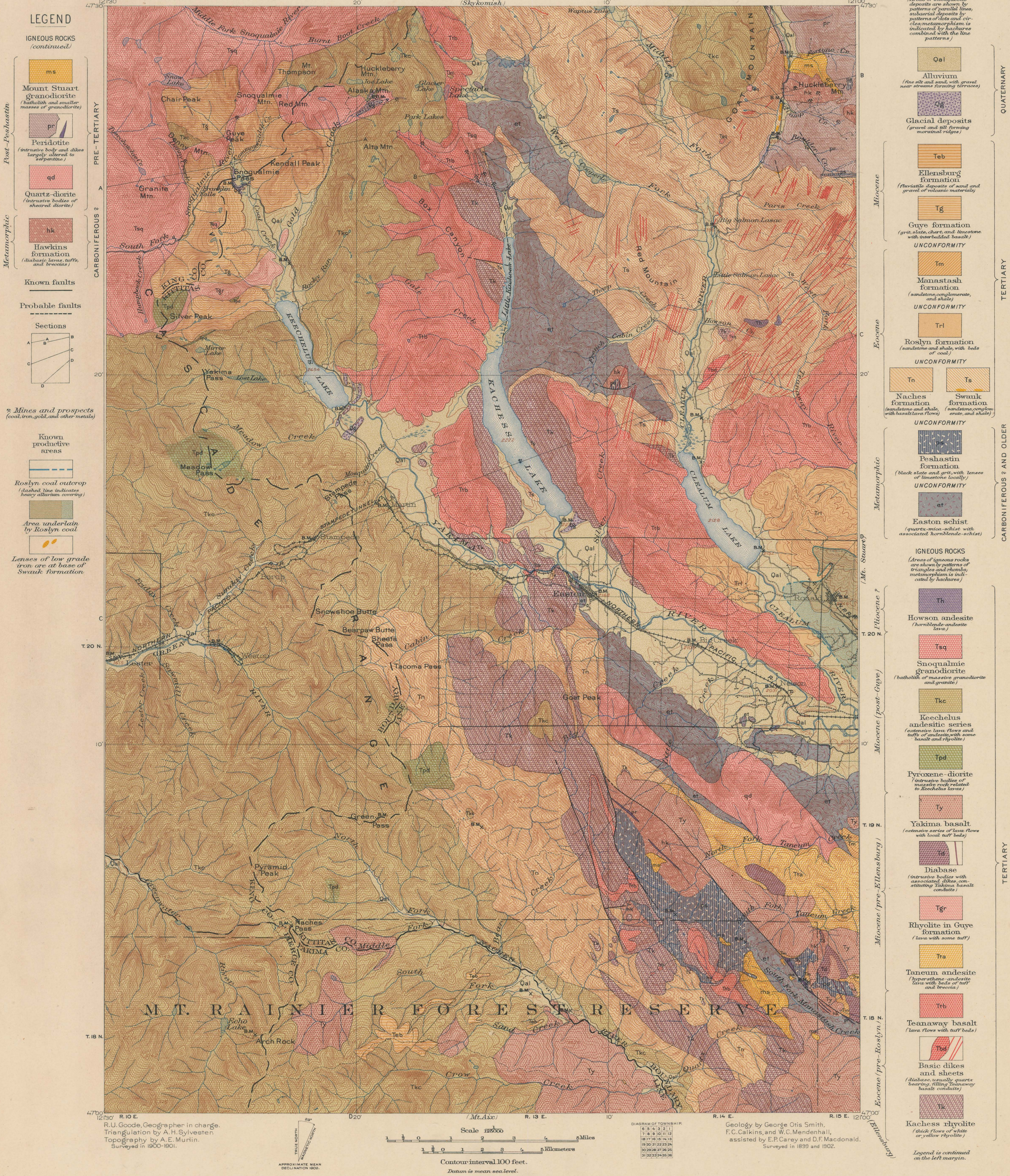
# AREAL GEOLOGY

WASHINGTON
SNOQUALMIE QUADRANGLE



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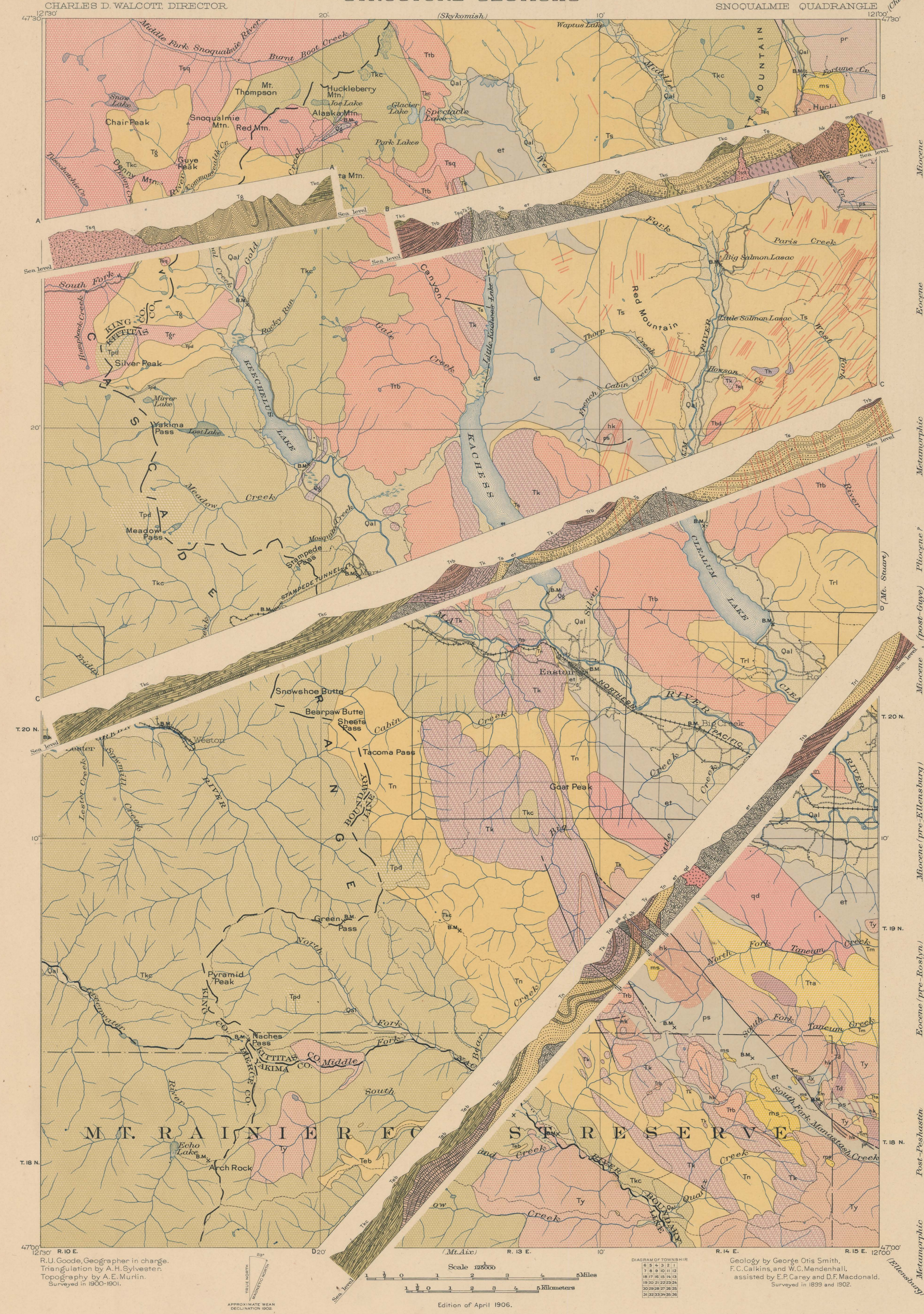
# STRUCTURE SECTIONS

WASHINGTON
SNOQUALMIE QUADRANGLE




R.U. Goode, Geographer in charge.
Triangulation by A.H. Sylvester.
Topography by A.E. Murlin.
Surveyed in 1900-1901.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Edition of April 1906.

