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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

A GEOLOGICAL RECONNAISSANCE ACROSS THE CASCADE RANGE NEAR THE FORTY-NINTH PARALLEL

BY

GEORGE OTIS SMITH AND FRANK C. CALKINS

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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., March 17, 1904.

SIR: I have the honor to transmit herewith the manuscript of a paper entitled "A Geological Reconnaissance across the Cascade Range near the Forty-ninth Parallel," by George Otis Smith and Frank C. Calkins. The report embodies the geologic results of field work during the season of 1901 in connection with the northwestern boundary survey. I recommend its publication as a bulletin.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

A GEOLOGICAL RECONNAISSANCE ACROSS THE CASCADE RANGE NEAR THE FORTY-NINTH PARALLEL.

By George Otis Smith and Frank C. Calkins.[a]

INTRODUCTION.

SCOPE OF REPORT.

In 1901 three geologic parties were assigned to the reconnaissance of the northwestern boundary. The duties of these parties included not only the geologic and economic investigation of a strip of country in the vicinity of the forty-ninth parallel, but also the examination of the area with special reference to the condition of the monuments on the international boundary. The results of the surveys made by them are incorporated in a joint report to the Superintendent of the United States Coast and Geodetic Survey and the Director of the United States Geological Survey.

The party assigned to the western section, from Osoyoos Lake, in northern Washington, across the Cascade Mountains to the coast, was in charge of George Otis Smith, with Frank C. Calkins as assistant geologist. While the major portion of the work was topographic and connected with the examination of the boundary, considerable general information was obtained regarding the geology of the region traversed. Only a portion of such data is contained in the report mentioned above, and it has seemed advisable to place the results of the reconnaissance in a form in which they will be available for reference.

The region in the vicinity of Barron has been described by Prof. I. C. Russell,[b] but there is no literature containing geologic descrip-

[a] This report is based upon the field observations of both authors. The work near the boundary was roughly subdivided, Mr. Smith taking the territory immediately adjacent to the boundary, while Mr. Calkins examined the area farther to the south. The larger part of the "Description of formations" was written by Mr. Calkins. The chapter on "Petrography" was entirely the work of Mr. Calkins, by whom the laboratory study of the rock specimens was performed. The remainder of the report, except a part of the notes on coal, was written by Mr. Smith.

[b] A preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 83-210.

tions of the northernmost part of Washington other than the reports of the geologists connected with the boundary commissions, 1857–1860.[a]

ROUTE FOLLOWED.

The party outfitted at Ellensburg, Wash., the latter part of June, 1901. The route by which the forty-ninth parallel was reached was practically the same as that used at the time of the earlier survey of the boundary, crossing Table Mountain to the mouth of the Wenatchee and thence northward along the west bank of Columbia and Okanogan rivers.

Work was commenced in the vicinity of Lake Osoyoos July 10, and the reconnaissance extended west until October 5. The route taken by the pack train is indicated on the map. Until the valley of the Pasayten was reached it was found possible to keep within a few miles of the forty-ninth parallel. Here, however, a detour southward was made to the mining camp, Barron, whence we proceeded down Slate and Ruby creeks to Skagit River.

A side trip was made on foot up this river over the abandoned Fort Hope trail. Direct access to the mountainous country west of Skagit Valley being out of the question, the trail down the Skagit from Ruby to Marblemount was followed, and thence country roads were traveled, by way of Sedro-Woolley and Deming, to Maple Falls, on the North Fork of the Nooksak. This river was followed as far east as Hannegan Pass and the boundary line visited on Silicia and Tummeahai creeks. The approach of bad weather did not permit a trip to the head of Chilliwhack Lake, so that the region between Silicia Creek and Skagit River was not visited.

The route followed from Ellensburg to Osoyoos Lake afforded opportunities to roughly extend the observations made in central Washington during previous years, and thus to connect in some degree the areas that have been mapped in detail for folio publication with the boundary section. In lower Skagit Valley connection was also made with the route followed by the senior author in 1895 in the course of a reconnaissance made by the party of Mr. Bailey Willis. In this way the geologic observations on the present reconnaissance were made in the light of earlier work in adjacent parts of the Cascade Range.

GEOGRAPHY.

TOPOGRAPHY.

Primary divisions of the region.—Between 119° 30′ and 122° 45′ the forty-ninth parallel crosses three distinct regions, viz, Okanogan Valley, Cascade Range, and the low coastal country west of the latter.

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[a] Gibbs, George, Physical geography of the northwestern boundary of the United States: Jour. Am. Geog. Soc., vol. 3, 1870–1872, pp. 134–157; vol. 4, 1872–73, pp. 298–392. Bauerman, H., Report on the geology of the country near the forty-ninth parallel of latitude west of the Rocky Mountains, from observations made in 1859–1861: Ann. Rept. Geol. Survey Canada, 1882–1884.

RECONNAISSANCE MAP OF THE CASCADE RANGE NEAR THE 49TH PARALLEL

BY GEORGE OTIS SMITH AND FRANK C. CALKINS

Scale

0 1 2 3 4 5 6 7 8 9 10 15 20 miles

0 1 2 3 4 5 6 7 8 9 10 15 20 kilometers

Contours, interval 250 feet based on actual surveys

Contours, interval 1000 feet, sketched

Roads

Trails

Routes followed 1901 off established trails

International boundary 49th. parallel

TERTIARY

Andesite

Sandstone and conglomerate

MESOZOIC

Granite, granodiorite and diorite

Pasayten formation (lower Cretaceous)

Gabbro

Pyroxenite and peridotite

PALEOZOIC

Slate, quartzite, schist, and greenstone (Carboniferous?)

Limestone; beds and lenses in slate

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OKANOGAN VALLEY.

Okanogan Valley is the lowest point on the international boundary between Red River of the North and the Pacific coast. Lake Osoyoos has an elevation of 913 feet above the sea, so that the Okanogan has a deeper valley than the Columbia itself at the forty-ninth parallel. Within this valley there is considerable relief, the mountains south of the big bend of Similkameen River attaining an elevation of 4,500 feet. The topography is of the plateau type, with rounded tops and gentle slopes. The steep-sided canyons which cross the valley divide it into a labyrinth of channels, many of which are without drainage at present. These channels are largely the result of effective corrasion when the streams were swollen with the drainage of the melting glaciers. This whole valley, in fact, was occupied by a tongue of ice that came from the north and extended south across the Columbia.

For a few miles south of Lake Osoyoos the valley has a width of several miles and is floored with alluvium. Similar alluvial plains border Similkameen River where it crosses the boundary and also the tributary stream by which Haipwil, or Palmer, Lake empties into the Similkameen. Extensive gravel terraces border both Okanogan and Similkameen rivers as well as many of the dry channels.

CASCADE RANGE.

GENERAL CHARACTERISTICS.

The western limit of Okanogan Valley is very sharply defined at the boundary, this abrupt change in topography being due to the fact that the east side of the Cascade Range is there without the usual foothills. Mount Chopaka rises from the marshes bordering the Similkameen as a steep wall over 7,000 feet in height. Standing on its summit one sees extending to the south and west a vast expanse of mountain peaks, with the white dome of Mount Baker in the far distance. These mountains, for the most part snow-capped in early summer, are the Cascades, which in this latitude have their maximum development, the distance from Chopaka to Baker being over 90 miles.

Northern termination of Cascade Range.—A noteworthy feature of this region is the manner in which this range loses its mountainous character immediately north of the forty-ninth parallel and descends to a plateau several thousand feet lower. Pl. IV, *A*, illustrates this abrupt change near the boundary, the view being to the north from a peak about 8,000 feet in height on Bauerman Ridge. This feature is noticeable for essentially the whole length of this section, and was noted by Gibbs,[a] who described the mountains east of the headwaters of the Skagit as having a uniform height, with few prominent peaks, and a general elevation of 5,500 to 6,000 feet, and noted that this equality of elevation does not exist south of the boundary.

[a] Op. cit., p. 350.

The western portion of this boundary section was rather thoroughly studied by Doctor Daly, of the Canadian survey, who calls attention to this same change in the topographic character of the international boundary.[a] "By a curious accident the international boundary line, roughly speaking, divides the coast range into two parts of contrasted scenic quality. In Washington the summits are the higher and more peaked, the ridges the more serrate, while all are dominated by the majestic cone of Mount Baker. On the Canadian side the massifs are somewhat lower, are more rounded, and less abundantly supplied with a perennial snow cover."

In view of these observations it seems proper to consider the Cascade Range as finding its northern termination approximately at the forty-ninth parallel.

Subdivision of Cascade Range.—In northern Washington, where the Cascade Mountains are so prominently developed, the range is apparently a complex one and should be subdivided. This was recognized by Gibbs, who described the range as forking and the main portion or "true Cascades" crossing the Skagit, where that river turns west, while the "eastern Cascades" lie to the east. Bauerman, geologist to the British commission, recognized three divisions, and as his subdivision is evidently based upon the general features of the relief it will be adopted here. To the eastern portion of the Cascades, extending from Mount Chopaka to the valley of Pasayten River, the name of Okanogan Mountains is given, following Bauerman. To the middle portion, including the main divide between the Pasayten, which belongs to the Columbia drainage, and the Skagit, which flows into Puget Sound, Bauerman gave the name Hozomeen Range, taken from the high peak near the boundary. For the western division the name Skagit Mountains is proposed, from the river which drains a large portion of this mountain mass and also cuts across its southern continuation. It will be noted that the north-south valleys of the Pasayten and the Skagit form the division lines between these three subranges, which farther south coalesce somewhat so as to make subdivision less necessary.

OKANOGAN MOUNTAINS.

The Okanogan Mountains form the divide between the streams flowing north into the Similkameen and thence into the Okanogan and those flowing south into the Methow drainage. In detail this divide is exceedingly irregular, but the range has a general northeast-southwest trend, joining the main divide of the Cascades in the vicinity of Barron. The highest peaks, such as Chopaka, Cathedral, Remmel, and Bighorn, have a nearly uniform elevation of 8,000 to 8,500 feet, and commonly are extremely rugged. Over the larger portion of this area the heights are above 7,000 feet, and below this are the deeply

[a] Summary Report Geol. Survey Canada, 1901, p. 41.

cut valleys. A few small glaciers exist on the northern sides of certain peaks at the head of some branches of the Pasayten, and the former extent and importance of glaciers in this region are shown by the conformation of nearly every ridge and mountain in the range. As a rule, the south slope of every spur or ridge is regular and without marked features, while the opposite face is deeply carved with steep-sided cirques and gulches. Tiny lakes with bordering snow banks occupy almost all of these amphitheaters, in which head the streams flowing north into the Similkameen drainage system. In some cases the divides are cut well down, and the U-shaped gaps or passes are occupied by grassy meadows. The tops or uplands in this area are generally only sparsely timbered, but bunch grass is abundant where the snow does not remain too long into the summer. The valleys are U-shaped, with moderate grade and gravel-covered bottoms and terraces along the lower courses of the larger streams. The tributary streams have steeper grades, but the bottoms nevertheless are often very marshy. In the valleys the timber, though small, is dense, and windfall areas are frequently encountered on the northern slopes.

HOZOMEEN RANGE.

The valley of the Pasayten, which heads 20 miles south of the boundary, has an elevation of 3,500 to 4,500 feet in the main portion, and is a broad feature well adapted to serve as a natural boundary between the Okanogan Mountains and the Hozomeen Range. This latter range includes the main crest of the Cascade Mountains and takes its name from Mount Hozomeen, a prominent peak close to the forty-ninth parallel and overlooking Skagit River. The valleys of Pasayten and Skagit rivers are nearly parallel and only about 20 miles distant, so that the tributary streams flowing east and west from the crest have a very rapid descent and flow in canyons which deeply dissect this rugged range. In the western part of this range the creeks entering Skagit Valley have remarkably narrow canyons, which at their mouths are barely wide enough for the passage of the stream. Above, the valleys widen somewhat and apparently have much lower grades in some parts of their courses. Devil Creek, for instance, enters Skagit Valley through a cleft in the rock wall, yet this tributary extends about 8 miles back and drains a wide basin.

The divide has an elevation of from 7,000 to 8,000 feet, and about 10 miles south of the boundary is made up of sharp peaks which owe their rugged outlines to the beds of coarse conglomerate of which they are composed. The spurs in this central portion of the Hozomeen Range are rather level topped, and north of the boundary the topography becomes much less bold in character. The western portion of this range has even higher and sharper peaks, of which Mount Hozomeen is the type. Being close to Skagit Valley, which here has an elevation of from 1,400 to 1,700 feet, and isolated by the deep gorges of the tributary streams, these mountains, some of which, notably Mount Hozomeen and Jacks Mountain, probably reach an elevation of 9,000 feet, command attention from whatever side they are seen. Numerous glaciers are found in this region, and glacial cirques have been cut back into the mountain masses until the peaks are of the Matterhorn type.

SKAGIT MOUNTAINS.

The upper valley of the Skagit extends southward from the forty-ninth parallel as a broad valley with gravel-covered bottom and low grade. The river in this portion of its course has many meanders, and swamps occupy large areas in its valley. Large timber is found here, and the dense undergrowth of the west slope of the Cascades makes its appearance. Below the point where Beaver and Ruby creeks enter the Skagit the river turns west, and in a wild canyon cuts through the mountains. The spur of the Cascades, which is crossed by the Skagit at this point, extends northwest, and is the range to which the name of Skagit Mountains is here given.

Without question the Skagit Mountains, which form the western subrange, include the wildest and most rugged country in the whole Cascade Range. Looking west from the valley of Skagit River one sees high peaks with precipitous faces, on whose lower slopes are extensive glaciers, from which flow Beaver and Glacier, or Little Beaver, creeks; and the scene is no less picturesque when viewed from the west in the vicinity of Hannegan Pass. For this mountain mass, which extends south from the boundary, the name of Custer Ridge is proposed, in honor of Mr. H. Custer, who had charge of the reconnaissance party of the United States Boundary Survey that in 1859 crossed this ridge from the headwaters of the Chilliwhack, making its way down Glacier Creek to the Skagit, a trip probably not duplicated by any explorer, despite some unsuccessful attempts. Mount Shuksan, farther west, is another example of the sharp pyramidal peaks characteristic of this region about the headwaters of Nooksak and Chilliwhack rivers. So many of the mountain slopes are precipitous that much of the country is practically inaccessible and unknown even to the prospectors.

Another extremely rugged part of the Skagit Mountains lies on the forty-ninth parallel, between Silicia (or Slesse) and Tummeahai creeks. Small glaciers flank the higher peaks and represent the larger glaciers that have been so efficient in the development of the present topography. One feature well exhibited at the head of Tummeahai Creek, and common elsewhere in this region, is the occurrence of a succession of amphitheaters similar to those to which Daly has applied the expressive term "tandem cirques." This type of sculpture is plainly the result of glacial work. The stream gradient that is found in such a valley is an alternation of rapid cascade and flat reach, the latter often widening into a small lake or a mountain meadow through which the stream meanders. The valley walls are very steep, and slopes of 80° to 85° are not uncommon. From one point of view at least ten such cliffs could be seen.

Farther west the Skagit Mountains are somewhat lower, and serrate ridges and pinnacles, like Mount Shuksan, are succeeded by broader ridges, essentially flat crested, smooth, and grass covered, separated by the deep canyons of the Nooksak and its tributaries. The canyons are rather broad and have gentle grades, so that it is only the luxuriant vegetation that prevents easy access to this portion of the range, which includes the Mount Baker mining district. The glacier-covered cone of Mount Baker is prominent, rising nearly 5,000 feet above the high plateau that forms its base, and standing somewhat apart from the high peaks of the Skagit Mountains.

The east limit of the Cascade Range is at about longitude 120°, where there is an abrupt descent to the gravel-covered plain that extends west to Semiahmoo Bay. Sumas Prairie is probably less than 50 feet above sea level, and from its eastern border precipitous walls of rock rise almost a thousand feet, making a most noticeable topographic feature. To the west the plain is somewhat diversified with low ridges and hills, but this relief is comparatively inconspicuous.

DRAINAGE.

Almost the whole of the region included in this boundary section is drained by the three rivers, the Similkameen, the Skagit, and the Nooksak. Small headwater streams tributary to the Methow and the Frazer drain the remainder. Similkameen River, where it crosses the boundary, is deep and swift. Its tributaries, the Ashnola and the Pasayten, which are encountered farther west in the Okanogan Mountains, have steep gradients, but can be easily forded. Skagit River at the forty-ninth parallel has a considerable volume of water and is deep and rather sluggish, but 30 miles below, where it enters its canyon, it is an impetuous river, with few quiet places along its course. The tributaries of the upper Skagit from both the east and west are short streams with steep grades and many cascades. The North Nooksak occupies a valley with somewhat even grade, except at one point where the channel narrows and the river dashes over the Nooksak Falls, which are nearly 100 feet high.

Small glaciers persist in the Okanogan Mountains, notably on Jacks Mountain in the Hozomeen Range and in the Skagit Mountains on Custer Ridge at the head of the North Nooksak, as well as on Mount Baker.

CLIMATE.

Within this 150-mile section along the forty-ninth parallel there is a considerable range in climatic conditions. In the vicinity of Lake

Osoyoos the country has a decidedly desert aspect, cactus and sagebrush constituting the characteristic vegetation and forming an index of the comparative aridity. Few trees are seen, and bunch grass is less abundant than it is either east or west of this low country. The occurrence of undrained alkali lakes in this vicinity also testifies to the small annual precipitation. The summers are hot and dry, and the dry season is probably longer here than at any point on the northwest boundary west of the Great Plains region.

The Cascade Range, on the contrary, is a region of short summers. In the Okanogan Mountains the snowfall is not so heavy as farther west, but not until the middle of July does the snow disappear sufficiently to enable the region to be easily traversed. Several miles south of the forty-ninth parallel deep snow remains on these mountains throughout the summer, and snow squalls occur occasionally even in July and August. The summer months, however, are comparatively free from rains, and while the nights are cold the area is one well adapted for camping expeditions.

Similar climatic conditions obtain in the eastern part of the Hozomeen Range, but as soon as the western slope is reached evidences of the greater annual precipitation are at once noticed. The vegetation changes its character, the forests are more extensive, large trees with dense underbrush cover the valley bottoms and extend well up the slopes, and except on a few ridges grass is not plentiful. The banks of snow that persist throughout the year become more and more troublesome, and glaciers are seen on all the higher peaks. All of these features become even more noticeable west of Skagit River in the high country of the Skagit Mountains. Here the summer is very short, and July and August are the only months in which snow does not fall in considerable amounts, and at no time in the year are the passes in the Skagit Mountains free from snow. The low-hanging clouds and frequent snows in early September seriously embarrass work.

The climatic differences between the east and west slopes of the Cascades are well shown in the condition of the old vistas which were cut on portions of the boundary line. In the Ashnola and Pasayten valleys the old cuttings can be easily found, and the stumps and logs are sound. In the stations occupied over forty years ago the hewn blocks upon which instruments were placed and the camp stools remain as they were left, while at the Ashnola monuments ladders used in the construction of the high rock cairns are still solid. On the western slope, in Skagit Valley, the old stumps are so much decayed that only rarely can they be surely recognized as such, and the chopped surface must be hunted for on the ends of the logs. In the vista here and in the other localities farther west trees 75 feet high and 14 inches in diameter have grown up in the old cuttings, while dense underbrush most effectually conceals the line as once cut out.

West of the Cascades, in the low country extending to the coast, the climate is that characteristic of the Puget Sound region. The winters are not severe, there being little or no snow, and the rainy season extending from October to June. The summers are warm, with little rainfall.

ROADS AND TRAILS.

Within Okanogan Valley there are good roads, from which trails lead in every direction. A trail also extends west from the Loomis road to two ranches upon the south slope of Mount Chopaka, about 2 miles west of Haipwil, or Palmer, Lake. Beyond this there is an old trail that can be followed for 7 miles. There is some marshy country here, and also bad windfalls, so that this trail is hardly passable for pack animals. Beyond this there is no established trail and only for a short distance are there any signs to indicate that the region is ever visited. In the six weeks spent in traversing the section between Mount Chopaka and Barron no person was met by our party. The camps of the boundary survey of 1859 remain much as they were left. A few blazed lines in the Ashnola and the Pasayten valleys mark where trappers sometimes penetrate this country from the north, while along the latter valley there is an old trail leading from Princeton, in British Columbia, to Barron. This trail, however, has been little used in late years and near the boundary is much obstructed.

As can be seen on the map (Pl. I), a practicable route for the pack train was found following close to the divide between the streams flowing northward into the Ashnola and the headwaters of Chiwak Creek. This route crosses Bauerman Ridge and keeps within two miles of the boundary as far as Cathedral Peak. Little cutting is necessary to work across this part of the region, although there are several areas of old burns where there are bad windfalls. The ridges are usually rugged, but close to the conspicuous Cathedral Peak (Pl. III, *B*) there is an easy pass to the more open country to the west. Here most of the ridges are broad and only scantily timbered, bunch grass growing abundantly. Thus the only obstacle to travel with pack animals is found in the more heavily wooded bottoms where the larger streams are crossed. The beautiful open character of the uplands is best seen at Park Pass, west of which the route followed in 1901 was more south of west, and the only serious difficulty encountered was in crossing the deep valley in which the Hidden Lakes lie. The Pasayten Valley can be reached perhaps more easily by following the ridge which extends west from Park Pass, and the greater part of this distance, in fact, was traversed on horseback in the course of the reconnaissance.