Geology by George Otis Smith, F.C. Calkins, and W.C. Mendenhall, assisted by E.P. Carey and D.F. Macdonald.
Surveyed in 1899 and 1902.

## LEGEND

### SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

**QUATERNARY**

- Qal — Alluvium *(fine silt and sand, with gravel near streams forming terraces)*
- Qg — Glacial deposits *(gravel and till forming morainal ridges)*

**TERTIARY**

*Miocene*

- Teb — Ellensburg formation *(fluviatile deposits of sand and gravel of volcanic materials)*
- Tg — Guye formation *(grit, slate, chert, and limestone, with interbedded basalt)*

UNCONFORMITY

*Eocene*

- Tm — Manastash formation *(sandstone, conglomerate, and shale)*

UNCONFORMITY

- Trl — Roslyn formation *(sandstone and shale, with beds of coal)*

UNCONFORMITY

- Tn — Naches formation *(sandstone and shale with basalt lava flows)*
- Ts — Swauk formation *(sandstone, conglomerate, and shale)*

UNCONFORMITY

**CARBONIFEROUS ? AND OLDER**

*Metamorphic*

- ps — Peshastin formation *(black slate and grit, with lenses of limestone locally)*

UNCONFORMITY

- et — Easton schist *(quartz-mica-schist with associated hornblende-schist)*

### IGNEOUS ROCKS

**TERTIARY**

*Pliocene ?*

- Th — Howson andesite *(hornblende-andesite lava)*

*Miocene (post-Guye)*

- Tsq — Snoqualmie granodiorite *(batholith of massive granodiorite and granite)*
- Tkc — Keechelus andesitic series *(extensive lava flows and tuffs of andesite, with some basalt and rhyolite)*
- Tpd — Pyroxene-diorite *(intrusive bodies of massive rock related to Keechelus lavas)*

*Miocene (pre-Ellensburg)*

- Ty — Yakima basalt *(extensive series of lava flows with local tuff beds)*
- Td — Diabase *(intrusive bodies with associated dikes, constituting Yakima basalt conduits)*
- Tgr — Rhyolite in Guye formation *(lava with some tuff)*
- Tta — Taneum andesite *(hypersthene-andesite lava with beds of tuff and breccia)*

*Eocene (pre-Roslyn)*

- Ttb — Teanaway basalt *(lava flows with tuff beds)*
- Tbd — Basic dikes and sheets *(diabase, usually quartz bearing, filling Teanaway basalt conduits)*
- Tk — Kachess rhyolite *(thick flows of white or yellow rhyolite)*

**PRE-TERTIARY**

*Post-Peshastin*

- ms — Mount Stuart granodiorite *(batholith and smaller masses of granodiorite)*
- pr — Peridotite *(intrusive body and dikes largely altered to serpentine)*
- qd — Quartz-diorite *(intrusive bodies of sheared diorite)*

**CARBONIFEROUS ?**

*Metamorphic*

- hk — Hawkins formation *(diabasic lavas, tuffs, and breccias)*

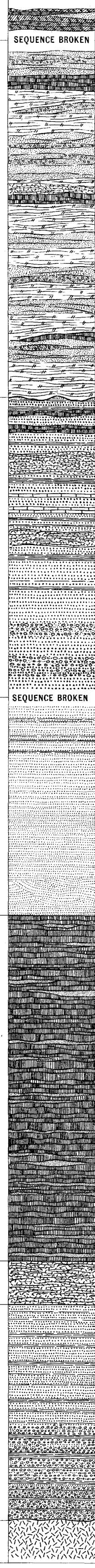
Known faults

Probable faults

# COLUMNAR SECTIONS

## GENERALIZED SECTION OF SEDIMENTARY AND VOLCANIC ROCKS OF NORTHERN PORTION OF SNOQUALMIE QUADRANGLE.

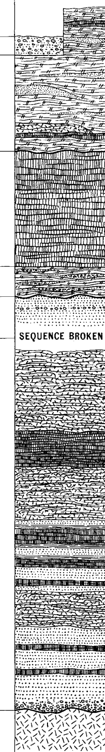
SCALE: 1 INCH=1000 FEET.