The route followed, up Pasayten Valley to Windy Pass, and thence down past Barron on Slate and Ruby creeks to the Skagit River, was on old trails of varying quality. No trails cross the Hozomeen Range north of Ruby Creek, although these mountains could be penetrated with horses both from the Pasayten Valley and up Canyon Creek. The Fort Hope trail up the east side of Skagit River has been abandoned for many years, except for a few miles at the lower end. Two prospectors traveled this trail with horses in 1901, but it is so badly blocked with fallen timber as to be difficult to follow on foot, and along the river bank the underbrush has so completely hidden the trail that for hundreds of yards it can be followed only by the feet feeling out the worn rut. At the time of the rush to the Ruby Creek placers, in the early seventies, this was the route by which the region was entered, and the trail was undoubtedly in excellent condition.

The Skagit Mountains are accessible only from the north and west. The Canadian boundary party in 1901 opened up trails along most of the streams tributary to the Chilliwhack as far as the forty-ninth parallel. From the west the state wagon road extends from Maple Falls along the North Nooksak to Shuksan, from which trails extend north across Twin Lake Pass to the Lone Jack mine, west up the river to Hannegan Pass, and south to the divide at the head of Baker River.

In brief, it may be stated that in the eastern portion of the section the absence of trails does not seriously trouble anyone wishing to traverse the region, but on the western side of the main divide the dense vegetation and the extremely rugged topography make it necessary to follow well-established trails, and the construction of new trails involves considerable expenditure of time and money.

GEOLOGY.

DESCRIPTION OF FORMATIONS.

CLASSIFICATION AND MODE OF TREATMENT.

It will be useful to introduce the discussion of the geology of the region by a brief statement of its plan and scope. It has been the endeavor to make these harmonize with the character of the field work upon which the report is based. A hurried reconnaissance through territory comparatively new to geologic exploration can not serve as the basis of complete and detailed description nor of exact correlations. The descriptions will therefore be made brief and general, and correlations, especially in the case of the older rocks, will generally be somewhat broad and in many cases merely tentative.

The stratified rocks, including some schists of uncertain origin, and the contemporaneous volcanics interbedded with the sedimentary deposits will be treated first, deferring the consideration of the important intrusive masses to the last. The primary grouping of these stratified rocks is based on geologic age, the divisions being made sufficiently broad to avoid committing the authors to any correlations more definite than their knowledge appears to warrant. The further subdivision of the groups thus blocked out is chiefly geographic, and the rocks belonging to each of the primary divisions are described for each district in which they are represented.

The plutonic masses and the dikes associated with them are treated separately from the stratified rocks for two reasons. In the first place, their ages are in general still less definitely known, and in the second place their petrographic relations to one another are more clearly brought out by placing them together.

In this section the igneous rocks will be made the subject only of such description as will be interesting and comprehensible to the reader unskilled in technical petrography. The various types will be defined rather broadly according to characters recognizable in the field. Their areal distribution will be described and their geologic relations pointed out in so far as they have been determined. For the benefit of petrographers the more exact descriptive data obtained by microscopic study and the discussion of certain petrologic questions will be incorporated in another chapter.

PRE-CRETACEOUS ROCKS.

GENERAL CHARACTER AND DISTRIBUTION.

Along the route of the party were found many important bodies of rocks, for the most part greatly metamorphosed, which appeared to be undoubtedly pre-Cretaceous. In the case of many of these a much more definite geologic age could be assigned with a fair degree of confidence, but in the case of many others, probably belonging to widely different periods, the existing evidence is insufficient to form a basis for any but broadly general and tentative statements—a fact that seems to render impracticable the application of any general subdivision of these old rocks throughout the region. For purposes of description, therefore, the strata in question are grouped together as pre-Cretaceous.

The rocks considered to be pre-Cretaceous include (1) some very old-looking schistose rocks along Columbia River and lower Okanogan Valley, (2) an assemblage of supposedly Carboniferous sedimentary and volcanic rocks exposed in the more northern part of Okanogan Valley, (3) strata somewhat similar to those last mentioned exposed in the basin of upper Skagit River, (4) some old sediments and a great volcanic mass seen in the vicinity of Hamilton, and (5) a great assemblage of strata ranging from Paleozoic to Jurassic to the west and north of Mount Baker. The rocks of each of these areas will be described and the available evidence will be given in regard to their stratigraphic sequence and geologic age.

COLUMBIA AND LOWER OKANOGAN VALLEYS.

Immediately above the Wenatchee basin, which is carved in soft Tertiary sandstones, the Columbia flows in a gorge intrenched in exceptionally resistant schistose rock. Immediately north of Wenatchee River a granitoid gneiss crops out, which appears to grade into the thinly laminated rock, of schistose rather than gneissic character, that forms the walls of the canyon farther north. In addition to the schistosity which causes weathered fragments to separate readily into thin slabs, there are several systems of joints, four well-marked joint planes being observed, for example, at one spot. While no microscopic examination of this rock was made, observations in the field showed that it consisted essentially of quartz and feldspar, with both light and dark mica.

Schists of similar character were the principal country rocks along the route traversed from a point near the mouth of Knapp Coulee to Chelan Falls. Still another mass of schist, or fine-grained gneiss, was observed to form a portion of the walls of Antoine Coulee near its north end.

In the vicinity of Clover light-colored schists or gneisses occur, similar, in a measure, to those of the Columbia gorge. The prevailing type found was a light-gray medium-grained laminated rock, which may be seen megascopically to consist essentially of feldspar, quartz, and biotite. At the same locality there were seen in small quantity darker biotitic schists and light gray-green pyroxene schists, probably produced by contact metamorphism from impure limestones.

Mention should also be made here of a mass of gneiss from which is carved a glaciated ridge north of Riverside, separating the main valley from a high abandoned side channel. The rock is a gray, well-foliated augen-gneiss, probably derived from a porphyritic granite. No specimens were collected to serve as a basis for detailed description.

UPPER OKANOGAN VALLEY.

In Okanogan Valley, from the vicinity of Riverside to the boundary, old rocks that have undergone considerable metamorphism are abundantly developed. On lithologic grounds they are tentatively classed together and correlated with the Cache Creek series of Dawson,[a] which is of Carboniferous age. It was in the vicinity of Oroville and Loomis that the rocks were most thoroughly studied, and it seems to be there also that the series is most typically developed.

The supposed Cache Creek series, as represented in this district, comprises both sedimentary and volcanic rocks. Its lower portion consists chiefly of clay slates and graywacke slates, usually of gray or greenish color, together with some moderately coarse metamorphic sandstones and fine conglomerates, but comprises no coarse conglomerates. Occasionally the arenaceous portions of the series take on the character of fairly pure quartzite. Material of this sort becomes especially abundant near Mount Chopaka. In the upper portion of the series, as developed at Loomis, there are at least two beds of light-

[a] Ann. Rept. Geol. Survey Canada, new ser., vol. 7, 1894, pp. 37B-49B.

gray limestone, whose areal distribution is indicated roughly on the geologic map. Farther south, to the west and northwest of Riverside, this rock plays a more important rôle. The western wall of the coulee north of that place is a cliff perhaps 200 or 300 feet high and composed mainly of limestone.

The upper part of the series comprises large volumes of volcanic material, which it was not found practicable to separate, on the preliminary map, from the slaty rocks. These old volcanics are for the most part extensively developed on the southern end of Palmer Mountain, in the basin southeast of that point, to the west of Blue Lake, and on the hill southwest of Palmer Lake. Lithologically, they were roughly classified in the field as greenstones. In broad, distant views the dark brownish hues of the weathered surfaces and their rugged erosion forms give them a resemblance to basaltic rocks. In hand specimens their original character is found to be obscured by decomposition, but the porphyritic texture is occasionally noted, as well as amygdaloidal structure and brecciated structure suggestive of pyroclastic origin. Microscopic study of these rocks is productive of no very satisfactory results, owing to the advanced decomposition which they have universally suffered, the original materials being almost always completely replaced. The character of the resulting secondary minerals, however, as well as the textural features, confirms the field diagnosis of the rocks. They are basic extrusives, probably for the most part basaltic, though perhaps including some basic andesite. Pyroclastics appear to be fully as abundant as the massive lavas.

The rocks tentatively referred to the Cache Creek series have suffered various degrees of metamorphism. The sedimentary portions have in general an indurated slaty character in the localities removed from granitic intrusions. In the vicinity of the several intrusive granite contacts, however, much more advanced alteration has taken place, the slates being more or less completely converted to mica-schist. Interesting changes have been produced also in the basic eruptives by the granitic intrusions, the description of which will be deferred to the chapter on petrography.

BASIN OF UPPER SKAGIT RIVER.

The upper part of Jacks Mountain, or Mount Nokomokeen, is carved from a series which has the aspect of being much older than the Cretaceous rocks farther east and may be equivalent to the supposed Cache Creek of Okanogan Valley. It comprises both sedimentary and volcanic rocks.

Most prominent of the sedimentaries are quartzites and bedded cherts. The latter are generally of a light-gray or drab tint and are cut by innumerable veinlets of quartz. Their bedding is their most noteworthy feature. They are built up of distinct laminæ, about an inch in average thickness, readily separable from one another. The similarity of their structure with that of the red cherts of the Franciscan series in California is striking. As in the supposed Carboniferous of Okanogan Valley, there are beds of limestone (which are, however, rather thin and lenticular), and the highest portion of the mountain reached was built up largely of altered volcanic rock, among which amygdaloids were observed. Although obscured greatly by alteration, the constitution and texture of these rocks as observed under the microscope indicate that these old lavas are basaltic.

The lower portion of the mountain is composed in part of dark mica-schists cut by dikes, that often show considerable shearing, and may be contemporaneous with the foliated granodiorite of the valley below. The mica-schists are completely metamorphosed, and impress one as being much older than the rocks already described as forming the upper portion of the mountain.

Old schists, slates, cherts, and quartzites are also the principal country rocks in the valley of the Skagit above Ruby Creek, as far north as Jackass Point, but some "greenstone" (basalt or basic andesite) also occurs. North of Jackass Point the country rock is mainly granitic, though interrupted by a belt of slate. The impression of the observer was that these sedimentary and volcanic rocks were plainly older than the Cretaceous and might in part be correlative with the Cache Creek series.

LOWER SKAGIT VALLEY.

From Marblemount to Hamilton the sides of Skagit Valley are chiefly made up of old rocks. In 1898 Messrs. Willis and Smith made a reconnaissance of a portion of the Northern Cascades, including Skagit Valley from Sauk to Hamilton, and since the authors passed through this region rapidly in 1901 without making any new observations of importance a brief outline of the facts observed in the earlier reconnaissance may be presented here.

At three localities in the valley of the Skagit sedimentary rocks were observed. On the southwest side of Sauk Mountain there are calcareous grit and slate, marble, and slate containing iron carbonate. A little west of Sauk, limestone, black slates, and sericitic slates occur, the phyllites forming the walls of Phinney Creek Canyon. The canyon of Baker River near its mouth is carved in limestone, cherty grit, and black slate. In the limestone occur some crinoid stems, which are the only fossils that have been found in the old rocks of this district, but they give practically no evidence in regard to the age of the rocks.

South of the Skagit, from Sauk River west to near the longitude of Hamilton, there is exposed a rock series distinctly more metamorphosed than the old rocks to the north and presumably of greater age. The rocks of this area comprise black and green slates, crystalline schists, chiefly chloritic and glaucophanitic, with ferruginous quartzites and jaspers. These quartzites are colored by oxides of iron, including both magnetite and hematite. They are sometimes banded parallel to the bedding and sometimes brecciated, in which latter case the angular reddish fragments are cemented by purer quartz.

One of the beds in the old series is so rich in iron as to have attracted the notice of prospectors. This ore band is definite and quite extensive, and shows a banding parallel to that of the schists with which it is associated. In cross section it shows a gradation from a pyritiferous slaty margin to more concentrated ore, richer in magnetite in the center. The thickness of the ore body at the Birdsview prospect is only about 3 feet, and it has not proved sufficiently rich, in view of its small volume, to lead to exploitation.

In addition to the old metamorphic rocks already described, there is also in this region an old volcanic series that is probably younger. These ancient volcanics were observed along the route of 1901 between Marblemount and Sauk. They also form Sauk Mountain, where their field characters were observed by the senior author in 1895. The rugged crest line of that elevation illustrates the characteristic erosion forms of the material.

In the field the volcanic nature of the rocks is easily recognizable, and their extrusive nature is proved abundantly by the frequent occurrence of amygdaloidal and pyroclastic structures. Their prevailing color is dark green, indicating their basic composition. Studied microscopically, they prove to be altered pyroxene andesite, a rock very common in the Cascades, where it has been erupted at various geologic periods.

MOUNT BAKER DISTRICT.

Preliminary statement.—The sojourn in the northwestern part of the boundary region was shortened by the approach of winter, and observations were confined almost entirely to traverses along the principal roads and trails. The description of the older rocks of this district can therefore be only of the most general character, and few statements can be made in regard to their age, which probably ranges from early Paleozoic to Jurassic, or possibly as late as Cretaceous.

Dr. R. A. Daly, of the geological survey of Canada, made, in 1901, a survey of the country just north of the boundary from the coast to Chilliwhack Lake, much more detailed in character than the reconnaissance of the present authors. He has found Paleozoic fossils in a series of shales and limestones which may be the equivalent of some of the old rocks exposed at Bear Mountain and about Twin Lakes.

The bedded rocks of the region may be divided roughly, for purposes of description, into three groups, as follows: (1) Metamorphosed, chiefly sedimentary, rocks, probably Paleozoic; (2) sedimentary rocks, generally not much metamorphosed, probably Mesozoic; (3) an area of volcanic rock of indeterminate age near Hannegan Pass.

Supposed Paleozoic rocks.—The rocks assigned to the first group were observed north of Hardan or Maple Falls, and in the eastern portion of the district, where they are the country rocks of the most important mines. Rocks that should be grouped with these also occur along the Seattle and International Railway south of its crossing of South Fork of the Nooksak and on the highlands between Middle Fork and North Fork. In this western area the old rocks are schists, slates, and quartzites, with perhaps some altered volcanic materials. The beds appear to have suffered intense folding, and no structure could be definitely made out in the hasty examination.

The rocks of the eastern area were somewhat more thoroughly examined. At Twin Lakes Pass there are metamorphosed sandstones and slaty rocks with peculiar breccias and conglomerates of limestone fragments in a slaty matrix. Along Tummeahai Lake the rocks of the supposed Paleozoic are less altered and deformed, but characteristic breccias of calcareous slate occur which resemble the limestone breccia near Twin Lakes. Some volcanic breccias occur here, apparently interbedded with the sedimentary rocks. Along Swamp Creek trail also the country rocks appear to belong to the old group and comprise sandstones, slates, and shales, with considerable volcanic material. These old volcanics are much altered, but microscopic study shows that although they include some rhyolite and dacite they are mainly andesitic lavas and tuffs.

East of Twin Lakes and in the canyon of Ruth Creek the rocks of this older group are more thoroughly metamorphosed, a fact probably due to their invasion by the large mass of granite from which Mount Shuksan and the ridges north of Hannegan Pass are carved. Their irruptive relation to the slaty rocks was clearly seen at Mamie Pass.

The most abundant rock in this metamorphic area might be called a gneiss rather than a schist, but is plainly of sedimentary origin. In mass it shows a blue-gray tint, but in the hand specimen shows a characteristic wavy lamination, marked by the alternation of light and dark layers a few millimeters in thickness. The dark layers are blue gray and slaty looking, and probably contain carbonaceous material, while the light layers are almost pure quartz. The quartz layers are not continuous, but have the character of thin deformed lenses, a feature that suggests that they may be of the nature of gash veins. Gash veins whose dimensions are to be expressed in inches occur abundantly, and frequently carry sulphides. It is in this type of rock that the Lone Jack vein is located.

Another schist found near Lone Jack mine suggests by its general appearance and mineralogic character a derivation from some basic volcanic rock. The old metamorphics of the Mount Baker district are often intensely crumpled and are generally cut by joint planes.

The schists exposed along the route from Sedro to Acme are, in the main, of a somewhat slaty or phyllitic character, with thin and often extremely crumpled laminæ. In color, they are prevailingly bluish. They have "gash veins" of quartz parallel to the lamination, but these are much less numerous than in the schists of the Silicia Creek district, to which they seem to be very similar, though less thoroughly metamorphosed.

In the vicinity of Wickersham there is apparently in this blue schist series a rock which, though with well-developed cleavage and jointing, exhibits distinctly a moderately coarse clastic structure, being composed of fragments of various tints of gray about 2 millimeters in average diameter. All these fragments have been thoroughly squeezed, so as to have a slaty structure, and are, as it were, so welded together that the rock splits across them indifferently.

Near the intersection of the western boundary of the Washington Forest Reserve with the parallel 48° 50′ N., gray, slaty, and phyllitic rocks, highly crumpled, and evidently very much older than the Tertiary sandstones by which they are overlain, are exposed. They are not improbably connected with the rocks of the last area described.

Supposed Mesozoic rocks.—For some miles below Shuksan the outcrops on the walls of the canyon of the North Nooksak are of sedimentary rocks distinctly less metamorphosed than those assigned to the Paleozoic. They are mainly sandstones, with some cherty layers and conglomerates. Green colors are rather characteristic of all the rocks. At Austin Pass there are greenish sandstones and banded shales which show on the average about the same degree of induration as the similar rocks of the Pasayten formation. On lithologic grounds, then, it appears probable that there may be a belt of Mesozoic rocks trending northwest from Austin Pass.

There is, moreover, some paleontologic evidence bearing on this question. In 1898 there were sent to Mr. J. S. Diller by Mr. W. H. Fuller, of Fairhaven, Wash., some fossils collected on Cowap, or Canyon, Creek and on the ridge north of it. Mr. T. W. Stanton examined the material and reported on it as follows:

The * * * fossils * * * are evidently all from one horizon, which I believe to be upper Jurassic, this opinion being based chiefly on the distinctly striated form of *Aucella*, identified with *A. erringtoni* (Gabb) of the California upper Jurassic Mariposa beds. This species was collected at both localities. The collection from Canyon Creek includes also a fragmentary *Pleuromya* and the impression of a small belemnite.

The collection from the divide between Canyon Creek and the waters of Fraser River contains the *Aucella erringtoni*, a fragment of an ammonite apparently belonging to the genus *Stephanoceras*, a small slender belemnite like that from the last-mentioned locality, and the phragmacone of a large robust belemnite.

Volcanics near Hannegan Pass.—North of Hannegan Pass the granite is overlain by volcanic rocks, in part massive, but chiefly consisting of green and purple breccias apparently of andesitic character. Dikes apparently connecting with these extrusives cut the granite, and further evidence of their relation to the older rocks is found in the presence of fragments of granite and schist in the breccias. These are probably the rocks through which the vents penetrated, indicating that the eruption was local in its character. Regarding the period of this eruption, it can only be said that the appearance of the rocks indicates that they are much older than the lavas of Mount Baker, while the other limit to their age is given by their relation to the granite.

CRETACEOUS STRATA.

PASAYTEN FORMATION.

Occurrence.—Professor Russell, in his reconnaissance of 1901, examined an assemblage of folded sedimentary strata in the neighborhood of Barron and Crater Pass.[a] From these rocks he collected fossils which are commented on in the following extract from his report:

> A thick bed of bluish sandstone at the base of Gold Ridge, penetrated by the tunnels of the St. Paul and Minneapolis mines, contains fossil fern and nearly upright tree trunks. One sample of fern collected has been determined by F. H. Knowlton as approaching closely *Dryopteris oerstedi*, from the Cretaceous rocks of Greenland. A siliceous limestone in the same ridge, but several hundred feet higher in the series and extending southward to the border of Crater Pass, is abundantly charged with bivalve shells, which, as determined by T. W. Stanton, are of a species of *Actæonella*. The evidence furnished by the fossils just mentioned indicates a Cretaceous age.

The authors of this paper found that these Cretaceous beds extended eastward along their route to the Hidden Lakes and were very extensively developed to the north, and believe that they extend west to a point not far above the mouth of Granite Creek. In this, however, they differ from Professor Russell, who believes that the slaty rocks with steep dips exposed along lower Slate Creek and Ruby Creek are much older than the Cretaceous.[b] This opinion, however, is not supported by stratigraphic evidence, but apparently rests merely on the older appearance of the rocks to the west, due to greater metamorphism. The value of this lithologic evidence will be considered presently; meanwhile it may be said that the authors do not consider that the assumption of the pre-Cretaceous age of these beds is justified, and have provisionally considered them as belonging in the same formation with those at Barron.