| System. | Series. | Formation Name. | Symbol. | Columnar Section. | Thickness in Feet. | Character of Rocks. |
|---|---|---|---|---|---|---|
| TERTIARY | PLIOCENE ? | Howson andesite. | Th | | 250 | Porphyritic hornblende-andesite lava, mostly light gray, some pink. |
| | | | | SEQUENCE BROKEN | | |
| | MIOCENE | Keechelus andesitic series. | Tkc | | 4000 | Lava, tuff-breccia, and tuff; the pyroclastics considerably more abundant than the lavas. Chiefly pyroxene-andesite, but including considerable dacite and some rhyolite and basalt. Much altered and indurated in the northwest by Snoqualmie granodiorite. |
| | | UNCONFORMITY | | | | |
| | | Guye formation. | Tg | | 3500± | Shales, sandstones, grits, and conglomerates, with a little limestone and chert, and contemporaneous flows of basalt and rhyolite. Altered and indurated by Snoqualmie granodiorite. |
| | | | | SEQUENCE BROKEN | | |
| | EOCENE | Roslyn formation. | Trl | | 3000± | Massive yellow sandstone, with clay and bony shale. Roslyn coal and other less valuable beds in upper portion of formation. |
| | | Teanaway basalt. | Ttb | | 4000 | Lava flows, with interbedded tuffs. Lava, black and dark gray, compact or vesicular, sometimes weathering brown or red. Some interbedded sandstone in western portion. A little basic andesite and rhyolite occur locally. |
| | | Kachess rhyolite. | Tk | | 0-2000 | Rhyolite, white to pinkish and greenish, with small phenocrysts of feldspar. Mostly laminated lava and little tuff. Thin andesite near the top. |
| | | Swauk formation. | Ts | | 200-5000 | Well-stratified conglomerate, arkose, quartzose sandstones, and shale, light and dark gray in color. In eastern part of area, sandstone more purely quartzose, and white and yellow in color. Cut by numerous dikes of diabase. Some tuffaceous beds at the top near Clealum Lake. |
| | | UNCONFORMITY | | | | |
| PRE-TERTIARY | | Granodiorite, peridotite, slate, and other rocks. | | | | Descriptions in table of intrusive and pre-Tertiary rocks. |

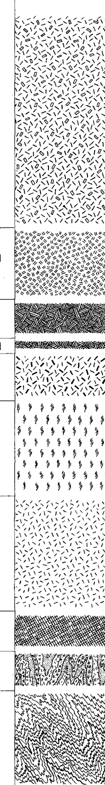
## GENERALIZED SECTION OF SEDIMENTARY AND VOLCANIC ROCKS OF SOUTHERN PORTION OF SNOQUALMIE QUADRANGLE.

SCALE: 1 INCH=1000 FEET.