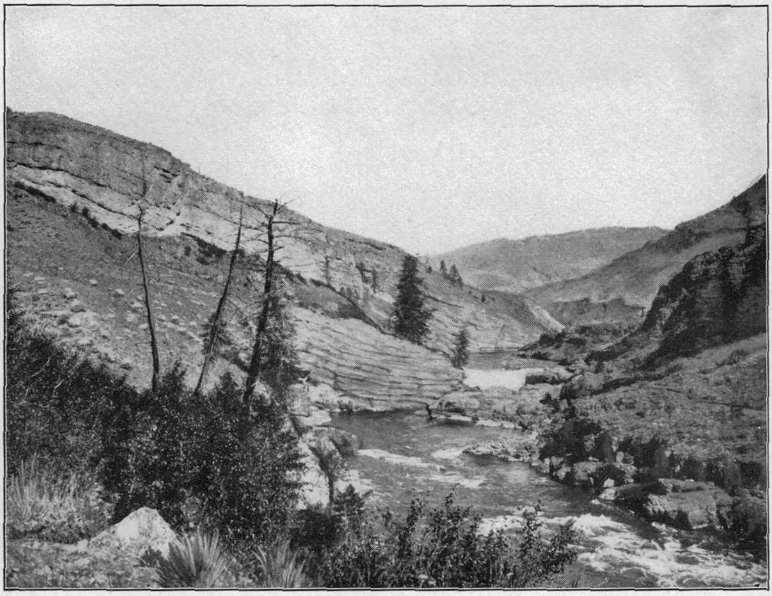
Name.—To the rocks of this locality which he recognized as Cretaceous Professor Russell provisionally applied the name Similkameen formation.[c] This name was, however, applied ten years earlier by Dawson to a Miocene formation in British Columbia,[d] and hence it

[a] Russell, I. C., Geology of Cascade Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 114–117.

[b] Op. cit., p. 112.

[c] Op. cit., pp. 114–117.

[d] Dawson, J. W., Proc. and Trans. Royal Soc. Canada, vol. 8, sec. 4, 1890, pp. 75–91.



A TERTIARY SEDIMENTS, SQUANTL FALLS, SIMILKAMEEN RIVER, WASHINGTON.

B. CRETACEOUS CONGLOMERATE FORMING CREST OF HOZOMEEN RANGE.

Head of Three Fools Creek, Washington.

seems advisable to abandon it. As a substitute, the name Pasayten formation is proposed. This name, rather than Similkameen, is applied on all of the old as well as the most authoritative of the more recent maps to the stream which is the southwest tributary of the main Similkameen, so that it is also on this account more appropriate as a formation name for the rocks here described.

Lithologic character and thickness.—The Pasayten formation is composed of sedimentary rocks without contemporaneous volcanic materials. East of the main fork of Pasayten River sandstone appears to be the dominant rock. It is along the main divide north of Barron that the most instructive exposures of the Pasayten formation are seen. The lowest part of the section, as seen along the crest of the Hozomeen Range, includes at least 1,000 feet of black shale. Above this shale is a sandy conglomerate, with pebbles from 1 to 8 inches in diameter. About 500 feet of this conglomerate is exposed at the head of Canyon Creek. Sandstone overlies the conglomerate and is succeeded by more black shale. The steep dips here indicate the presence of a great thickness of these rocks, which extend far out on the spurs at the head of Three Fools Creek (Pl. II, *B*), so that 6,000 feet would appear to be a very conservative estimate for the thickness of the Pasayten formation.

There are a few thin and discontinuous beds of limestone in the Pasayten formation, but they constitute only an insignificant proportion of its total volume. Along the lower portion of Slate Creek the supposed Cretaceous rocks are mainly black indurated shales with nearly vertical dips.

The argillaceous portions of the Pasayten formation are generally dark-colored, distinctly bedded shales. They are often siliceous and in general more or less indurated, and are popularly referred to as "slate." In no case, however, was there observed any true slaty cleavage oblique to the bedding. The beds upon lower Slate Creek and Ruby have, as their high dips indicate, suffered more intense folding than those to the east, and are in general more indurated. There is, however, no difference between these rocks and the shales of known Cretaceous age such as would justify their separation on lithologic grounds.

The sandstones, while occasionally quartzitic, are more commonly gray or greenish gray in color, and evidently composed in large part of feldspar and rock fragments. The conglomerates contain a variety of pebbles, including several granitoid rocks, gabbro, diabase, metamorphosed volcanics, chert, quartzite, and vein quartz, illustrating the character of the pre-Cretaceous formations of the region.

The whole series has undergone a considerable degree of "static" metamorphism, as shown by the generally thorough cementation of the sandstones and the presence of joints in all the varieties of rocks. Both these phenomena are exemplified strikingly in the conglomerates, which often are divided into great blocks whose faces are nearly as smooth as if made by a saw that had cut indifferently through the pebbles and their compact matrix.

The series is cut by many dikes and sheets of igneous rock; these are especially numerous along the main divide, where they must add materially to the volume of the formation. At three localities there are exposures of granitoid rock, apparently intrusive in the Pasayten formation. These igneous rocks will be described in another section.

TERTIARY FORMATIONS.

CLASSIFICATION AND DISTRIBUTION.

Tertiary rocks have much less importance along the boundary section of the Cascades than in central Washington. Of the formations to be described some are known positively to be Tertiary, while for others a Tertiary age is tentatively assumed on grounds that will be stated.

The areas of known and supposed Tertiary rocks, in the order in which they were seen, are as follows:

(1) Near Wenatchee there are exposed sedimentary beds that have been connected areally with the Swauk formation, of known Eocene age. With these are associated some andesite and rhyolite, and all these are overlain by the Miocene Yakima basalt.

(2) In Okanogan Valley are extensive sedimentary and volcanic deposits, the structure and lithologic character of which indicate that they are not very old. They are supposed to be Tertiary.

(3) East of the great Cretaceous area there is a belt of volcanic rocks which seem to overlie the Cretaceous and are tentatively referred to the Tertiary.

(4) In the western foothills of the Cascades and on the low coastal region there are great bodies of Eocene rocks, in part coal bearing. Exposures of these strata were seen in the vicinity of Hamilton and in the drainage basin of Nooksak River.

COLUMBIA RIVER VALLEY.

Swauk formation.—The expansion of Columbia Canyon at Wenatchee, which has determined the location of the town, owes its existence to the softness and consequent extensive erosion of the Swauk formation, which is splendidly exposed in the canyons southwestward from Wenatchee and on the slope facing that town across Columbia River. This formation, which is of Eocene age, has been made the subject of detailed description in the Mount Stuart, Washington, folio by the senior author of this paper and needs to receive but brief description here.

As regards its lithologic character the Swauk of the Wenatchee basin consists for the greater part of sandstones, usually light colored and of arkose character. The sandstones are frequently pebbly, however, and beds of conglomerate occur, in which the pebbles include light-colored rhyolite- and andesite-porphyries, quartzite, granite, and schist. Shales of variegated colors, including purple, red, green, gray, and white, are abundant in the Swauk of this vicinity, notably across the Columbia from Wenatchee and in the canyons to the south. These colored shales are not represented in the Swauk of the Mount Stuart area. Plant remains are of frequent occurrence in the Swauk formation, and there are some beds of impure lignitic coal which have been prospected but not found to warrant exploitation.

The relation of the Swauk formation to the basalt which overlies it is beautifully exposed in cliff sections on the sides of a gulch about 3 miles south from Wenatchee, where basalt gravel and basalt rest upon the truncated edges of folded sandstones that have a dip of about 45°. Farther west the angular unconformity is still greater, the sandstones having an inclination of 60°, while the overlying basalt is nearly horizontal.

Andesite and rhyolite.—Associated with the sandstones and shales of the Swauk formation near Wenatchee are volcanic rocks, probably in part intrusive and in part extrusive, belonging to the species rhyolite and andesite.

The andesite forms a rugged crag, prominent and of striking appearance, a few miles southwest of Wenatchee. Hasty examination of the occurrence led to the belief, based mainly on the absence of scoriaceous structures, that the rock is probably intrusive. The mass is in line with the axis of an anticline observed on the ridge south of it and may be of laccolithic nature. The rock shows lamellar and columnar jointing. It is in general much decomposed, but shows porphyritic texture, and on microscopic study proves to be andesite.

The rhyolites occur at two localities across the canyon south of the andesite crag. The first is at the edge of the alluvial flat where the rhyolite forms a small dome-shaped hill. The rock has here a pronounced lamination more or less parallel to the surface on all parts of the dome. It is mostly porphyritic, showing crystals of quartz and feldspar in a strong fine-grained groundmass, but there is some perlitic glass, breaking down into a coarse sand. Near the crest of the ridge south of the little dome there is another outcrop of rhyolite which overlies a bed of hard conglomerate and in part is massive, laminated, with distinct flow structure, and in part shows very beautifully the structure of a flow breccia. The rhyolite of this locality is doubtless extrusive and probably flowed in an old river channel, but the mass of rhyolite at the base of the hill seems more probably intrusive.

Yakima basalt.—The basaltic series overlying the Swauk formation at Wenatchee is the same that covers the greater part of eastern Washington and Oregon. Being the most important formation of the

Pacific Northwest, it has received notice from most of the writers on the geology of that region. In the Ellensburg and Mount Stuart folios of the Geologic Atlas of the United States it has been described with some detail by the senior author, and its characters need only be recapitulated briefly here.

In the many splendid cliff exposures afforded by the erosion of the Columbia and its tributaries the series is seen to consist of many layers of lava and pyroclastic material. In some of the sections near the crest of the Cascades there is a large proportion of tuff, but in the vicinity of Columbia River the massive lavas are in decided preponderance. The most universal and striking structural feature of the Yakima basalt is the columnar jointing so characteristic of basalt in general. Amygdaloids and scoriaceous layers give abundant testimony to the extrusive origin of the series.

The route of the party to the region of the boundary lay in great part near the edge of the basalt area. Table Mountain, which forms the northeastern rim of Kittitas Valley, is a structural uplift formed of basalt which is deeply intrenched by the Columbia along its eastern base. The north face of the mountain is a splendid erosion scarp, along the base of which the Swauk formation is exposed. The surface north of the basalt cliff is of a peculiar hummocky character and has many undrained basins, its topography being evidently due to landsliding from the precipitous slope. Large blocks of basalt are indeed found at some distance from the escarpment, toward which their bedding planes usually have a gentle inclination. The boundary between the basalt and the older formations swings away from the river opposite Wenatchee for a few miles, then again swings westward, so that the basalt forms the rim of the canyon of the Columbia as far up as the mouth of the Okanogan. From that point it extends in a northeasterly direction, and the formation is soon lost to the view of the traveler proceeding up Okanogan Valley.

OKANOGAN VALLEY.

In Okanogan Valley, near Oroville, the slates and granites are overlain by sandstones whose structure and lithologic character indicate a comparatively recent age. These sedimentaries are overlain by andesites.

This group of beds is especially well exposed in the precipitous faces of the bold butte southwest of Loomis, known as Whitestone Hill. The height of the hill is about 1,300 feet above the alluvial deposits at its foot. Its base is composed of old rocks, presumably of the Cache Creek series, but the greater portion is built up of a succession of conglomerates, white sandstones apparently consisting in large part of volcanic material, and brownish and gray sandy shales. A thick capping of hornblende-andesite has been the agent in protecting these soft beds from erosion.

In the basin north of Blue Lake, and in the valley of the Similkameen near its mouth, sandstones, conglomerates, and andesites, presumably of the same formation, are also exposed. (Pl. II, *A*.) The conglomerates that were observed low down on the slope north of Blue Lake and that seem to be the sole, or at least the principal, representatives of the formation in Similkameen Valley are of somewhat remarkable character. They are generally very coarse and are especially characterized by the angularity of the fragments composing them. The materials are derived from the immediately underlying old rocks, and consist of slate, greenstone, granite, and schist. These are often intermingled, but some beds, especially those in Similkameen Valley, are composed solely of angular blocks of granite with a matrix of feldspathic sand and fragments of feldspar crystals. The section of Tertiary sediments in Similkameen Valley is illustrated in Pl. II, *A*.

West of Lake Osoyoos the presence of abundant fragments of andesitic lava gives the material a tuffaceous appearance. This green breccia and conglomerate also includes large bowlders of granite, and it is doubtless simply another phase of the Tertiary sediment. The andesite is both intrusive and effusive at this locality, and in the three exposures near Lake Osoyoos the andesitic lava rests unconformably upon the sedimentary series.

Somewhat farther down the valley there are clastic beds which appear to be mainly tuffaceous, and which are associated with considerable volumes of rhyolitic lava. The rhyolites are extensively developed a few miles north of Clover, between Salmon Creek and Johnson Creek, and north of Johnson Creek. A specimen from the first-named locality proves, on microscopic study, to be a soda-rhyolite.

VOLCANICS EAST OF HIDDEN LAKES.

From the point where the Pasayten crosses the boundary a belt of volcanic rocks extends southeast with gradually increasing breadth. Along its eastern border the volcanic series rests upon granite. To the west it is in contact with and apparently overlies the sandstones of the Pasayten formation. The lithologic species represented in this volcanic area are (1) dacite, (2) hornblende-pyroxene-andesite, (3) basic pyroxene-andesite, and (4) hypersthene-basalt.

The dacite, which is a light-gray or drab rock containing rather abundant phenocrysts of quartz and feldspar with fewer of dark minerals, is mainly developed along the slopes southeast of the Hidden Lakes and also forms dikes in the Cretaceous sediments to the west. The hornblende-pyroxene-andesite, a dark-colored rock in which small black prisms of the dark minerals are abundant, was collected in the eastern edge of the belt about 9 miles south of the boundary. The basic pyroxene-andesite which is exposed along the East Fork of the Pasayten and the most northern of the Hidden Lakes is a dark greenish rock somewhat resembling basalt, but distinguished by the presence of noticeably large porphyritic crystals of greenish feldspar.

The hypersthene-basalt is a dense, fine-grained, dead-black rock containing large, conspicuous grains of yellowish green olivine. It forms a small knob on the slope east of the middle lake, standing up above the andesites, into which it appears to be intrusive.

WESTERN SLOPE.

Hamilton district.—In the northwest part of the area of this reconnaissance there are important masses of Tertiary strata containing beds of coal, which have been prospected near Hamilton and in the valley of the Nooksak, without, however, any encouraging results. In 1895 some observations on these rocks were made in the vicinity of Hamilton, and some fossils were collected at the coal prospect known as the Skagit-Cumberland mine. The fossils collected at that time, and a collection made in the same vicinity by Prof. Henry Landes, State geologist of Washington, in 1901, have been examined by Dr. F. H. Knowlton, who reports that they prove the age of the beds to be Tertiary.

Nooksak Valley.—A sedimentary series, possibly in part correlative with the beds of Skagit Valley, is exposed about the confluence of the forks of the Nooksak and also in the valley of the North Fork of the Nooksak below Glacier Creek. Professor Landes has also collected from these beds near Keese, obtaining some excellent material, which was submitted for examination to Doctor Knowlton, who reports that much of this material is identical with or similar to forms from vein XII at Franklin, thus correlating the beds at Keese with the Puget formation, which is of Eocene age.

Lithologically the material constituting the Tertiary series of Nooksak Valley is chiefly sandstone, generally of light-olive or gray color, containing considerable amounts of feldspar and rock fragments. Some shale and conglomerate also enter into the constitution of the series. The character of the rocks shows that shallow-water conditions prevailed during the entire period of their deposition.

QUATERNARY FORMATIONS.

CLASSIFICATION AND DISTRIBUTION.

The Quaternary formations of the region consist of the Mount Baker lava and of extensive stream deposits. The fresh condition and topographic relations of the lava show that it is post-Pliocene, and its considerable erosion and glaciation at Austin Pass show that it is also pre-Glacial. On the other hand, the extensive deposits of sand, gravel, and silt in the valleys and mountain canyons and on the coastal plain were laid down by streams and glaciers in Glacial and post-Glacial time.

MOUNT BAKER LAVA.

Geologic relations.—Mount Baker, like most of the higher peaks of the Cascades, is an extinct volcano built up of andesitic lavas of comparatively recent age. The mountain was not ascended by our party, but lavas that emanated from the ancient crater were seen at Austin Pass and at a point in the canyon of Nooksak River almost directly north of the mountain. At the latter point the end of the flow forms a steep bluff on the south side of the river, but does not appear on the north side. North of Austin Pass a gray dome rises up above the general height of the neighboring ridges, capped by purplish andesitic material, and this mass appears to have been an island-like projection of older rocks above the lava streams. East of the pass the lava overlaps vertical beds of sandstone and greenstone. The relations of the lava to the older terranes are interesting because they show that the lavas were poured out upon a topography as rugged as the present, and that the main drainage feature of the region, the Nooksak, had, at the time of their eruption, the same position, and even practically the same level, that it has now.

Lithologic characteristics.—Although fragmental materials probably form part of the cone, all of the volcanic materials from Mount Baker observed at close range are lava. They present considerable variety in respect to the features observable in the field. In structure they vary from highly scoriaceous to compact, the latter being always divided by joints either into prismatic columns usually standing nearly vertical, or into thin slabs more commonly horizontal. The first type of jointing is seen in striking illustration in the end of the flow that comes down to the Nooksak, and the second type is seen in the exposures at Austin Pass. The degree of crystallinity also varies between wide limits; porphyritic texture is nearly always evident, but the groundmasses are in part evidently crystalline, in part distinctly glassy. The more crystalline varieties are generally of a gray color, while the more glassy phases are black, or, less commonly, red. The specimens collected are all to be classified as pyroxene-andesites, and thus belong to the type of lava most abundantly represented in the Pleistocene eruptions of the Cascade volcanoes.

GLACIAL AND STREAM DEPOSITS.

In describing the glacial and stream deposits it is convenient to make a geographic subdivision, considering in turn the deposits (1) of Columbia and Okanogan valleys, (2) of the mountain area, and (3) of the western area, including the coastal plain and the lower parts of Skagit and Nooksak valleys.

Columbia and Okanogan valleys.—The Pleistocene deposits of Columbia and Okanogan valleys record a most interesting Glacial and post-Glacial history, of which the principal episodes are, briefly, as follows: (1) Glaciation of the valleys; (2) melting and recession of glaciers and partial filling of valleys with gravel deposits from streams overladen with glacial débris; (3) reexcavation in the gravel deposits. While it is not improbable that there was more than one advance and retreat of the ice, no definite evidence of this has been found.

The Pleistocene deposits in these valleys, then, may be classified according to origin as (1) deposits of Glacial age, including (a) true morainic accumulations and (b) aqueous deposits laid down by streams flowing along the sides of glaciers or in ponds held back by ice dams, and (2) post-Glacial stream deposits.

The discussion of these deposits may well be prefaced by a brief résumé of observations by earlier workers in this field:

Mr. Bailey Willis, in 1887, first called attention to the former existence of glaciers in the extreme northern part of Washington, either as portions of a general ice sheet or as tongues pushed forward from disconnected ice rivers descending from the north.[a] The glacial geology of northern Washington has since received attention from Russell,[b] W. L. Dawson,[c] Salisbury,[d] and others. It has been established by the observations of these writers that the Quaternary ice in northeast Washington was in the form of great valley glaciers which did not merge into a general ice sheet unless in the vicinity of the northern boundary. Upon the latter point some evidence will be presented on another page.

Of the great ice streams that existed in this region in Pleistocene time, probably the most important was that which flowed down Okanogan Valley. Professor Russell,[e] ten years ago, published a vivid account of the impressive traces left by the Okanogan Glacier on the plateau embraced by the Great Bend of the Columbia. He noted the huge erratic blocks of basalt and granite, the glacial scorings on the bed rock, and the terminal moraine that sweeps across the plain. From his observations he deduced that a great glacier had once flowed down Okanogan Valley and, on reaching the Columbia, had divided, one arm flowing down the valley of the master stream, the other and greater one crossing the 2,500-foot canyon and pushing south about 35 miles farther.

In 1901 the terminal moraine was definitely traced by Messrs. George H. Garrey and Eliot Blackwelder. Its extent is indicated by Professor Salisbury[f] as follows: "The moraine of the ice lobe * * * loops southeast from Chelan Falls to a point about 6 miles west of Coulee City, where it bends northeastward to a point 5 miles north of the city, on the bluff of the Grand Coulee." This description seems

[a] Willis, Bailey, Bull. U. S. Geol. Survey No. 40, 1887, p. 10.

[b] Russell, I. C., Bull. U. S. Geol. Survey No. 108, 1893, pp. 25, 86–89; Am. Geologist, vol. 22, 1898, pp. 362–369; Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pp. 150–170.

[c] Am. Geologist, vol. 22, 1898, pp. 204–217.

[d] Jour. Geol., vol. 9, 1902, pp. 212–213.

[e] Bull. No. 108, loc. cit.

[f] Jour. Geol., vol. 9, p. 721.

to imply that the southern extension of the Okanogan Glacier was not bifurcated as Professor Russell suggested, but extended continuously from the Grand Coulee to the mountains west of the Columbia. The present depth of the portion of the Columbia Canyon that was occupied by ice is from 2,000 to 2,500 feet below the plateau to the south and east, and the elevation of the east end of the moraine as measured barometrically by the junior author in 1902 is about 2,200 feet above sea level. If the inference from Professor Salisbury's statement given above is correct, it follows that there was at the maximum development of the Okanogan Glacier a thickness of something like 2,500 feet of ice in the canyon of the Columbia between the mouth of the Okanogan and the Chelan crossing.

The authors of this report, in their course up Columbia and Okanogan valleys, had some opportunity to observe the evidences of their former occupation by ice. The most striking and unmistakable of these evidences are the erratic bowlders, the remarkable accumulation of which opposite the mouth of the Methow was first described by W. L. Dawson.[a] The western slope of the Columbia Canyon at this locality is strewn with great numbers of huge fragments of basalt and granite, many of them larger than the ordinary settler's cabin. They continue to occur along the left bank for some miles below this point, and a few are found on the Great Terrace above the right bank. North of the mouth of the Methow the slope of the valley has many erratics of basalt, although that rock does not occur in place on that side of the Columbia. The highest of these glacial bowlders for which a barometric observation is recorded is 1,100 feet above the river, but others in the vicinity lie, by estimate, at least 300 feet higher. These figures of course give minimum estimates for the thickness of the ice at this locality.

Along the sides of Columbia and Okanogan valleys there are numberless side channels of peculiar history, which will be described more fully in a later section. To the authors, both the form of these canyons and the character of the deposits on their floors seem to furnish abundant evidence that they had been occupied by ice. These deposits are characterized topographically by their hummocky and irregular surfaces, with numberless undrained basins and kettle holes. Most of the channels in question are occupied by chains of lakes or ponds, while the small streams that flow through others meander through a succession of meadows, often finally disappearing beneath the porous deposits before reaching the master streams.

Professor Russell has noted accumulations of such character in Antoine Coulee south of Methow River, but considers them to be merely talus.[b] To the authors of this bulletin these accumulations, while doubtless comprising much talus material, seemed to be so

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[a] Loc. cit., p. 215.

[b] Am. Geologist, vol. 22, p. 367.

voluminous and of such topographic form that they could not be accounted for except as morainal deposits. Moutonnée surfaces of granite were observed projecting from the terrace north of this coulee, and on the southern wall of Peters Canyon, which joins it at the other end. Professor Russell's contention that the ice did not reach an elevation as high as the bottom of the channel seems to be quite invalidated by the fact that the highest point in the bottom of the coulee is only about 700 feet above the river, while glacial bowlders were observed about 5 miles north perched upon the canyon side 400 feet higher.

Closely related to the morainal deposits above described are numerous bowlders of schist and granite strewn upon the low terraces at Wenatchee, of so great size that they could only have been transported by ice. They are supposed to have been carried to their present position by icebergs broken from the front of the Okanogan Glacier.

Upon the sides of the canyon of the Columbia are a succession of terraces, in part benches carved from bed rock, but mainly fill terraces built of stream-laid rounded gravels. From a point near the mouth of Knapp Coulee to the mouth of Okanogan River one of these gravel benches is markedly distinguished from all the others by its extent and perfection, and has been designated by Professor Russell the "Great Terrace of the Columbia." There are other benches of minor extent above and below the Great Terrace. The Great Terrace itself and those below it are of post-Glacial age, while those above it are believed to be contemporaneous with the glacial occupation of the valley. In order of age, then, the higher terraces will be described first.

From a point of view near the southern end of Antoine Coulee the observer may see, on the opposite side of Columbia Canyon, at least ten unmistakable, though often rather indistinct, benches above the level of the Great Terrace. The junior author examined the slope north of Ives and found it largely covered with soft sand and gravel and broken by a series of terraces, of which the highest recognized was about 2,300 feet above the water level at the mouth of the Methow. These high terraces seem to have been either ignored or passed over briefly by previous writers,[a] but they should be considered in any attempt to construct a complete history of Columbia River. They are attributed to the period when the valley was occupied by ice, the hypothesis being based upon the position of the terraces, their form, and the character of the materials composing them. The highest terrace is apparently at the highest level which the surface of the ice attained, according to the evidence of the terminal moraine, and the fact that many of them are on that part of the slope strewn

[a] Salisbury and Willis examined in 1900 similar terraces above Chelan Ferry, and considered them to be in part stream terraces, indigenous to the brooks that now cut them, and in part moraine terraces of small glaciers that formed from snow drifted over the scarp of the plateau.—*Communication from Mr. Willis.*

with glacial bowlders precludes the supposition that these features are pre-Glacial. It appears, on the other hand, utterly improbable that they are of the nature of the Great Terrace and prove a filling of the valley with stream deposits to a depth of over 2,000 feet. As regards their form, they are less regular than the lower benches, and characterized by more numerous deep pittings than on the Great Terrace. The pebbles and bowlders entering into the construction of the terraces are generally subangular, suggesting glacial débris only slightly worked over by water. The facts of observation, therefore, are taken to indicate that the high terraces were built by streams flowing along the sides of the Okanogan Glacier during the period of its decline.

Probably to be correlated with the features just considered are the deposits of unconsolidated sand and gravel which mantle the slopes carved from the old rocks in the basin east of Loomis in which Whitestone Hill and the Spectacle Lakes are situated. The maximum elevation of these beds just east of the low pass between this basin and the canyon of the Simlahekin is not less than 700 feet above the nearest point on Okanogan River.[a] It is supposed that these deposits belong to a period when the main Okanogan channel was filled with ice, which acted as a dam and formed a great pond in this lateral basin.

Extensive high-level deposits of coarse gravel in Peters Canyon between Methow and Chelan rivers are described by Professor Russell[b] and were observed by the authors. Opposite the southern end of Antoine Coulee a barometric reading, checked on a near bench mark, gave the elevation of the upper surface of these gravel deposits as 1,820 feet, which is about 1,100 feet above the nearest point of Columbia River.

W. L. Dawson observed these deposits in 1896, and in explaining their origin says that they "were evidently accumulated at a time when the occupation of the Columbia gorge by the still moving Okanogan Glacier prevented the free escape of drainage waters."[c]

Professor Russell[d] does not adopt this explanation, but says: "As the locality is, by estimate, about 4 miles from the Columbia, it would seem as if the gradient of the stream which deposited the gravels was sufficient to account for their elevation above that river." It seems to be implied that the deposits in question are an extension of the Great Terrace, whose nearest point is probably not more than 2 miles from the locality where the deposits of Peters Canyon attain a height of 540 feet above it. It is difficult to imagine a stream of such a gradient as 270 feet to the mile depositing an important body of gravel. In objection to the hypothesis advanced by Dawson, it is urged by Professor Russell that no evidence of a sufficient thickness of ice in

[a] Based on barometric readings and surveys of the Great Northern Railroad.
[b] Op. cit., pp. 180-182.
[c] Am. Geologist, vol. 22, p. 212.
[d] Loc. cit., p. 181.

the valley of the Columbia has been obtained. Reasons for disagreement with the latter statement have been given on preceding pages, to which the reader is referred. The authors are therefore inclined to accept the explanation advanced by the first observer and to consider the gravels at Peters Canyon as in the nature of a delta deposit laid down in a tributary canyon dammed by the Okanogan Glacier.

The Great Terrace is first clearly recognized by the traveler going north from Wenatchee about 3 miles beyond Entiat. For several miles northeast of that point it is well developed along the left bank of the river, and is shown by the contours on the Chelan topographic sheet of the United States Geological Survey. It is also in general well marked all along the west side of the valley from Chelan nearly to the Okanogan. The Great Terrace naturally extends up the tributaries of the Columbia, and in the lower portion of Okanogan Valley attains a breadth greater than the maximum observed along the master stream, amounting perhaps to as much as 3 miles just northeast of Brewster and about the same a few miles north of Clover.

The height of the Great Terrace above Columbia and Okanogan rivers was measured barometrically by the authors at several points. The results are of interest as giving some indication of the relative grades of those streams at the present time and at the time when the terrace was formed.

Barometric measurements of the elevation of the Great Terrace above Columbia and Okanogan rivers.

No.	Locality.	Approximate height.	Observer.
		Feet.	
1	Mouth of Knapp Coulee	528	G. O. S.
2	Howard Flat	520	G. O. S.
3	do	505	F. C. C.
4	Near Ives, brink of terrace	460	G. O. S.
5	do	465	F. C. C.
6	Near Ives, one-half mile from brink	490	F. C. C.
7	Brewster	470	G. O. S.
8	North of Ophir	320	G. O. S.
9	North of Clover, back of terrace, 2 or 3 miles from river	390	F. C. C.
10	North of Johnson Creek	345	F. C. C.

On comparison of the observations it is at once evident that, neglecting small discrepancies and allowing for the slope from the back of the terrace, illustrated by observations 5 and 6, the difference between the present water level and the Great Terrace decreases as we go upstream. It is thus proved that the old gradient of the

Columbia and Okanogan was less than the present gradient, unless there has been post-Glacial deformation.

As regards its origin, this remarkable feature is evidently constructional. The slope from its brink to the river is composed entirely of gravel, and the Columbia, within the area considered here, either flows on gravel or has intrenched itself but slightly in bed rock. It follows that the bed-rock canyon of the Columbia, practically as deep as the present one and broader bottomed, was once filled with fluviatile deposits at least to the level of the Great Terrace. That level, furthermore, probably marks the upper limit of post-Glacial filling, for there are no extensive terraces above it. The benches below the Great Terrace simply mark pauses in the process of clearing out the gravel deposits, to which the stream has mainly devoted itself in late Quaternary time.

Mountain area.—In the mountain valleys the authors made few detailed observations in regard to glacial deposits. The evidence that the principal mountain valleys were once occupied by ice consists principally in the characteristic erosion forms produced by glaciers. Stream erosion has been active in post-Glacial times, so that the morainal accumulations have been largely removed and redistributed as flood-plain deposits. Locally, however, the materials in the valley bottoms show the hummocky arrangement that is characteristic of glacial deposits. The great majority of the numerous lakes of the region owe their existence to glacial action. In addition to the multitudes of rock-rimmed tarns that lie in the abandoned high cirques and glacial benches, there are in the deeper valleys several larger bodies of water, such as Hidden Lakes, that have morainal dams. Dr. R. A. Daly[a] notes that Chilliwhack Lake, which was not visited by the authors of this paper, is held by a moraine.

Although no well-defined lateral moraines were seen by the authors, erratic bowlders were noted on some of the valley walls. Two observations were made near the international boundary which may bear upon the question of the southern extension of the Cordilleran ice sheet. Directly west of Mount Chopaka, on the southern slope of the divide extending westward from that peak, some blocks of granite were found in a position to indicate that they had been transported from the northern slope. The size of these erratics necessitated ice transport, and the locality is such as to preclude the work of any valley glacier. It seems probable, therefore, that the ice sheet here extended a few miles south of the forty-ninth parallel and attained an elevation of about 6,500 feet. Again, in Pasayten Valley granite blocks were found 1,000 to 2,000 feet above the river level, on the tops of ridges. Glacial bowlders, presumably left by the valley glacier, occur on the lower slopes, but these higher-level erratics were thought to be possibly of different derivation. Unless there is gran-

[a] Summary Report Geol. Survey Canada, 1901, p. 43.

ite occurring at points at the head of this valley not visited, these granite bowlders must have come from the north, where the granite extends down to the river level. These two occurrences of glacial erratics with a possible northern derivation are quite in accord with the southern limit of the ice sheet as mapped by Dawson.

As in the larger valleys to the east, glacial débris accumulated when the glaciers were extensive and probably overloaded the streams in the period following. The small high-grade streams of the mountains are bordered by gravel deposits of considerable importance. West of Toats Coulee Creek, near the opening of the Horseshoe, there is a gravel terrace more than a hundred feet above the stream and several hundred yards in width, while the valley of the stream draining the cirques of Bighorn Peak contain similar accumulations, which, through the present stream channel, has been excavated. The flat-bottomed valleys of the Pasayten and its principal forks are floored with gravel deposits of great lateral extent and considerable thickness, which have been carved into terraces. Near the boundary, on the main stream, two gravel benches were noted at 80 and 150 feet, respectively, above the stream, which has not reached bed rock.

High-level gravel terraces are found in protected localities along the steep gorge of Ruby Creek, but are developed extensively only near its mouth, where it really flows across a portion of the broader U-shaped valley of the Skagit before joining the main stream. The gravels here lie on a high shelf in the bed rock, the creek itself flowing in a narrow canyon intrenched in the gneiss; gravel deposits are also spread upon the floor of Skagit Valley above the junction.

Western area.—On the western side of the Cascades it is still more difficult than in the mountain area to separate glacial from fluviatile deposits. Below the point where the Skagit emerges from its splendid gorge gravel terraces are found on either side, and become of increasing importance as one continues downstream. The valley becomes constantly broader and at Hamilton has widened to an alluvial plain several miles in breadth.

Along Nooksak River, especially between Keese and Maple Falls and for a few miles above the latter point, there are broad gravel terraces, of which the highest are not less than 200 feet above the river. For many miles also below Shuksan the road is laid upon a terrace which is not high above the water level. Above Shuksan gravel deposits are not so important, and the stream channel is generally in bed rock. Below that point there are rock gorges at the Falls and other points, and near the junction of North Fork and Middle Fork at Deming the bank of the North Fork is a bluff of Tertiary sandstone.

In the lowlands adjacent to the coast, in the western portion of the area traversed in this reconnaissance, there are extensive deposits of gravels, sands, and silts, which are in part continuous with the deposits of the western valleys. Much of this material possesses characters that testify to its glacial origin, but some of the gravels are typical stream deposits. The topography is generally of the low plateau type, only a hundred feet or so above sea level, these higher flat-topped features being diversified with swamps and separated by broad flood plains.

The higher areas are composed generally of coarse, well-washed gravels, as shown in stream cuts or shore cliffs, but on the surface the soil, where not concealed by vegetation, has till characters. There is every indication that these surficial deposits near the boundary are of the same origin and record much the same Pleistocene history as those farther south in Puget Sound basin.[a] The gravel plains and alluvial bottoms represent the constructive work of streams, the former being more of the nature of low delta deposits and terraces built up in the vicinity of a large piedmont glacier. The till which covers many of these gravel plateaus was deposited at times of glacial advance, and in some localities moraines and other features of relief occur which are plainly the work of ice. The interaction of ice and stream work has been productive of considerable variety of minor features, the understanding of which would necessitate detailed observations.

INTRUSIVE ROCKS.

PRELIMINARY STATEMENT.

General classification.—Granular igneous rocks, intruded into older sedimentary formations and solidified under great masses of strata that have since been removed by erosion, occupy a greater proportion of the area examined in this reconnaissance than do all other classes of rocks combined. Of much less geologic importance, yet very generally distributed, are igneous dikes of various composition which cut both the plutonic and the stratified rocks. These usually appear to have direct relation with the great plutonic masses.

The plutonic rocks might readily be divided by the nonpetrographic observer into two groups. The first, which has by far the less importance in this region, comprises the rocks characterized by petrographers as "basic" and "ultrabasic." They include diorite, gabbro, pyroxenite and peridotite, and serpentine, which is formed by the alteration of the last-named rock. These are distinguished by dark color and high specific gravity, due to the predominance of dark minerals rich in iron and magnesia, and to the subordination or absence of quartz and the feldspars.

The second group, the representatives of which have an enormous development in the Northern Cascades, consists of comparatively light-colored rocks, of which the principal constituent is feldspar, and in which quartz plays an essential part, generally being visible to the naked eye. These rocks have mostly been designated on the map, in a general way, as "granitic rocks," and most of them would prob-

[a] A full description of these is given by Willis and Smith in the Tacoma folio, No. 54, Geologic Atlas of United States.

ably be called "granite" by a nontechnical observer, using the term in a loose sense. In fact, however, the group includes three species (granite, granodiorite, and quartz-diorite), sufficiently distinct to be generally separable in the field. It seems advisable, therefore, to recognize these divisions in the following pages, and, instead of using "granite" or "granitic" rocks in a popular sense, to employ specific names defined in terms of features recognizable in the field by a person acquainted with the rudiments of mineralogy. Additional reason for using petrographic names lies in the fact that this description of the areal and geologic relations of the plutonic rocks must serve as an introduction to their petrography. A too broad use of terms at present would necessitate much repetition later. The dike rocks, however, being fine grained and often only determinable by microscopic study, must frequently be designated in less definite terms, and on account of their small geologic importance will not receive extended consideration here.

Method of treatment.—For the general consideration before us it seems best to adopt an arrangement based on geographic distribution without regard to petrographic classification. The principal intrusive masses will therefore be considered in the order in which they were encountered during the progress of the reconnaissance.

ALONG THE COLUMBIA.

Megascopic features of granodiorite.—In the valley of the Columbia there are extensive masses of granular rock of a type that attains enormous development in the Sierra Nevada, where it has been given the name "granodiorite." The characteristic features of this rock visible in the field are as follows: The color of large masses viewed at a distance appears rather light gray. On closer inspection this hue is found to be due to the combined effect of a mixture of a relatively small proportion of dark-colored minerals with a preponderant amount of light constituents. Of the latter class decidedly the greater part is feldspar, usually clear white and distinguished by its cleavage from the more transparent, irregularly fractured quartz. Quartz, though subordinate to feldspar, is an important constituent, easily recognizable on close examination. The dark minerals are hornblende and biotite; the former, the color of which is greenish black, forms roughly prismatic individuals with cleavage in two intersecting sets of planes parallel to the direction of elongation; the latter, which is deep brown in color, forms tablets or short prisms characterized by the well-known micaceous cleavage. These dark minerals are usually present in about equal quantities, although biotite predominates in certain lighter-colored varieties.[a]

[a] This brief characterization is not intended as a general definition of the term "granodiorite," its purpose being merely to aid the lay reader to recognize the rock under description in the field. The specific character of the feldspars is not mentioned, because not determinable megascopically. The description given applies to all the granodiorites of this region and is believed adequate to distinguish them from the other rocks of the region. The definitions in this chapter of other rocks will be constructed with a similar purpose in view.

Occurrences of granodiorite.—Of this nature was the first plutonic mass encountered, which extended along the route from Entiat to Knapp Coulee. At neither limit were the contacts with the adjacent rocks directly observed; the greater age of the rocks on either side of the granodiorite is sufficiently proved, however, by the evidence of extreme metamorphism in the former, in contrast to the absence of foliation or other evidences of dynamic action in the granodiorite.

In the neighborhood of the southern boundary there is additional evidence of this rock's intrusive nature. The schist and gneiss forming the walls of the gorge below Entiat are cut by a multitude of white, coarse-grained pegmatite dikes, whose increasing abundance, as the granodiorite is approached, strongly points to their genetic relationship with that rock. Other dikes appear within a few miles of the contact, which may be grouped as basic and acidic. The former are dark colored, with feldspar crystals sometimes standing out from the general mass, but generally not prominent. The acidic rocks are fine grained, but evidently crystalline, and show inconspicuous phenocrysts of feldspar and quartz in a white groundmass. These complementary dikes cut the great granodiorite mass as well as the schists.

Near the northern boundary of this mass there is a zone in which the abundant dark-colored rocks rich in hornblende are mingled in the most intricate manner with light-colored material similar to the granodiorite of the main mass, or in part even more acidic.

From a short distance above Lake Chelan nearly to the mouth of the Methow the country rock is granodiorite similar to that just described. It may be that these two areas, separated along the route by schist, are connected farther west. This mass is evidently intrusive into the schists on the north, and the contact zone is characterized by abundant hornblendic material such as was mentioned in the last paragraph.

OKANOGAN VALLEY.

Granitic and dioritic rocks.—In the southern portion of Okanogan Valley occurs a more siliceous rock, which it is thought may properly be designated granite. This granite is very light colored, owing to the very insignificant rôle of the dark minerals, the only ones visible in the hand specimen being a little light-brown titanite and dark-brown biotite; there is also a little white mica. Quartz is very abundant, and among the feldspars large crystals of orthoclase having a faint rose tint are conspicuous.

In the vicinity of Clover post-office rocks of two distinct types are developed, both of which are probably younger than the schists of that district. The first of these is dark gray and dioritic in aspect, coarse grained, except at its irruptive contact with the schists, and generally shows a more or less pronounced foliation. On certain glaciated surfaces on the ridge south of Clover this rock is seen to be full of darker blotches of more basic material which have been drawn out into lenticular forms by the same forces that have produced the gneissic lamination of the general mass. Petrographically this rock is closely related to the granodiorite, differing from it in containing a large proportion of hornblende and a smaller amount of quartz. It is to be classified as a quartz-diorite.