| System. | Series. | Formation Name. | Symbol. | Columnar Section. | Thickness in Feet. | Character of Rocks. |
|---|---|---|---|---|---|---|
| TERTIARY | MIOCENE | Ellensburg formation. | Teb | | 200 | Conglomerate; pebbles mostly andesite, with some of pumice, in a soft tuffaceous matrix. |
| | | Keechelus andesitic series. | Tkc | | 0-3000± | Mostly pyroxene-andesite, with some basalt and rhyolite lavas, tuffs, and breccias. The pyroclastics, which predominate in all but the southernmost part of the area, are much decomposed, and in color usually green, but sometimes red. Upper part probably younger than Ellensburg formation. |
| | | UNCONFORMITY | | | | |
| | | Yakima basalt. | Ty | | 1500± | Black lava, weathering gray or brown, compact or scoriaceous, with columnar partings common. Tuffs present, but not important. |
| | | Taneum andesite. | Tta | | 0-1000 | Loose-textured lava, with tuff and tuff-breccia, pink, green, gray, and brown in color. |
| | | UNCONFORMITY | | | | |
| | | Manastash formation. | Tm | | 0-400 | Massive, light-colored sandstone and pebbly conglomerate, with shale and seams of bone. |
| | | | | SEQUENCE BROKEN | | |
| | EOCENE | | (Tk) | | | |
| | | Teanaway basalt. | Ttb | | 500 | Lava with some tuff. Lava black, weathering dark brownish red, generally showing lamellar partings. Tuff, olive-green. |
| | | Kachess rhyolite. | Tk | | | Rhyolite, mostly lava, with little tuff. Lava is generally cream-white to pink, thinly laminated, lithoidal, showing small phenocrysts of feldspar. Spherulitic phases not uncommon. Pitchstone and obsidian rare. A little andesite occurs locally. |
| | | | (Tn) | | | |
| | | | (Tk) | | | |
| | | Naches formation. | Tn | | | Gray sandstone and olive shale, with contemporaneous flows of basalt and a little basalt tuff. The basalt increases in importance toward the top of the formation and is lithologically similar to the Teanaway basalt. |
| | | UNCONFORMITY | | | | |
| PRE-TERTIARY | | Granodiorite, peridotite, slate, and other rocks. | | | | Descriptions in table of intrusive and pre-Tertiary rocks. |

## GENERALIZED TABLE OF THE INTRUSIVE AND PRE-TERTIARY ROCKS OF SNOQUALMIE QUADRANGLE, ARRANGED ACCORDING TO AGE.



| Age. | Formation Name. | Symbol. | Lithologic Symbol. | Character of Rocks. |
|---|---|---|---|---|
| MIOCENE OR LATER | Snoqualmie granodiorite. | Tsq | | Light-gray massive granular rocks of granitic character. Porphyritic near contacts and in smaller masses. Mostly granodiorite, but passing locally into more basic phases of relatively slight importance, and including a considerable mass of more siliceous biotite-granite. |
| MIOCENE | Pyroxene-diorite. | Tpd | | Gray holocrystalline rocks in stock-like masses projecting up through Keechelus volcanics. Mostly porphyritic, but centers of larger areas are granular. Represent volcanoes from which Keechelus andesites were extruded. |
| | Diabase. | Td | | Brown, medium-grained diabase in intrusive bodies, with associated dikes, occupying vents from which Yakima basalt was derived. |
| | Basic dikes and sheets. | Tbd | | Diabase filling conduits leading up to Teanaway basalt. |
| PRE-EOCENE | Mount Stuart granodiorite. | ms | | Massive, gray, granular rock of granitic appearance, varying in grain and in proportion of darker minerals. Porphyritic near contacts and in smaller masses. |
| | Peridotite. | pr | | Massive and schistose, according to degree of alteration to serpentine. Colors range from black to nearly white, with yellow, red, and green common. Massive peridotite, compact, with waxy luster, and somewhat porphyritic. |
| | Quartz-diorite. | qd | | Light-gray granular rocks with rather large and conspicuous crystals of hornblende, showing a fairly distinct gneissic banding due to pressure and shearing. Marginal portions porphyritic and generally more basic. |
| CARBONIFEROUS ? AND OLDER | Peshastin formation. | ps | | Black slate, with bands of chert, thin beds of grit, and lenses of limestone. |
| | Hawkins formation. | hk | | Breccia, tuff, and amygdaloid, of purplish or greenish color, usually of diabasic composition, although much altered. In some areas intricately associated with Peshastin formation. |
| | Easton schist. | et | | Quartz-mica-schist, silvery green, crumpled, and gashed with quartz veins. Amphibolites and epidote-schists less prominent. Some bluish carbonaceous schists in northern part of quadrangle. |

GEORGE OTIS SMITH,
FRANK C. CALKINS,
*Geologists.*

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