The other rock is a coarse pink granite, containing a small amount of biotite and an abundance of quartz. The relation of this granite to the sheared diorite was not made out with certainty, but the evidence obtained seemed to indicate that the granite is intrusive in the diorite. The two rocks are contrasted in petrographic characters, and no transition between them could be made out such as would indicate that they were produced by the differentiation of a single intrusion. No dikes of one within the other were observed in place, though a block of the diorite was seen to be penetrated by a dikelet of fine-grained light-colored granite. The relative distribution of the two rocks and the absence of gneissic lamination in the more acidic granite also seem to confirm the supposition that the latter is the younger.

A few miles south-southwest of Lake Osoyoos there is a comparatively small mass of granite bounded on the south, west, and north by slates and schists, and on the east by the Okanogan terraces, though it continues across the river to the east. This granite is undoubtedly intrusive in the slaty rocks, which generally show considerable metamorphism near its boundaries and are cut by dikes of pegmatite.

In mineralogic composition it resembles the granites seen farther down the valley. The color is in general decidedly pinkish. The most characteristic feature consists in the presence of abundant large phenocrysts of orthoclase feldspar, which are often more than an inch in length.

Along the route from a little north of Conconnully to Fish Lake there are extensive exposures of quartz-diorite, similar to that at Clover, but generally finer grained. Farther north this diorite gives way to granodiorite and true granite. The character of the transition was not studied. The rock may indeed be merely a marginal phase of a large mass, for these exposures are along the border of the great area of acidic plutonic rocks from which Okanogan Mountains are carved.

Gabbro and diabase near Loomis.—To the north of Loomis is developed an intrusive rock more basic than any heretofore noted. In its finer grained phases it appears almost uniformly dark green in color, and the constituent minerals are not readily distinguished. Where it is more coarsely crystalline, however, as just east of the foot of Palmer Lake, it is seen to consist essentially of large lath-shaped feldspar crystals embedded in a dark crystalline material, which microscopic study shows to be pyroxene partly altered to amphibole. The finer grained rock is to be classified as diabase, and the coarser as gabbro.

These rocks are chemically similar to the old lavas of the supposed Cache Creek beds. They appear also to be connected with them, and although the relation has not been demonstrated it appears highly probable that the diabasic rocks in question represent the partly unburied roots of the ancient volcano from which the Cache Creek extrusives were poured forth.

OKANOGAN MOUNTAINS.

Ultrabasic intrusives of Mount Chopaka.—Mount Chopaka, which overlooks the boundary at the eastern border of the Okanogan Mountains, is carved from a more or less complex series of dark-colored basic rocks. The summit is an altered dark gray-green gabbro. On the east and north slopes are excellent exposures of dark-green compact serpentine with a sprinkling of lustrous pyroxene crystals, and some coarsely crystalline rocks, consisting mainly of pyroxene and amphibole. All these rocks are evidently much altered. Their relation to the supposed Cache Creek rocks was not observed.

Composite character of the granitic belt.—The Okanogan Mountains at the boundary are almost coextensive with a great belt of plutonic rocks extending from a few miles west of Lake Osoyoos to the Pasayten River. This great mass is by no means homogeneous; while composed chiefly of granite and allied rocks, it comprises important masses of granodiorite and more basic types that have local development. The hasty character of our work made it impossible to separate these species on the map, even roughly. In the following paragraphs, however, the general distribution of the principal types will be indicated.

Biotite-granite.—The largest part of the plutonic rocks of the Okanogan Mountains may be classified as biotite-granites. The rocks assigned to this class are all characterized by having biotite as the dominant ferromagnesian constituent, although they sometimes contain an insignificant amount of hornblende or of muscovite. The biotite-granites prevailingly show the pink color characteristic of many granular rocks rich in orthoclase, this being often developed porphyritically, as in the similar rocks of Okanogan Valley.

As to its areal distribution, the biotite-granite appears to be the dominant type throughout the northern part of the 10-minute strip, except for its interruption by a belt of light-colored granite between Cathedral Peak and Ashnola River. Although the southern portion is mostly occupied by other types, the biotite-granite extends south of the 48° 50′ line approximately from the longitude of Bighorn Peak to the stream flowing southeastward from Mount Remmel. It is especially well exposed on the northern slope of the Horseshoe and in Cathedral Peak and the neighboring elevations.

Granodiorite.—This rock has its most extensive development in the area south of the Chopaka group of peaks and of the Horseshoe. It has the same general characteristics as the similar rocks along Columbia River, and is distinguished from the biotite-granites by its gray tint, in contrast with the pink tones of the latter, and by its prominent hornblende crystals.

In addition to the main area, the granodiorite forms the triangular area west of Haipwil Lake and the tongue-like projection from the main mass to the north. There is also a small area of similar rock southeast of Park Pass.

The geologic relationship of the granodiorites to the biotite-granites was in no case definitely ascertained. On Horseshoe Mountain, where the contact between the two rocks is exposed on glaciated surfaces somewhat defaced by weathering, the conditions appear most favorable to the hope of determining this important question, but this hope was not fully realized. At the best exposure there seems to be a rapid gradation between the two rocks, which, however, show their typical aspects within a few feet of each other.

Diorite of the Horseshoe.—Mention may be made here of a comparatively small mass of fine-grained diorite, apparently an elongated oval in plan, which lies between the granodiorite and biotite-granite at the east end of the northern spur of the Horseshoe. The relation of this rock to those with which it is in contact is obscure.

Biotite-muscovite-granite.—The third well-defined type represented in the great granite area was first met with just west of Cathedral Peak, where its contrast with the pink coarse-grained biotite-granite was immediately evident. The rock is fine grained, pale gray in general tint, and carries small quantities of both black and white micas, with small red garnets often visible. A gneissic banding is very commonly developed, but not universally. The coarse pink granite comes in again as the country rock west of Ashnola River, but the lighter colored two-mica granite reappears near the southwest corner of the 10-minute strip across the main granite belt. The peak 3 miles south-southeast of Park Pass is composed of somewhat similar granite, changed by pressure to a well-foliated gneiss.

Dike rocks of various kinds occur in association with all the plutonic rocks of the Okanogan Mountains. Perhaps the most common are aplites—light-colored rocks which are essentially fine, even-grained mixtures of feldspar and quartz. Of similar composition, but different texture, are the pegmatites, in which the feldspar crystals are frequently of great size. Various basic dike rocks occur also, usually dark gray-green in color, sometimes porphyritic and sometimes of fine, even texture. The granodiorites southwest of Chopaka have sent tongues into the quartzitic schists, and have the same composition as the granodiorites, but are of porphyritic texture, and are therefore designated granodiorite-porphyries.

In the granite north of Park Pass there are dikes of a very dark-colored, rather coarsely crystalline rock which attracted notice in the field from its decided effect on the magnetic needle of the plane table.

HOZOMEEN RANGE.

Quartz-diorite.—The Hozomeen Range presents a contrast to the Okanogan Mountains in the subordinate rôle which is played in its constitution by intrusive rocks.

Two small masses of quartz-diorite practically identical in constitution were observed. The most striking megascopic feature distinguishing this rock from the granodiorites is the darker gray color, which is due to the greater abundance of hornblende. Feldspar is the most abundant constituent; quartz and biotite, though present, are inconspicuous.

This rock was observed in a small outcrop southwest of Hidden Lakes, in the Okanogan Mountains, and a mass about half a mile in diameter is cut into by Ruby Creek just below the junction of Slate and Canyon creeks, on the western slope of the Hozomeen Range. In both cases the areal relations seem to indicate that the diorite is intrusive in the Cretaceous sediments.

Serpentine (saxonite).—On Ruby Creek below the mouth of Granite Creek there is exposed a mass of dark greenish granular rock which may be classified roughly as serpentine, or, more accurately, as altered saxonite. This rock was observed by Professor Russell and indicated, not very accurately, on his map. It is apparently intrusive in the gneisses coming in just to the west of Granite Creek. These can best be described a little further on in connection with the great plutonic areas of the Skagit Mountains with which they are connected.

Dike rocks.—Along the main crest of the range, near Barron and to the north, the Cretaceous sediments are cut by a multitude of dikes comprising a wide variety of lithologic types, including light-colored quartz-porphyries, dark even-grained diabase, and basic porphyries in which crystals of hornblende and pyroxene stand out prominently. The 8,000-foot peak southwest of Hidden Lakes also is ribbed with acidic and basic dikes. It is possible that these dikes have some genetic relationship to the quartz-diorite masses already noted. Professor Russell has recorded his observations on dikes in the vicinity of Barron and on others in Methow Valley[a] which may be related to these.

SKAGIT VALLEY AND SKAGIT MOUNTAINS.

Eastern portion.—Near the north-south stretch of Skagit River the party reached the eastern boundary of a broad zone of granitic rocks, comparable in extent to that which forms most of the Okanogan subrange and extending west to the longitude of Mount Shuksan. This broad granite belt is by no means simple in its nature, but includes various types of rock which probably represent several intrusions of widely different ages.

[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 115, 116.

The valley of the Skagit near its junction with Ruby Creek is floored with gray coarse-grained gneiss, distinctly foliated, but evidently produced by the action of pressure on a plutonic rock allied to granodiorite. Farther up the valley there occur finer grained rocks, not foliated, which are in all probability much younger than the gneiss. Although no actual contacts were observed the areal relations appeared to indicate that this mass was intrusive in the Cretaceous, and is probably to be correlated with the quartz-diorite mass near the junction of Canyon and Ruby creeks. Petrographically the rocks are similar, but the Skagit River material is slightly more siliceous.

For some distance west of the mouth of Ruby Creek the gneissic formation is complex, and contains streaks of dark schists apparently representing old rocks into which the igneous magma forming the main mass was intruded. Beyond Goodell's ranch some nonfoliated younger-looking granodiorite was observed.

Western portion.—No important masses of plutonic rock were seen along the route from Marblemount to the Mount Baker mining district. According to Dr. R. A. Daly,[a] however, granitoid rocks extend along the international boundary to the crossing of Silicia Creek. They are mainly characterized, according to him, by the presence of biotite and hornblende, which become so abundant near the western border of the area as to give the rock a dioritic appearance.

The writer was able to make some observations on the plutonic rocks exposed along Silicia Creek and in the vicinity of Mamie Pass. This granite is irruptive into the schists that form the country rock of the mines in the Mount Baker district, the relation of the intrusive to the sediments being very clearly displayed at the Mamie Pass locality. This locality is of peculiar interest owing to the variations exhibited there by the igneous rock near the contact. While a few hours' examination was, of course, quite insufficient for a thorough study of the phenomena, the main facts appear to be as follows:

The normal character of the magma appears to be represented by specimens collected at Mamie Pass and along Silicia Creek, where the rock was observed at a distance from any contact and is uniform over considerable distances. This normal type is a rather light-gray, medium-grained, evenly granular rock, in which the main constituent is white feldspar, but in which quartz is fairly prominent megascopically. The characteristic dark mineral is biotite, but a little hornblende occurs locally. The character of the feldspars, which is not evident megascopically, places this rock among the granodiorites, but it approaches the true granites more closely than the granodiorites already described.

The modifications of this primary type are both chemical and structural in their nature, but the chemical variations, which are

[a] Summary Report Geol. Survey Canada, 1901, p. 47.

recognizable in the field by the variations in mineralogic character, are the more important. The most significant fact seems to be the universal presence of more basic rocks between the normal granite and the surrounding schists. The material generally found near the periphery of the mass is darker colored than the rock just described by reason of a higher proportion of iron-bearing silicates, among which the hornblende assumes a prominent rôle, becoming equal to or greater than the biotite in amount, while the quartz becomes inconspicuous or absent. The most abundant types of the peripheral zone are diorites and granodiorites, but there are subordinate amounts of even more basic material in which the dark ferromagnesian minerals are more abundant than the feldspar.

The rocks of this plutonic mass are generally distinctly granular and moderately coarse grained. Textural modifications occur, however, as illustrated by a granodiorite-porphyry occurring on the summit of Granite Mountain, and a fine-grained phase of the acidic granodiorite appearing on its southern slope.

The granular rocks are cut by dikes, from which were collected specimens of fine white aplite, a white granite-porphyry with strikingly rounded phenocrysts of quartz, and a dark fine-grained rock showing interesting microscopic features that will be described later.

PETROGRAPHY.

INTRODUCTORY STATEMENT.

A detailed account of the igneous rocks of the region would not be included properly in a report of this kind, nor do the writers possess sufficient material for such an account. Opportunity was not had to make a fully representative collection, and many interesting occurrences of igneous rocks, the close study of which may afford to future workers the data for interesting petrologic essays, had to be passed over in a cursory manner. The following account can therefore be little more than a sketch.

It is believed, however, that the field observations and the specimens collected will afford a basis for a brief description of the principal types of plutonic rocks and their general distribution, of a variety of dike rocks, and of most of the volcanic rocks occurring in the region. The variety of types is comprehensive enough to afford a basis for a general characterization of the region considered as a petrographic province. In many places the marginal portions of acidic plutonic masses exhibit interesting variations, the thorough investigation of which might throw light on some of the deeper petrologic problems. The observations on such occurrences are given, but they have generally been too imperfect to properly serve as a basis for anything more than mere suggestion. A few interesting metamorphic rocks occur which seem to deserve brief notice.

The arrangement of the subject-matter is intended to give prominence to the more interesting facts. The metamorphic rocks will be disposed of first; there will then be considered, in order, the volcanic rocks, the plutonic rocks, and the hypabyssal rocks; finally, brief consideration will be given to some matters pertaining to general petrology.

METAMORPHIC ROCKS.

ALTERED BASIC LAVA NEAR LOOMIS.

On the steep western wall of the valley between Loomis and Palmer Lake the intrusive relation of the granodiorite to the supposed Cache Creek volcanics is well displayed, and interesting metamorphic rocks have been produced by the action of the plutonic mass on the basic lavas.

This metamorphism is well illustrated in a specimen which has megascopically the appearance of a rather fresh amygdaloidal basalt. It consists mainly of a fine-grained greenish black aphanitic base, in which are embedded roundish or somewhat irregular masses of light greenish gray crystalline material that appear to represent filled-in amygdaloidal cavities. A little calcite occurs similarly.

Examined in thin section the rock shows no trace of basaltic texture, yet its composition indicates that the field diagnosis was correct. The base is very thickly interspersed with granules of iron ore, often forming clusters. Each grain, under high magnification, appears surrounded by a little transparent crystalline material with high refractive index and double refraction, which is probably some secondary titaniferous mineral. The constitution of the base is somewhat obscured by the abundance of this iron ore, but its chief constituent appears to be zoisite, recognizable by its characteristic indigo-blue interference color. Considerably less abundant is ordinary green hornblende. Both minerals form irregular interlocking grains, thickly charged with the magnetite granules. In addition to these essential constituents there seems to be a little biotite, and perhaps also chlorite. The constitution of this base is evidently indicative of a basaltic composition in the original rock, for it is extremely common to find altered basalts or diabases in which the feldspar has been largely replaced by zoisite and the augite by hornblende.

The amygdules, which are perhaps the most interesting feature of the rock, are found to be somewhat variable in constitution. The largest consist mainly of a monoclinic pyroxene, practically colorless in thin section, with an allotriomorphic granular structure. Mixed with the pyroxene are occasional individuals of deep-green hornblende and of very pale-green chlorite interleaved with biotite, from which it appears to be derived. These minerals are often developed abundantly on the border of a pyroxene amygdule. The smaller amygdules sometimes contain some pyroxene, especially in the center, but consist mainly of hornblende, biotite, and chlorite. As accessories there occur a little calcite, some apatite in rather large grains or irregular, stout prisms, and a little of what appears to be siderite.

The constitution of the amygdules, as well as the complete effacement of original structures in the mass of the rock, seems to indicate clearly that we have here no product of weathering or static metamorphism. The alterations seem to be explained most naturally as due to the intrusion of the neighboring batholithic magma.

Some other specimens collected in the same neighborhood appear to illustrate more advanced stages in this metamorphism. One of especial interest is a fine-grained, greenish black, amphibolitic rock, full of irregular lenticules of greenish gray feldspathic material.

In thin section the dark portion is found to be essentially deep-green hornblende, showing rude schistosity, together with a little feldspar and pale-green monoclinic pyroxene. These last are especially abundant near the boundaries of the light-colored areas, which are rather ill defined. They consist mainly of feldspar, near andesine, but there is a considerable proportion of the pale-green pyroxene already noted. The feldspar grains interlock as in a typical aplite, and poikilitically inclose rounded grains of pyroxene. This feldspathic material resembles the aplite of some dikes of this locality, to be noted in their place.

It appears strongly probable that the amphibolitic portion of this specimen represents metamorphosed basalt, and that the aplitic lenticules represent material introduced, perhaps by some pneumatolytic process, from the intrusive magma.

SCHISTS OF SKAGIT VALLEY.

Chloritic schists.—Of the chloritic schists one typical specimen shows megascopically a well-marked foliation modified by intense crumpling. The color is gray green and the luster of the cleavage faces is silvery, owing to the presence of a white micaceous mineral, probably talc. Under the microscope the rock is found to contain, besides chlorite and talc, much quartz, less feldspar, and, as abundant accessories, apatite and an undetermined mineral. The apatite is in slender prisms with very striking parallel arrangement. The other accessory, which forms minute, sharply developed, isometric crystals of greenish yellow color and high refractive index, may be a garnet. Another specimen of somewhat similar microscopic appearance shows under the microscope a quasi porphyritic structure, containing somewhat rounded grains of plagioclase in a schistose base of quartz, feldspar, and chlorite. The structure and composition of the rock rather suggest its derivation from andesite, and it may be that the chloritic schists of the series represent in general volcanic materials.

Glaucophane-schists.—The occurrence of rocks of this interesting and comparatively rare group in Skagit Valley appears worthy of especial notice. The petrographic character of the glaucophane-schists of this locality may be illustrated by descriptions of three specimens representing fairly distinct phases.

The first is a dense, fine-grained schist composed of nearly equal amounts of chlorite and glaucophane with scattered grains of epidote. It is cut by secondary veins of quartz, calcite, epidote, and chlorite.

The second specimen does not much resemble the first except in containing glaucophane, which forms prisms of moderate size scattered in a fine-grained schistose base composed largely of a colorless mica (perhaps paragonite) with some quartz and feldspar and a sprinkling of epidote. Standing out from this groundmass, however, are clusters of perfectly clear grains. In polarized light these occasionally show simple twinning or are marked by a single lamella. Many of the grains are not twinned, but all the nearly isotropic sections show in convergent light the interference figure characteristic of biaxial minerals, and the mineral is therefore probably all feldspar, though it was not determined specifically. The glaucophane individuals have an imperfect prismatic form, and each is bordered by a zone of epidote and chlorite, minerals which are also scattered through the blue amphibole.

The thin section of a third specimen shows beautiful blue crystals of glaucophane in a fine-grained base of quartz and chlorite. Small isometric crystals of garnet are thickly disseminated through all the essential constituents, and magnetite occurs in a similar manner, though less abundantly.

In all these rocks the blue amphibole shows the optical properties of normal glaucophane.

It is interesting to note the sporadic occurrence of glaucophane in some of the ferruginous quartzites.

VOLCANIC ROCKS.

DISTRIBUTION AND CLASSIFICATION.

As compared with their immense preponderance in the southern Cascades the part played by volcanic rocks in the boundary section of the range appears very subordinate. Yet such rocks occur in nearly all parts of the geologic column, and their present comparative scarcity may be due less to any lack of volcanic activity in former times than to the immense denudation which the region has undergone.

Lithologically the volcanic rocks of the region vary from typical basalt to acidic rhyolite, these extremes being connected by a fairly complete chain of intermediate types. It would be useless to describe all these rocks in detail. A few having especial interest will be treated somewhat fully, others will be characterized briefly, while many will be passed over with mere mention, these last including many old lavas so altered that they can be classified only roughly.

In order to condense the presentation of the rather scattered observations on the volcanic rocks, it has been deemed advisable to construct the following table, in which the species are arranged in order of increasing basicity and their distribution and mode of occurrence are noted:

Species, distribution, and relations of the volcanic rocks of the region.

Species.	Locality.	Geologic relations.
Soda-rhyolite	South of Wenatchee	Flow in Swauk formation, and perhaps intrusive in same formation lower down.
Do	North of Clover	Apparently extrusive, age unknown.
Rhyolite-porphyry, sheared and altered.	Swamp Creek, Mount Baker district.	Probably pre-Cretaceous.
Rhyolite- or dacite-porphyries.	do	Do.
Dacite	Near Hidden Lakes	Dikes in the Pasayten formation (Cretaceous) and flows overlying.
Hornblende-andesite	Near mouth of Similkameen River.	Tertiary (?) flows overlying sandstones and dikes.
Hornblende-pyroxene-andesite.	East of Hidden Lakes	Flows, post-Cretaceous (?).
Pyroxene-hornblende-andesite.	Southwest of Wenatchee.	Intrusive (?) in Swauk (Eocene).
Hypersthene-andesite	South of Nooksak River	Flows from Mount Baker, probably Pleistocene.
Basaltic augite-andesite	East of Hidden Lakes	Flows and breccia, post-Cretaceous (?).
Andesites, altered	Nooksak Valley	Flows and breccias, probably pre-Cretaceous.
Pyroxene-andesites, altered.	Lower Skagit Valley, Sauk Mountain.	Probably pre-Cretaceous.
Hypersthene-basalt (with quartz).	(*a*) Just east of Hidden Lakes; (*b*) about 10 miles east of Hidden Lakes.	(*a*) Apparently small stock or dike in post-Cretaceous (?) andesites; (*b*) dike in granite.
Basalt	Columbia Valley	Yakima Miocene.
Basalt (perhaps with basic andesite).	Okanogan Valley	Flows and breccias in Cache Creek (?), Carboniferous.
Basalt	Upper Skagit Valley and Jacks Mountain.	Flows and breccias interbedded with pre-Cretaceous sediments (Cache Creek?).

RHYOLITES.

Soda-rhyolite near Wenatchee.—The general hues of these rocks are very light, varying from gray or pale lilac to nearly white. In hand specimens the main portion is seen to consist of a laminated, usually lithoidal, groundmass, carrying rather numerous small phenocrysts of quartz and feldspar and a few inconspicuous tablets of biotite.

On examination of the thin section one is struck at once by the extreme corrosion shown by both quartz and feldspars. The quartz phenocrysts are rounded and embayed, while those of feldspar show very irregular outlines and abundant glass inclusions.

The feldspar phenocrysts, which in the absence of chemical analysis afford the best available indication as to the composition of a rhyolite, seem to be all plagioclase. Different species are represented, a few crystals showing marked zonal structure and having rather basic cores, while others are practically homogeneous and generally characterized by very fine and sharp twin lamellæ. Some of these latter in sections perpendicular to the negative bisectrix were determined as albite. The character of the phenocrysts thus seems to indicate that these rocks belong to the group of soda-rhyolites.

Soda-rhyolite near Clover.—The rock of this locality appears to be allied in composition to the one just described. It is more crystalline, showing, megascopically, abundant and rather large phenocrysts of quartz and dull-pink feldspar, with some biotite, in an aphanitic gray groundmass. Under the microscope it appears that the feldspar phenocrysts are much altered, many being almost completely replaced by calcite, while others are clouded with kaolin. Most of the determinable feldspars are striated; some were identified as albite, though the abundance of calcite would indicate the original presence of a more basic species. There are a few small phenocrysts of orthoclase, but it appears probable that soda is the dominant alkali in this rock as in that near Wenatchee. It may be that the orthoclase phenocrysts belong to a later stage of crystallization than was reached in the Wenatchee rock and therefore do not indicate any marked difference in chemical composition.

ANDESITES.

Dacite.—This rock shows, megascopically, abundant phenocrysts of plagioclase, with fewer of quartz and of ferromagnesian constituents, in an aphanitic groundmass of light-gray or drab hue. By the aid of the microscope the plagioclase phenocrysts are determined as andesine-oligoclase with some oligoclase. Biotite is found porphyritically developed in all the specimens, and all contain pseudomorphs after another ferromagnesian mineral of prismatic form, presumably hornblende. The groundmasses are holocrystalline and consist essentially of plagioclase, quartz, and orthoclase; in texture they are sometimes microgranular, sometimes micropoikilitic.

Hornblende-pyroxene-andesite.—This rock, seen along the eastern border of the Hidden Lakes volcanic area, has phenocrysts of labradorite, brownish-green hornblende, augite, and hypersthene, in order of abundance. The groundmass contains plagioclase microlites and allotriomorphic microscopic grains supposed to be quartz and orthoclase. Magnetite also abounds in the groundmass and forms heavy borders about the hornblende phenocrysts.

The hornblende-pyroxene-andesite, developed south of Wenatchee, is mostly much weathered, but some exceptionally fresh material was collected from the bold western face, which is worthy of description. Macroscopically it is seen that the greater part of the rock is constituted by a light olive-green, glassy groundmass of resinous luster, while there are abundant phenocrysts of glassy striated feldspar and of prismatic dark ferromagnesian minerals. By microscopic study of the thin section it is found that the phenocrysts are plagioclase, hypersthene, hornblende, augite, and magnetite, while the groundmass is of the hyalopilitic type, consisting of microlites of plagioclase and hypersthene, with grains of magnetite, in a clear glassy base.

The phenocrystic plagioclase is strikingly characterized by evidences of corrosion and by very pronounced zonal structure. The most abundant species entering into the constitution of the zonally-built crystals is sodic labradorite (Ab_1An_1), but other species more basic and much more acidic occur. Many of the crystals have curved outlines, evidently resulting from resorption, and nearly all are more or less honeycombed with glass inclusions. In some cases the entire crystal is a mere sponge or skeleton, while in others there is a broad zone of irregular glass inclusions, frequently surrounded by a rim of clear feldspar.

The feldspar microlites of the groundmass show extinction angles that indicate a composition slightly more acidic than Ab_1An_1.

Of the ferromagnesian constituents the most abundant is strongly pleochroic hypersthene, occurring in well-formed elongated prisms. Next in order of abundance is a hornblende, of deep brownish green tint, which in part shows dusty borders containing magnetite and some indeterminate substance. Green augite, in rather stout, imperfectly developed prisms, is rather subordinate in amount. Parallel intergrowths of hornblende with hypersthene and of hypersthene with augite were noted.

An interesting segregation was observed, consisting of a granular aggregate of plagioclase and hornblende of the same character as that occurring porphyritically.

Pyroxene-andesite of Mount Baker.—It appears worth while to describe in some detail a nearly holocrystalline specimen which probably best expresses the composition of the lava.

This rock, which was observed at Austin Pass, has a distinct lamellar parting. Megascopic examination of the hand specimen shows rather abundant phenocrysts of striated feldspar and dark-green pyroxene in a light-gray, fine-grained, but evidently crystalline groundmass, with rather silky luster.

Under the microscope the constituents of the rock are found to be plagioclase, augite, hypersthene, iron ore, apatite, and a rather small amount of glass. All the minerals are perfectly fresh.

The texture is fluxional and porphyritic, but is peculiar in that the feldspar occurs in three generations. At the first preliminary examination of the thin section through low-power lenses, the writer was struck by the fact that the feldspars were divisible on the basis of size into three classes. Speaking generally, the first class consists of those crystals which are easily recognized as plagioclase in the hand specimen by the unaided eye; the second, of those that produce the reflections that give the groundmass its sparkling crystalline appearance; the third, of those of purely microscopic dimensions. Attempts to determine the average size of the crystals of each class led to the perception of the fact that the divisions are not absolutely sharp, and that the intervals between them may be bridged over by graded series; nevertheless, the number of doubtful or intermediate individuals is very subordinate to that of the feldspars readily assignable to a particular generation. Estimates based on actual measurements give the average length for the crystals of each class as follows: For the large phenocrysts, from 2 to 3 millimeters; for the large crystals of the groundmass, about 0.2 millimeter; for the microlites of the last generation, about 0.06 millimeter. The largest part of the feldspar belongs to the second division.

The pyroxene crystals are not so definitely classifiable with regard to size as the feldspars. The greater portion is in crystals intermediate in magnitude between the first and second generations of feldspar, the maximum dimensions for the pyroxene being less than for the feldspar phenocrysts. Grains and prisms of pyroxene with microlitic dimensions are also abundant.

The magnetite occurs in two generations, the first being represented by rather sparsely distributed grains of about 0.15 millimeter in average diameter, very frequently in association with the pyroxenes.

The study of the optical properties of the feldspar shows the larger crystals to be built up zonally, with cores having a composition near $Ab_3 An_4$, and shells that show an oscillation of composition during growth, but are in general more acidic than the kernel. The crystals of the second generation are very similar to those of the first, and are but little, if any, less basic in average composition. The microlitic feldspar gives extinction angles of about 25° in the "square sections" nearly normal to the edge 001 : 010, and is therefore slightly more sodic than $Ab_1 An_1$. The larger phenocrysts are often in part honeycombed with irregular inclusions of brown glass that tell the story of corrosion that has taken place at certain periods of their growth.

The pyroxenes comprise augite and hypersthene, with the latter apparently in slight excess. The rhombic species has fairly strong pleochroism in green and reddish brown tints, while augite is in thin section pale green and not sensibly pleochroic. The glassy residue is brown and contains crystallitic bodies of undetermined nature, comprising the globulitic and longulitic forms.

The foot of the flow that reaches the Nooksak shows a characteristic columnar structure. As regards the petrographic character of the rock collected here, brief description will suffice to indicate its differences from the rock described above.

The mineralogic constitution of the two is essentially the same, but the vitreous character of the black aphanitic groundmass of the second specimen is evident megascopically. Under the microscope the threefold classification of the feldspar crystals becomes apparent, though less striking than in the case of the more crystalline rock, since the second generation is but sparingly represented.

The feldspar phenocrysts are somewhat less basic than in the first specimen; the kernels give no extinction angles higher than 27°, which would indicate their composition to be near $Ab_1 An_1$, while the outer zones are in general even more acidic. In addition to augite and hypersthene there is an occasional corroded individual of brownish green hornblende with a rim of magnetite. The groundmass shows the typical hyalopilitic texture, being composed of brown glass filled with microlites of feldspar and pyroxene and grains of magnetite.

The lavas of Mount Rainier have been described by the senior author,[a] and it is noteworthy that the type most abundantly represented on Rainier is essentially similar to the Mount Baker lava that has just been described.

Basaltic augite-andesite.—The rocks along the canyon north of the Hidden Lakes seem to occupy a position in the classification scheme about on the line between andesite and basalt. Megascopically they appear dark colored and conspicuously porphyritic. The most prominent phenocrysts are large plagioclases, and there are also numerous much smaller phenocrysts of augite. In thin section it is found that the plagioclase phenocrysts are too much altered for specific determination. The fine-grained groundmass contains both plagioclase and augite in a second generation, together with magnetite and perhaps originally hypersthene, and some glass. The plagioclase of the groundmass is in sharply developed laths, and the pyroxene, having less perfect crystallographic development and often showing a tendency to inclose the feldspar, is plainly posterior to it. The texture is therefore intersertal and emphasizes the relation of the rock to basalt. The prisms of augite often have a sort of central "rib" of olive-green material, which resembles the common alteration product of hypersthene, and indicates that there was originally some rhombic pyroxene intergrown with the augite on the usual plan. The plagioclase microlites were determined in some cases as labradorites of the composition $Ab_1 An_1$.

There is considerable secondary material, of which the most interesting is a yellowish green substance resembling serpentine. The mineral forms irregular patches in the groundmass, and oblong or somewhat rounded areas about as large as the augite phenocrysts. It

[a] Smith, G. O., Rocks of Mount Rainier: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 416-422.

is supposed to represent either hypersthene or olivine, more probably the former.

Pyroxene-andesites of Skagit Valley and Sauk Mountain.—The great body of old volcanic rocks from which Sauk Mountain is carved is too much altered for very satisfactory study. Their porphyritic texture has been observed, however, and their basic composition is evident from the abundance of such secondary minerals as chlorite, calcite, epidote, and leucoxene. The feldspars are mostly replaced by saussuritic material, but some still show albite twinning. Remnants of augite phenocrysts are still present. Hypersthene is not represented by any recognizable pseudomorphs, but, in view of its susceptibility to weathering, it may nevertheless have been present. The andesites of this locality appear to have belonged to ordinary pyroxene-andesite or to an augite-andesite approaching basalt, both of which types have important development in the great Tertiary accumulations of volcanic rocks farther south.

BASALTS.

Hypersthene-basalt.—The hypersthene-basalt was observed to form a small knob overlooking the smallest of the Hidden Lakes. In the hand specimen large phenocrysts of olivine are conspicuous, rather sparingly distributed in a dense black aphanitic groundmass. Under the microscope this groundmass is found to be hyalopilitic, consisting of plagioclase, augite, hypersthene, and magnetite, with considerable glass. The rhombic pyroxene also forms phenocrysts, which are, however, much smaller than those of olivine. There are a few patches of brown glass with stout prisms of augite embedded in them, which are altogether similar to the features produced in quartz basalts by the complete resorption of the quartz grains. There is little doubt, therefore, that quartz has been present in the rock.

Comparable with this rock is the material forming certain dikes in the granite about 10 miles east of Hidden Lakes. Here, however, augite forms large phenocrysts, and olivine appears to be lacking. The thin section contains a grain of highly corroded quartz surrounded by a zone of calcite and a material like iddingsite, which appear to replace glass, both forming irregular areas in the groundmass.

Yakima basalt.—This formation has been made the subject of detailed description in other publications,[a] and only its leading characteristics need be noticed here.

The petrographic character of the rocks is remarkably constant. They seem to be almost without exception normal basalts, composed essentially of labradorite, augite, olivine, and iron ore (usually titaniferous magnetite); the order given being, in general, that of relative

[a] Smith, G. O., Description of Mount Stuart quadrangle: Geologic Atlas U. S., folio 106, U. S. Geol. Survey, 1904; Smith, G. O., Description of Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903; Calkins, F. C., Bull. Geol. Dept. Univ. of California, vol. 3, No. 5, 1902, pp. 159-165.

abundance. Apatite is the only constant accessory. As regards degree of crystallinity, the lavas vary from nearly pure glass to holocrystalline dolerites, crystalline matter nearly always predominating markedly over glass. The basalts are rarely notably porphyritic, the common textures being intersertal for the hypocrystalline and ophitic for the holocrystalline phases.

Metabasalts.—The basaltic rocks of the old formations of Okanogan Valley and the region just east of Skagit River are represented only by specimens of extremely altered rock, which it would be unprofitable to describe in detail. Generally there is little or none of the original material left, and the basaltic character of the rocks is inferred from the nature of the secondary compounds or from traces of the original textures. It is quite possible, however, that these volcanic masses may include some basic pyroxene-andesites.

PLUTONIC ROCKS.

DISTRIBUTION AND CLASSIFICATION.

The vast development of plutonic rocks in the Northern Cascades has been shown in the preceding chapter, and in view of their geologic importance their petrographic character must have greater general interest than that of any other class of rocks. The description of the various species may, therefore, it seems, be conveniently preceded by a table, arranged in order of increasing basicity, showing their areal distribution. Such an arrangement will help to bring out the close petrographic relationship between the different types, and the descriptions which follow will have the emphasizing of these relationships for their most important object.

Species and distribution of the plutonic rocks of the region.

Species.	Occurrence.
Biotite-muscovite-granite	Batholiths near mouth of Okanogan Valley and in central and western parts of Okanogan Mountains.
Biotite-granite	Batholiths, probably post-Carboniferous, Okanogan Valley and Okanogan Mountains.
Acidic granodiorite	Batholiths in western part of Skagit Mountains.
Basic granodiorite	Batholiths, probably post-Carboniferous. Valley of Columbia River, in eastern portion of Okanogan Mountains, Skagit Valley, and Skagit Mountains. Marginal phase of acidic granodiorite in Skagit Mountains and of biotite-granite in Okanogan Mountains.
Quartz-mica-diorite	Batholiths in Okanogan Valley and in Pasayten formation (Cretaceous) of Hozomeen Range. Marginal phase of acidic granodiorite in Skagit Mountains and of biotite-granite in Okanogan Valley. Minor intrusions in Cache Creek rocks northeast of Loomis.

Species and distribution of the plutonic rocks—Continued.

Species.	Occurrence.
Quartz-pyroxene-mica-diorite	Small mass at east end of Horseshoe.
Hornblende-diorite	Marginal phase of acidic granodiorite, western Skagit Mountains.
Quartz-bearing augite-mica-diorite.	Do.
Gabbro (uralitic)	Abyssal representative of flows in Cache Creek group, Okanogan Valley, and intrusive (?) in serpentine, Mount Chopaka.
Olivine-hornblende-gabbro	Marginal phase of acidic granodiorite, western Skagit Mountains.
Saxonite	Batholith in pre-Cretaceous rocks, Ruby Creek, Hozomeen Range.
Peridotites and pyroxenites, altered.	Batholithic masses, Mount Chopaka.

In relative importance the rocks tabulated above vary widely. The most extensively developed class of rocks are probably the granodiorites. The granites, taken together, are little inferior in extent to the granodiorites; of the two types the biotite-granites are probably the more abundant. The quartz-diorites apparently come next, while diorite without essential quartz is very scarce. The gabbros and ultrabasic rocks have relatively slight volume. The most striking general fact is the preponderance of acidic over basic plutonic rocks.

GRANITES.

Biotite-muscovite-granite of Mount Remmel type.—The granite from the central belt, in which Mount Remmel lies, is apparently the most acidic plutonic rock with which we have to deal. As seen in the field on weathered surfaces it appears almost white. This, however, is not the color of the freshest material, which is rather brownish, owing to the smoky tint of the quartz and the flesh color of part of the feldspar. Biotite and muscovite are essential, but both together constitute but a very small part of the rock. A gneissic banding evident on broad exposures, though not sufficiently distinct to appear in hand specimens, is developed in portions of the mass. This structure was observed on the slopes of Mount Remmel, but the rock forming the ridge across the canyon to the west, while otherwise similar, is not foliated. An interesting feature is the local occurrence of small red garnets. The texture is evenly granular and the grain rather fine.

The essential mineralogic composition of a specimen from Mount Remmel, as determined by microscopic study, is roughly indicated by the expression quartz > orthoclase > oligoclase > biotite-muscovite. In addition to small amounts of magnetite, zircon, and apatite, garnet occurs in well-formed rhombic dodecahedra about one-half millimeter in average diameter. Some evidence of pressure and shearing is afforded by undulatory extinction in the quartz and a tendency to linear arrangement of the mica.

A specimen from farther north in the same belt of granite, though very similar in megascopic appearance to the rock just described, is free from garnet and appears to have more plagioclase than orthoclase. Whether or not this soda-rich phase is merely local, and what is the proportion of the alkalies in the magma as a whole, we are not prepared to say, though we should rather expect to find potash feldspar predominant. It does not seem probable, however, that there is, on the whole, decided predominance of potash feldspar over soda-lime feldspar.

Classificatory position.—The question will present itself at once to many petrographers whether or not it is proper to call this rock a granite, for it evidently has a close relationship with the adamellites of Brögger. Several considerations, however, have induced us provisionally to designate this and other related types soon to be described granites.

The term adamellite, it may be remarked in passing, is open to some objection on theoretical grounds. It is evident, for example, that if in the Mount Remmel rock a considerable part of the soda in the oligoclase were combined with potash in soda orthoclase, or went into albite intergrown with orthoclase, the rock, though not changed in chemical composition, would be called a granite. The objection to the name on this ground is of course common to all terminology based on mineralogic composition, and is one of the strong arguments for basing the classification of rocks primarily on chemical composition. Without chemical analysis, however, we are unable to classify our rocks according to a chemical scheme.

But the principal reason for using the term granite here consists in the approximate character of our data in regard to the quantitative relations of the feldspars. Optical estimation of the mineral constitution of coarse-grained porphyritic rocks is attended with difficulty and uncertainty, and it did not seem justifiable, in view of the preliminary nature of this report and the scarcity of the material in hand, to have chemical analyses made. Since the use of the term adamellite would seem to imply a more exact knowledge of the constitution of the rock than we really have, it has seemed best to use the more familiar and possibly less definite term "granite."

It is desired, however, to call attention emphatically to the fact—more important than the question of terminology—that the most acidic plutonic rocks of the Northern Cascades are comparatively rich in oligoclase, and thus richer in soda than the typical granites.

Biotite-muscovite-granite of Okanogan Valley type.—A rock closely related to the Mount Remmel type, but perhaps a little less siliceous, is represented by handsome fresh material collected a few miles west of the mouth of Okanogan River.

The general hue is light gray. The feldspars, taken together, constitute more than half of the rock, and quartz, often in large, irregular anhedra, is very abundant. Biotite in small flakes is present in small amount, and many yellowish brown crystals of titanite are rather noticeable megascopically. A little muscovite is present, but it is quite inconspicuous. The most interesting feature of the rock is the potash feldspar, which mostly occurs in phenocrysts measuring usually between 2.5 centimeters and 0.8 centimeter in diameter. The large phenocrysts have well-defined crystal boundaries, but have fairly numerous inclusions consisting of small feldspar grains and biotite, while quartz often penetrates the borders. Other smaller areas of the potash feldspar, however, are more irregular, some appearing as mere allotriomorphic plates poikilitically inclosing grains of the other constituents.

Microscopic examination shows the plagioclase to be oligoclase with faintly defined zonal structure. The potash feldspar, which shows in large part the twin structure of microcline, incloses oligoclase, biotite, and sometimes quartz and micropegmatite. Zircon, apatite, and magnetite occur as accessories in addition to titanite. The quantitative relation between potash feldspar and plagioclase can hardly be satisfactorily determined without chemical analysis; megascopically the alkali feldspar, and microscopically the plagioclase, appears the more prominent, and they are probably not far from equal in amount. The remarks on the classification of the Mount Remmel type of granite have their application here.

The gneiss forming the last peak passed in our westward course across the Okanogan granite belt appears mineralogically very similar to the rock from Okanogan Valley. The feldspars are partly pink and partly white and glassy. The quartz, which is abundant, has a noticeable and peculiar greasy luster, due to its microstructure, which will presently be described. The essential minerals and their rough quantitative relations in the one thin section examined are: Oligoclase > quartz > orthoclase > biotite > muscovite. Only the usual accessories, magnetite, apatite, and zircon, were noted.

The textural modification produced by pressure and shearing deserves brief notice. Megascopically the rock shows a distinctly banded appearance, but under the microscope it exhibits some more unusual phenomena. The micas exhibit the usual disposition in wavy lines, and the feldspar crystals have suffered some crushing. The quartz, however, shows the most interesting cataclastic structure. The original anhedra have been crushed to fine mosaics of elongated, lenticular, irregularly bounded grains, each exhibiting marked undulatory extinction. These folia of quartz have a parallel arrangement and show a fluidal disposition about the larger grains of feldspar. The appearance of this structure in polarized light is intrinsically beautiful and most clearly expressive of the intense dynamic stresses which the rock has undergone.

Biotite-granite.—The biotite-granites developed so extensively in the Okanogan Mountains and the adjacent portion of Okanogan Valley have a clear relation to the type just described, and mostly resemble it closely in mineralogic and textural characters. These rocks vary somewhat among themselves, yet not so markedly but that our present purpose may be served best by describing them together.

The biotite-granites are in general characterized megascopically by rather abundant quartz and orthoclase, the last mineral being very commonly but not always conspicuous for its porphyritic development. The biotite is not generally abundant, and the hornblende and muscovite which occur locally are perhaps not to be considered as essential. Microscopically, small quantities of magnetite, apatite, and zircon are observed, while titanite is usually a rather abundant accessory.

The accessories and the micas and hornblende present no features that entitle them to especial notice in this brief description. The quartz occurs commonly in rather large masses, which are found on microscopic study to be granular aggregates. The mineral is often very conspicuous megascopically, especially where, as is frequently the case, it has a smoky tint, contrasting with the white or pink of the feldspars. The feldspars are the most interesting minerals of these rocks, and of these, while orthoclase is rather the most prominent megascopically, plagioclase is found on microscopic study to be almost equally important.

The interesting porphyritic development frequently shown by the orthoclase is strikingly illustrated in the area near the foot of Lake Osoyoos and on the north side of the Horseshoe, where well-formed crystals may be picked up in any quantity from the sand that arises from the surface disintegration of the rock. In thin section these phenocrysts are found to inclose rather numerous individuals of plagioclase, green hornblende, and quartz, in order of abundance, all of which show good crystal form except the quartz. The inclusions, which are evenly distributed, generally show no definite crystallographic relation to their host, except that a considerable proportion of the plagioclase crystals appears to have approximately the orientation expressed as follows: $\breve{a}$ of plagioclase parallel to $\breve{a}$ of orthoclase, and $\dot{c}$ of plagioclase parallel to $\bar{b}$ of orthoclase.

These phenocrysts often show perthitic veining, and microcline twinning may be developed in a portion of the crystal. In addition to the phenocrystic alkali feldspar there is generally some microcline forming a poikilitic cement for the other constituents of the groundmass in which the phenocrysts are embedded. Where the potash feldspar is not porphyritic it is generally microcline and allotriomorphic toward all other minerals, even quartz inclosed in it sometimes showing sharp crystal form.

The plagioclase generally shows good crystal form. It is always slightly zoned, but nearly all belongs to acidic oligoclase. It commonly shows much greater susceptibility to weathering than the orthoclase, a fact strikingly illustrated in the rock from near the foot of Lake Osoyoos, where, although the potash feldspar is almost fresh, the plagioclase is thoroughly clouded with mica, kaolin, quartz, calcite, and epidote.

The proportion between the feldspars in these rocks deserves especial comment. The plagioclase, not very conspicuous megascopically, is found by microscopic study to be of the same order of importance as the potash feldspar. Exact optical estimates in regard to the relative proportions between the two classes are made difficult by the coarse grain and porphyritic textures. While merely megascopic examination would probably lead to an overestimate of the potash feldspar, the phenocrysts are rather more apt to be lost in grinding than the groundmass, in which plagioclase predominates, so that estimates based solely on microscopic evidence would lead to error in the opposite direction. Taking everything into consideration, it appears probable that on the whole the granites of this region contain more potash feldspar than plagioclase, but that the predominance of the potash feldspar is not very decided.

From the main type, constituting the larger areas, there are local variations. A specimen taken near the boundary north of Loomis differs from the ordinary porphyritic phase in having a slightly larger proportion of dark minerals, including some hornblende as well as biotite. Farther south toward Loomis the approach to the border of the mass seems to be attended by an increase in the basicity of the intrusive rock, and the principal zone contains types that, falling under granodiorite and quartz-diorite, will be described further on.

GRANODIORITES.

Acidic granodiorite of Mount Baker district.—In megascopic aspect the plutonic rock, so important about the headwaters of Silica Creek, resembles the biotite-granites just described, in so far as it contains abundant quartz, a rather small amount of biotite as the characteristic ferromagnesian constituent, and feldspar constituting more than half the rock. Close examination shows, however, that most of the feldspar is striated, a fact that distinguishes this rock clearly in classificatory position from the true granites.

In large masses the rock shows a light pure-gray color, caused by the combined effect of the dominant pure-white feldspar and colorless quartz with a rather small amount of biotite and a very little hornblende. The orthoclase may be seen on close examination showing the characteristic allotriomorphic relation toward the other constituents.

Careful study of the thin sections shows that the rough qualitative relations of the essential constituents may be indicated by the expression: Plagioclase$>$ quartz$>$ orthoclase and microcline$>$ biotite$\gg$ hornblende. The last-named mineral is found in so small amount that it should perhaps be ranked as an accessory, together with a very little muscovite and ordinary amounts of magnetite, apatite, and titanite.

The plagioclase is generally idiomorphic and strongly zoned, the cores of the crystals usually belonging to andesine, while the more acidic shells are of oligoclase. The quartz occurs in the usual manner, forming coarse irregular aggregates, allotriomorphic against plagioclase and biotite. This mica is of the common greenish brown variety. The orthoclase has the usual structural relationships, occurring in fairly large spongiform individuals, allotriomorphic toward all the other constituents but quartz. Intergrowths of orthoclase and quartz are found, in some of which, contrary to the usual quantitative and structural relations, the feldspar is subordinate and makes cuneiform figures in the quartz. The general order of crystallization for the essential constituents is: Plagioclase, biotite, quartz and potash feldspar (nearly contemporaneous).

As regards classification this rock clearly falls within the group of granodiorites, which are defined by Lindgren as—

> A member of the great family of rocks with predominating soda-lime feldspars, distinguished by a granular texture, grayish color, and a mineral composition of quartz, oligoclase or andesine, orthoclase or microcline, hornblende or biotite (usually both), the accessories being titanite, apatite, magnetite, and zircon.[a]

The small amount of dark minerals, however, and the high percentage of quartz—rather noteworthy in view of the predominance and moderately basic character of the plagioclase—place the rock well toward the acidic end of the granodiorite group. On the other hand, the character of the feldspars very clearly separates it from the granites or the quartz-monzonites.

The basic rocks which have already been noted as occurring in the marginal portion of this mass include granodiorite of a more basic type, diorite, and gabbro, which will be described in their places. The origin of the marginal variations will also be discussed later.

Basic type of granodiorite.—The extensive masses of granodiorite found along Columbia River, in the Okanogan Mountains, and in Skagit Valley are of a type more basic than the rock of the Mount Baker district, from which it differs in containing as much hornblende as biotite and a considerably smaller though still essential proportion of quartz, while orthoclase plays a still more subordinate rôle than in the rock last described.

The typical material is a gray rock of moderately coarse-granular texture. The feldspars, which constitute together about half the rock, are generally pure white, though in exceptional cases where they are clear and glassy they appear gray, giving the rock a darker

[a] Lindgren, W., Am. Jour. Sci., 4th series, vol. 9, 1900, p. 281. In the article referred to, Doctor Lindgren has discussed thoroughly the limits of this group and its relation to neighboring types. As he points out, the granodiorites form a well-defined natural group, which is extensively developed in the Sierra Nevada, and which has perhaps received insufficient recognition from European petrographers.

tone. The outlines of the striated feldspar are idiomorphic, but the orthoclase when recognizable is always in the form of a cement for the other constituents. By observation of the basal reflections it often may be seen to form irregular plates often 1 square centimeter or more in area, thickly interspersed with crystals of plagioclase and the dark minerals. The quartz, which is colorless, occurs in irregular grains. The hornblende always shows a tendency to prismatic form, and occasionaly builds well-developed crystals with a maximum length of about 1 centimeter. The biotite forms tablets that are sometimes hexagonal, but oftener of irregular outline.

Microscopic examination shows the presence as accessories of considerable magnetite, apatite, and titanite, and of a little zircon.

The relative amounts of the essential minerals are indicated by the expression: Plagioclase > quartz > hornblende >< biotite > orthoclase.

The plagioclase almost always shows some zonal banding, which, however, is not generally very distinct. Usually the central and larger portion of each crystal is andesine, while the peripheral portion is oligoclase. The hornblende and biotite are of the most common varieties, the amphibole being deep green and pleochroic, and the mica a deep greenish brown lepidomelane with an interference figure that is clearly biaxial, but in which the hyperbolic brushes do not separate in a complete revolution of the stage.

The general order of crystallization seems to be as follows: Apatite, titanite, zircon and magnetite, plagioclase, hornblende and biotite, quartz and orthoclase. It is interesting, however, to note that innumerable exceptions to this general order occur in every slide. Each one of the essentials has been found to inclose all the other minerals excepting orthoclase; in a few cases large irregular grains of iron ore inclose plagioclase and quartz. The hornblende and biotite sometimes show the poikilitic structure developed to an extreme degree.

Basic segregations occur in the granodiorite, which mineralogically differ from the normal rock in containing a larger proportion of the ferromagnesian constituents, among which hornblende is usually dominant. Of the light-colored minerals, quartz becomes very subordinate, while the orthoclase increases relatively and sometimes equals or exceeds the plagioclase, which is generally andesine as in the normal granodiorite.

Such a rock forms blotches in the normal granodiorite west of the Horseshoe, just described. The rock consists of irregular interlocking sponge-like individuals of orthoclase, often an inch or more in diameter, filled with inclusions of the other constituents. These in the aggregate exceed the cementing feldspar, and the presence of the latter is recognized macroscopically only by observation of the mottled reflections from cleavage faces.

The thin section cut from this rock shows a single crystal plate of orthoclase, in which are interspersed, without any regularity of orientation, plagioclase, hornblende, biotite, quartz, and augite, besides the usual accessories.

DIORITES.

Quartz-mica-diorites.—The rocks of this species show a most markedly close relationship with the more basic granodiorites, the mineral constituents and their structural relations to one another being the same as in the granodiorites. It will not be necessary, therefore, to describe them very fully. The difference between the two classes of rocks lies in the quantitative relations of the constituents, the quartz-diorites being distinguished by having a large proportion of ferromagnesian minerals, with quartz and orthoclase distinctly subordinate and not readily seen megascopically. The accessories are the same as in the granodiorite, but magnetite and apatite are more abundant, titanite rather less so, and zircon scarce. The plagioclase is, as would be expected, rather more basic than in the granodiorites. The crystals are strongly zoned, with oligoclase, andesine, and labradorite entering into their constitution. Usually the average composition is not far from $Ab_4\ An_3$.

Such are the general characteristics of the quartz-mica-diorites of this region. There is, however, some variation within the group. On the side closer to granodiorite lie the gneissic quartz-diorite of Clover and a rock from the marginal zone of the biotite-granite north of Loomis. The latter rock, being even grained and of moderately fine texture, is well fitted for analysis by direct optical measurement of the constituents in thin section, according to the method of Rosiwal.[a]

The results obtained by this method, the average composition of the plagioclase being estimated as $Ab_4\ An_3$, are as follows:

Mineralogic composition of quartz-diorite north of Loomis.

Quartz	11.8	
Orthoclase	4.9	
Albite	31.4	48.1
Anorthite	16.7	
Biotite	16.8	
Hornblende	15.6	
Augite	.6	
Magnetite	1.9	
Apatite	.3	
Total	100.0	

In addition to the constituents measured there is a small amount of titanite. The order of crystallization is in general the following: Accessories; plagioclase; augite, hornblende, and biotite; orthoclase and quartz.

The quartz-diorite of Ruby Creek is apparently somewhat more

[a] Rosiwal, A., Verhand. d. K. -k. geol. Reichsanstalt, 1898, pp. 143-175.

basic. The quantitative relation of the essential constituents is: Plagioclase > hornblende > quartz > orthoclase > biotite; magnetite and apatite are rather abundant accessories, and some titanite occurs. The plagioclase is in idiomorphic strongly zoned crystals whose kernels are often as basic as Ab_1 An_1, but whose outer shells belong to andesine and oligoclase. The order of crystallization of the essentials is very clear. The plagioclase is always in well-developed crystals.

The hornblende forms prisms which are sharply idiomorphic against quartz and orthoclase, but are xenomorphic against the the plagioclase. The biotite, which is represented by pseudomorphs of chlorite, exhibits the same relations toward the respective light-colored minerals as does the hornblende. The quartz and orthoclase are in characteristic anhedra.

Quartz-pyroxene-mica-diorite.—This rock is found in a rather small mass at the east end of the Horseshoe. Megascopically it appears as a dark greenish gray, evenly granular rock of rather fine texture. Under the microscope its constituent minerals are found to be plagioclase, hypersthene, augite, hornblende, biotite, quartz, orthoclase, with accessory apatite, zircon, and iron ore. The accessories are all relatively abundant, zircon occurring in unusually large crystals. The plagioclase is in zonally built crystals, the kernels usually being approximately of the composition Ab_1 An_1 and the rims belonging to oligoclase. The quartz and orthoclase are subordinate in quantity and fill the anhedral spaces between the other constituents.

Especially interesting is the mode of occurrence of the ferromagnesian minerals, which are generally intergrown with one another. The most common intergrowths are of either pyroxene with the hornblende, but not infrequently all four minerals are found in parallel intergrowth, the order of succession from center to periphery being: Hypersthene, augite, hornblende, and biotite.

The rock is similar to some of the Electric Peak diorites, and the intergrowths of the ferromagnesian minerals are identical in character with those so well described and figured in Professor Iddings's classic memoir on the petrography of Electric Peak and Sepulchre Mountain.[a]

Quartz-augite-mica-diorite.—This rock, found in the peripheral zone of the granodiorite at Mamie Pass, is a rock well toward the basic end of the quartz-diorite group.

Megascopically it appears as of moderately coarse grain and of dark-gray color. Ferromagnesian constituents are abundant, including dark-brown biotite in irregular foils, and black minerals with prismatic cleavage. The feldspar, which is of a light-gray color, constitutes about half the rock, while the quartz is not to be recognized macroscopically without careful search.

[a] Eruptive rocks of Electric Peak and Sepulchre Mountain: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, pp. 603-607, Pl. L.

Microscopically, accessory iron ore, apatite, and titanite are noted. The most abundant constituent is found to be plagioclase, which is chiefly labradorite, but it shows pronounced zonal structure, and a peculiar and characteristic mottled appearance in polarized light, owing to an irregular intergrowth of different forms of plagioclase with different optical orientations. The species thus intergrown vary from calcic labradorite to oligoclase.

The ferromagnesian constituents are greenish augite, rather pale-green hornblende, and biotite, which is strongly pleochroic and of a deep reddish brown color. The amphibole and pyroxene together slightly exceed the mica in quantity. The augite always occurs intergrown with hornblende, the former generally being in the form of irregular areas inclosed in the latter, with the vertical and ortho axes in common for the two minerals. The hornblende is massive, sharply marked off from the pyroxene, and is thought to be original. The biotite is also frequently intergrown with hornblende, the basal pinacoid of the biotite coinciding with the orthopinacoid of the amphibole.

Quartz, which occurs in the usual small anhedra, is scarcer than in the diorites already described, and orthoclase, in the usual interstitial relation, is a rare constituent.

The order of crystallization in the granodiorites and quartz-mica-diorites is, in general: accessories, plagioclase, ferromagnesian minerals, quartz, and orthoclase.

Probably in close chemical relation to the quartz-diorite is a rock occurring on the ridge east of Granite Mountain. Macroscopically it differs from it considerably, being of a lighter grayish green color. The chief constituent is gray feldspar with twin striations on the elongated basal cleavage faces. Subordinate to the feldspar is a dark gray-green mineral with prismatic cleavage.

Under the microscope the structure is seen to be medium grained, hypidiomorphic granular, and the essential constituents are found to be plagioclase and amphibole, the latter perhaps in part secondary. There is a little interstitial orthoclase, but no quartz. A little biotite, iron ore, apatite, titanite, and epidote are also present. The titanite, in sharply developed crystals of rhomboidal section, is remarkably abundant. The plagioclase, which is somewhat clouded by decomposition products, is similar in microstructure and in chemical composition to that of the quartz-bearing diorite just described.

GABBROS.

Olivine-hornblende-gabbro.—This rock, found in the peripheral zone at Granite Mountain, is very dark in general hue, with ferromagnesian minerals in the aggregate predominant over feldspar. Under the microscope it is seen to be composed essentially of plagioclase, monoclinic pyroxene, olivine, and hornblende, this order being approximately that of relative abundance. The plagioclase and olivine are generally in the form of grains with irregularly curved boundaries. These are inwrapped, though rarely completely inclosed, by allotriomorphic plates of pyroxene, with which the hornblende is intergrown.

The plagioclase, which is without zonary banding, shows in sections perpendicular to the brachypinacoid a maximum extinction angle of about 44°, indicating a composition near $Ab_1 An_2$. It is but slightly altered.

The olivine is very largely decomposed to talc and serpentine, the process of alteration being attended by the usual separation of iron ore.

The pyroxene is in thin section almost colorless, with a faint tinge of green. An imperfectly developed cleavage is sometimes found parallel to the orthopinacoid.

The hornblende is partly green, partly deep brown. As already noted, it nearly always occurs in parallel intergrowth with the pyroxene, sometimes included in that mineral in the form of small splinters or plates, but more frequently surrounding it. The boundary between the brown hornblende and the pyroxene is always absolutely distinct; that of the green amphibole is less evidently so, because of the similarity in color, but appearances indicate that all or nearly all of the hornblende is primary. The brown and green hornblende, however, frequently appear to grade into each other, and it is suggested that the latter may be derived from the former by some process of reduction.

There are irregular aggregates of actinolite which may arise from the decomposition of pyroxene or olivine.

Uralitic gabbro of Palmer Mountain.—In the exposure east of the head of Palmer Lake this rock shows macroscopically a marked ophitic structure of rather coarse grain. Microscopically the rock is found to consist essentially of plagioclase and hornblende. The amphibole is peculiarly mottled, its color in thin section varying from deep grass green to colorless. It is generally massive, but sometimes forms fine-grained aggregates. Although no pyroxene was found in the section, the ophitic relation of the hornblende toward the feldspar, in connection with the altered character of the rock, is rather suggestive of derivation from pyroxene. The plagioclase is less basic than is usual in gabbro and apparently belongs to the andesine division. The feldspar is rather badly decomposed, with the production of much calcite, mica, zoisite, and common epidote. No olivine seems to have been present in the rock, which apparently belongs near the acidic end of the gabbro family.

Uralitic gabbro of Mount Chopaka.—This rock is dark grayish green in mass and is texturally quite different from the gabbro of Palmer Mountain. The most prominent constituent is a green amphibole, which, instead of being ophitic, is in ragged prisms with a tendency to parallel arrangement. Under the microscope basic plagioclase is seen to be about equally abundant with the ferromagnesian mineral. A little diallage is found, but it is always surrounded by the amphibole, and the latter appears to have originated in part or entirely from the decomposition of pyroxene. It is deep to pale green, often fibrous, and with fringe-like borders. The feldspar has also undergone alteration, chiefly of a sort that indicates the agency of deep-seated forces rather than ordinary weathering. The large individuals are often changed to fine mosaics of clear grains, though the original twin striations, with crenulated borders, in some cases remain visible. Throughout the generally clear feldspar minute needles of green amphibole, evidently secondary, are thickly interspersed, and grains of zoisite are disseminated in moderate abundance. There are no vestiges of olivine in the rock.

ULTRABASIC ROCKS.

Serpentines and pyroxenites of Mount Chopaka.—These rocks are deeply altered, often containing no remnants of the primary minerals, one specimen being found to consist essentially of dolomite, serpentine, and talc, showing no traces of the original texture.

In another interesting rock the chief constituent is an amphibole almost colorless in thin section, and probably to be referred to tremolite. This rock also contains some diallage, enstatite, and serpentine with felted structure which may represent olivine. The tremolite occurs partly in moderate-sized, extremely irregular individuals, but much of it is finely granular. Occasionally it surrounds diallage with parallel orientation, and may be derived from the alteration of the pyroxene by a process similar to uralitization.

Saxonite of Ruby Creek.—The ultrabasic rocks of Ruby Creek are dark gray-green granular aggregates in which silvery-bladed crystals of enstatite are more or less prominent megascopically. Under the microscope the essential constituents are found to be olivine and enstatite, sometimes one and sometimes the other predominating. Grains of deep-brown chromite or picotite are also present. Decomposition has affected the rock only to a moderate extent. The most important secondary constituent is talc, which is epigenetic upon both olivine and enstatite, but serpentine accompanied by secondary magnetite is replacing olivine in the usual manner.

HYPABYSSAL ROCKS.

CLASSIFICATION AND DISTRIBUTION.

We have now to consider a large number of dike rocks, of great petrographic diversity, which have no known connection with volcanic flows, and are usually in evidently genetic relationship to plutonic masses. Passing by the apophyses from intrusive masses, differing from the parent rock only in texture, we shall discuss here only a group of rocks supposedly produced by secondary differentiation from large bodies of magma. In period of intrusion these are not widely separated from the batholithic masses, and are generally distinctly more acidic or more basic than the parent rock. Thus they fall chemically into two groups, the one comprising the acidic granite-porphyries, aplites, and pegmatites, and the other a variety of basic dike rocks which may be designated in the broad sense of the term lamprophyric.

The occurrence of the rocks of these groups represented in our collection is indicated in the following table:

Species, distribution, and occurrence of the hypabyssal rocks of the region.

Species	Locality.	Mode of occurrence.
Granophyre	Near Orondo	Dikes in schist, near contact with granodiorite.
Granite-porphyry	Antoine Coulee	Dikes in granodiorite.
Do	Near Barron	Dikes in Pasayten formation.
Soda-rich granite-porphyry.	East of Pasayten River	Do.
Do	Granite Mountain	Dike in diorite; periphery of acidic granodiorite.
Pegmatite	Between Wenatchee and Entiat.	Dikes in schists and gneisses.
Do	Okanogan Mountains	Dikes in biotite-granite.
Granite-aplite	do	Do.
Granodiorite-aplite	West of Loomis, and near Mamie Pass.	Dikes associated with granodiorite.
"Soda-syenite"	South of Bighorn Peak	Dike in granite or granodiorite.
Diorite-porphyry	Near Orondo	Dikes in schist and granodiorite.
Do	East end of Horseshoe	Dikes in diorite.
Do	Mount Remmel	Dike in granite.
Do	West of Hidden Lakes	Dike in Pasayten formation.
Hornblende-porphyries.	Main divide, head of Canyon Creek.	Dikes in Pasayten formation.
Diorite (?)	Granite Mountain	Dike in peripheral zone of granodiorite.
"Mica-diabase"	Near Orondo	Dike in schist.
Diabase	Barron	Dike in Pasayten formation.
Peridotite	North of Park Pass	Dike (?) in granite.

ACIDIC DIKE ROCKS.

Granophyre.—This rock, collected at Orondo, shows, megascopically, a very few small crystals of feldspar and quartz in a dull-white aphanitic groundmass, which is slightly speckled with limonite. With the aid of the microscope it is found that this groundmass is granophyric and composed of quartz and alkali feldspars. There are no ferromagnesian minerals.

Granite-porphyries.—In Antoine Coulee the granodiorite is cut by dikes of a handsome porphyry, which exhibits macroscopically abundant phenocrysts of feldspar and quartz, with small dark-green specks, in a gray aphanitic groundmass. In the thin section it is found that the most numerous phenocrysts are of oligoclase, while there are many small ones of altered biotite. There is a small proportion, however, of large phenocrysts of orthoclase, intergrown with quartz and poikilitically inclosing crystals of plagioclase and biotite. The groundmass is composed of quartz and alkali feldspar of rather peculiar structure, abundant irregular areas of micropegmatite being embedded in a microgranular paste.

Of the numerous dikes in the vicinity of Barron a very common type is composed of a porphyritic rock, with abundant phenocrysts of quartz and feldspar in an aphanitic groundmass, dull white except for frequent stains of limonite. It is found by study of the thin section that the phenocrysts are quartz, orthoclase, and less plagioclase, in a holocrystalline groundmass composed of quartz and alkali feldspar in pseudospherulitic intergrowths.

Other dike rocks of similar megascopic appearance are found in the eastern portion of the same belt of Cretaceous rocks, which are, however, apparently richer in soda. The feldspar phenocrysts are all striated and belong to the species oligoclase-albite. The groundmass consists in the main of quartz in broad irregular individuals inclosing laths of feldspar, but there is also a little microgranular interstitial material.

The quartz-porphyry occurring on Granite Mountain, in the Mount Baker district, appears likewise rich in soda. It shows, in a white aphanitic groundmass, phenocrysts of striated feldspar, small grains of green amphibole, and quartzes whose outlines are rounded by corrosion in a striking manner. The phenocrystic feldspar is determined microscopically to be oligoclase, but it is veined with a colorless mineral having very nearly the same refractive index and double refraction and without twinning, which may be orthoclase. The groundmass consists of quartz and feldspar in micrographic intergrowth. Noteworthy is the occurrence of a comparatively large amount of titanite in irregular grains.

Pegmatites.—The pegmatite intrusive in the schist below Entiat is composed of dominant orthoclase and quartz, with a little acidic plagioclase, considerable muscovite, and numerous crystals of garnet ranging in diameter from one-half millimeter to 5 millimeters. The rock has undergone dynamic stresses, which have produced schistose and mylonitic structures, but no such marked effect as the complete foliation produced in the schist itself.

A specimen of graphic granite collected near Mount Remmel and south of Park Pass is composed of a large individual of pink potash feldspar, which is found microscopically to consist of microcline with veins of striated feldspar, presumably albite. Included in this mineral are crystals of acidic plagioclase, quartz, and muscovite. Contrary to the usual rule, however, the quartz individuals have not a common orientation, although they appear macroscopically in cuneiform figures.

At several localities a sort of ribbon structure was observed in the small pegmatitic veins. The borders were fine grained and aplitic in texture, the next zone inward pegmatitic, and the center formed by a rib of pure quartz.

Aplites.—The aplites associated with the mica-granite have the usual mineralogic composition. Quartz is abundant, and the potash feldspars (orthoclase and microcline, often perthitic) predominate over the acidic plagioclase.

An aplitic rock of different type cuts the greenstones northwest of Loomis. The essential constituents are feldspar, much quartz, and a little biotite. The potash feldspar is inferior in amount to the plagioclase, which ranges from andesine to acidic oligoclase. Thus the rock shows a chemical relationship to the neighboring granodiorite, from which it is probably derived. It appears that the aplites resemble their parent magmas in regard to the proportion between the alkalies.

"*Soda-syenite.*"—The rock from Bighorn Peak referred to as "soda-syenite" is a rare type and apparently is the product of an exceptional kind of differentiation from a granitic or granodioritic magma. It is very light colored and of moderately fine granular texture. Under the microscope plagioclase is seen to form much more than half the rock; the other essential constituents are orthoclase and quartz in about equal quantity. There are also some green rhombic pyroxene and deep-green hornblende and iron ore, nearly equal to one another in amount, but their aggregate quantity is very small, and they may be considered accessory. Apatite and zircon are present as minor accessories.

The plagioclase, in polarized light, is remarkable for the fineness and regularity of its polysynthetic twinning after the albite law. A section almost strictly normal to the bisectrix showed a rather faintly defined zonal structure. The core gave an extinction angle of $+4°$, while the broad external zone, constituting the greater portion of the crystal, extinguished at $+9°$. These angles correspond, respectively, to the compositions Ab_3An_1 and Ab_5An_1. The orthoclase is in the usual interstitial relation and the plagioclase is usually idiomorphic against it, but not infrequently the boundary between the two feldspars is irregularly curved, and they sometimes appear to be intergrown. The pyroxene and amphibole are generally in parallel intergrowth, and the iron ore is mostly associated with them.

LAMPROPHYRIC DIKE ROCKS.

General characteristics.—The lamprophyric rocks of the collection comprise a wide variety of types, most of which find no place in the classification of lamprophyric rocks proposed by Rosenbusch. The only general statements that may be made in regard to them are that they invariably show a decided predominance of plagioclase over orthoclase and are rarely very rich in biotite; thus they do not seem to have the large percentages of potash that characterize most of the rocks that have been described as lamprophyres.

Diorite-porphyries.—Rocks of this type containing quartz are apparently the most abundant lamprophyric rocks found. A dark, fine-grained, porphyritic rock cutting the white gneiss of Mount Remmel contains a very few phenocrysts of labradorite in a holocrystalline groundmass which consists chiefly of strongly zoned plagioclase (andesine to acidic oligoclase) in idiomorphic prisms, and which contains considerable biotite and a smaller amount of deep-green hornblende occurring in small ragged individuals. The final products of crystallization are a small amount of quartz and an alkali feldspar, commonly in micrographic intergrowth.

The diorite collected at Orondo is of a similar type. The dike in the Cretaceous rocks west of the Pasayten is apparently somewhat more basic, carrying phenocrysts of zoned plagioclase (labradorite to andesine) and brown hornblende in a holocrystalline groundmass of plagioclase laths, a little quartz, and perhaps a second generation of hornblende. The diorite-porphyry from the Horseshoe has phenocrysts of zoned plagioclase (labradorite with more acidic shells), greenish-brown hornblende, augite (usually with borders of hornblende in parallel position), and biotite. The groundmass consists of the same minerals, together with some interstitial quartz and alkali feldspar.

Hornblende-porphyries.—Interesting specimens of this character were collected from dikes cropping out along the divide north of Barron. One of these is characterized by the presence of large phenocrysts of dark-green hornblende, with strikingly perfect crystal form. The microscope shows the presence of feldspar, apparently in two generations, although forming no prominent phenocrysts. There is a little green monoclinic pyroxene intergrown with the hornblende, as well as considerable iron ore and apatite. A little quartz is present in the holocrystalline groundmass.

Another rock from the same vicinity also shows, megascopically, abundant phenocrysts of amphibole in a crystalline groundmass. Under the microscope it appears that the groundmass is holocrystalline, consisting of feldspar, a little quartz, and small well-developed prisms of pale-green diopside. The amphibole is of especial interest, for the phenocrysts are found to be parallel intergrowths of two varieties. The more abundant is a colored hornblende, mainly deep brown, but shading into green near its borders. The other amphibole is colorless in thin section. It forms irregular areas within and borders about the colored variety, from which it is sharply marked off. Both minerals have an extinction angle of about 21°, but the colorless variety has a notably higher double refraction than the other. A small amount of diopside is also intergrown with the amphiboles.

The rock is considerably altered, containing much chlorite, and the feldspar is mostly too much decomposed for determination, but in some specimens shows albite twinning and high extinction angles.

Diorite (?) of Granite Mountain.—A dike rock associated with the granite at Mamie Pass is peculiarly interesting by reason of its mineralogic constitution and the structural relations of some of the accessories.

Megascopically it appears fine grained, though evidently crystalline. The color of the bulk of the rock is almost black, but there are oval and circular spots that are nearly white and stand out upon the weathered surfaces.

Under the microscope the essential constituents are seen to be, in order of abundance, feldspar, quartz, biotite. Green hornblende, iron ore, apatite, and titanite occur as accessories, though all in comparatively large amount. All the minerals are fairly fresh. Some epidote occurs in a rather peculiar manner, which will presently be described. The texture in the main is fine grained, hypidiomorphic granular, though a few feldspars stand out porphyritically. The whitish spots seen macroscopically are areas where quartz is unusually abundant and mica almost absent.

The plagioclase, which is idiomorphic and prismatic in the direction of the ă axis, has a strongly marked zonal structure. The kernels of the crystals are andesine and the rims very acidic; the outermost portions, indeed, are often without the albite twinning found in the centers and may be of alkali feldspar. The mica is of a peculiar olive-green color, but, like ordinary biotite, has straight extinction, high double refraction, and a very small optic axial angle. It occurs in peculiar radiating brush-like aggregates. The quartz is abundant and forms moderately large allotriomorphic individuals.

The most noteworthy feature of the rock consists in the anomalous position of the apatite and the titanite in the sequence of crystallization. The titanite, which occurs in comparatively large individuals, frequently is penetrated by the idiomorphic crystals of feldspar. In one case titanite was observed inclosing quartz with polygonal outline, but generally it is idiomorphic against quartz. The apatite, however, never shows a suggestion of crystal form. It occurs in broad, irregular plates, allotriomorphic against feldspar and biotite. In fact, the apatite, whose identification was based on the combination of high refractive index with weak double refraction, and confirmed satisfactorily by microchemical tests, plays a rôle very analogous to that of the quartz and is evidently one of the last products of crystallization.

The epidote occurs in veinlets and small inclosed areas, bordered by a fine aggregate of feldspar, quartz, and magnetite. It is supposed to be of the nature of vein material, filling spaces produced by dynamic brecciation of the rock.

Diabases.—A specimen collected by Professor Russell near Barron seems to be a normal diabase. It consists mainly of plagioclase and violet-brown titaniferous augite in the usual ophitic relation. There is much iron ore, and there are masses of iddingsite that appear to be pseudomorphs after olivine.

A rock collected near Orondo is of a different and quite unusual type. The leading constituents are labradorite and augite, but there is also considerable biotite and a little quartz. The lath-shaped plagioclase and rather irregular foils of biotite are inclosed ophitically by the augite, while the quartz is interstitial. The rock is decidedly different from the Yakima basalt which caps the plateau above this locality, and probably has no genetic relation with that lava.

Peridotite.—A rock apparently intrusive in the granite north of Park Pass attracted especial notice in the field by reason of its strong effect on the magnetic needle of the plane table. It is a dark-colored granular rock of high specific gravity, which proves under the microscope to be an exceptionally fresh peridotite.

Olivine is the most abundant constituent, while diallage is next in order of abundance. Bordering the areas of diallage and included within that mineral are small particles of a nearly colorless amphibole, the associated minerals always having their vertical and ortho axes in common. The amphibole is always massive and the boundaries between it and the diallage are always sharp; their relation seems, therefore, to be that of intergrowth rather than paramorphism. A little rhombic pyroxene (bronzite) is also present. The olivine is partially altered to a yellowish brown serpentine associated with a large proportion of secondary magnetite. The texture is that characteristic of the peridotites, the pyroxenes and amphibole occurring in irregular plates interstitial between the large rounded grains of olivine.

CONCLUSIONS.

PRELIMINARY STATEMENT.

The Cascade Mountains near the forty-ninth parallel are composed in greater part of igneous rocks that belong mainly to great batholithic masses of rather acidic composition. In areal extent the batholiths of this region are perhaps exceeded by few examples, and are quite comparable with the immense intrusions of the Sierra Nevada. To the student of batholithic magmas the Northern Cascades afford a most interesting field, and future workers there may obtain data bearing on such important theoretical questions as the normal succession of eruptive rocks, the laws and phenomena of differentiation, the mechanics of igneous intrusion, and the geographic relations of petrographic provinces.

Few data bearing on such broad problems were gathered by the present writers, but it seems justifiable (1) to consider briefly here some phenomena supposed to illustrate differentiation on the margins of batholithic masses and (2) to point out the apparent significance of certain relationships and general characteristics exhibited by the igneous rocks described on the preceding pages. As the reader hardly need be reminded, theoretical speculation based on reconnaissance observations and on microscopic study unsupported by chemical data can not properly be carried far. The object of the considerations which follow is to point out in connection with each of the points considered what appears to the writer the most probable bearing of the available evidence.

EVIDENCES OF MARGINAL DIFFERENTIATION.

The existence of basic peripheral zones in several intrusive masses has already been noted briefly, but consideration of their origin has been reserved for this place. The most notable examples were observed at two localities in the valley of the Columbia and about Granite Mountain in the Mount Baker district.

Columbia River Valley.—The phenomena at both localities in Columbia River Valley were only observed in passing, but there appeared to be in both cases granodiorites irruptive into schists and gneisses, which are not notably more basic than the intrusive rock. The peripheral part of the intrusive mass is very variable, but on the whole decidedly richer in ferromagnesian minerals than is the typical granodiorite away from the contact. The basic material is cut by innumerable dikes of more acidic material. There is no evidence at these localities of marginal absorption, and differentiation is suggested as the most probable explanation of the facts. The observed phenomena seem to indicate that a marginal basic zone was formed, partly solidified, and then broken up and injected with more acidic material from the still liquid interior portion of the mass.

Granite Mountain.—At this locality the phenomena are better exposed and have been studied more closely than in the case of Columbia River localities, though still very incompletely. The field observations and the results of petrographic study of the specimens collected may be summarized as follows:

(1) The intrusive rock at a distance from the contact is an acidic granodiorite of fairly uniform character (which may be referred to as the normal type).

(2) The peripheral portion of the intrusion is very variable and more basic on the whole than the normal granodiorite.

(3) The rocks of the peripheral zone comprise granodiorites, diorites, and gabbros, showing close petrographic relationship to the normal granodiorite and to one another.

(4) The rocks into which the igneous materials were intruded are metamorphics, chiefly of sedimentary origin, not notably more basic than the normal granodiorite.

(5) There is no evidence of any considerable assimilation of the metamorphics by the igneous rock.

There is a lack of chemical data in regard to the constitution of all the rocks concerned, which is counterbalanced to a greater extent for the igneous than for the metamorphic rocks by microscopic study. It seems altogether improbable, however, that the peripheral rocks could have been formed by assimilation, especially in view of the fact that no physical evidences of assimilation were observed. The close consanguinity of the rocks of the peripheral zone can not be devoid of significance, and seems to point to differentiation as the most probable agency concerned in the production of the various species.

In regard to the details of the process, our field notes afford little evidence. There is certainly not any such regular concentric arrangement of zones as occurs, for example, at Yogo Peak,[a] nor was evidence obtained of distinct intrusion of one rock by another.

RELATIONSHIPS AND GENERAL CHEMICAL CHARACTERS OF THE IGNEOUS ROCKS.

The petrographic descriptions have, it is hoped, brought out the fact that the igneous rocks of the region show certain family traits in common. This point is most clearly illustrated by the plutonic rocks, which are most fully represented by specimens, and the chemical characters of which are most capable of inference from the mineralogic composition. We have, therefore, in order to exhibit their relations most graphically, constructed the following table, in which the well-defined types of plutonic rocks represented by fresh specimens are arranged in order of acidity and their essential mineralogic constitution shown.

[a] Pirsson, L. V., Geology of Little Belt Mountains: Twentieth Ann. Rept. U. S. Geol. Survey pt. 3, p. 564.

Quantitative relations of essential minerals in plutonic rocks.

Rock.	Quartz.	Orthoclase.	Plagioclase.	Muscovite.	Biotite.	Hornblende.	Pyroxene.	Olivine.
Biotite-muscovite-granite	Much	Much	Oligoclase about=orthoclase.	Some	Some			
Biotite-granite	do	do	Andesine about=orthoclase	Occasionally accessory.	do	Occasionally a little.		
Acidic granodiorite	do	Some	Andesine > orthoclase	Accessory	Considerable	Little		
Basic granodiorite	Considerable	Little	do		do	Considerable biotite.	Occasionally present	
Quartz-mica-diorite	Little	do	do		Much to little	Much	A little generally present.	
Quartz-pyroxene-mica-diorite.	Some	do	do		Some	do	Much	
Quartz-augite-mica-diorite	Little	Very little.	Labradorite and andesine		Much	do	Considerable	
Olivine-hornblende-gabbro			Much labradorite			Considerable	Much	Considerable.
Saxonite							do	Much.

With the table before us it is easy to point out the following important facts:

(1) The rocks form a graded series, each closely related to its neighbor and varying from one end of the series to the other according to definite laws. With few exceptions, each essential constituent either decreases or increases in importance as we pass from the most acidic toward the most basic type.

(2) There is an absence throughout the series of alkaline rocks allied to syenite, essexite, shonkinite, etc. The rocks in this table all belong to the granite-dioritic and gabbro-peridotitic magmas of Rosenbusch.

(3) It is noteworthy that even among the granites there are no rocks in which potash feldspar predominates markedly over plagioclase.

We may now consider briefly how far the other classes of igneous rocks show similar relationships and general characteristics.

The volcanic rocks fall into a graded series, passing from rhyolite through dacite and andesite to basalt, without including any trachytes or other alkaline types. Corresponding to the absence of granitic rocks with dominant potash feldspar is the absence of rhyolites in which phenocrysts of orthoclase play an important part.

The hypabyssal rocks show less complete gradation and less evident relationships than the plutonics and volcanics. Some of the most acidic have abundant orthoclase phenocrysts, while in others apparently as acidic the phenocrystic feldspar is plagioclase. The "soda-syenite" of Bighorn Peak also shows exceptionally an alkaline composition, and many of the pegmatites have orthoclase as the dominant feldspar. In short, many of the hypabyssal rocks, chemically considered, would fall outside of the series formed by the plutonic and volcanic rocks. This apparent discrepancy is explainable, however, by supposing that the hypabyssal rocks are the product of differentiation of a higher order than that which produced the others, and does not affect the significance of the close relationship between the various volcanic and plutonic rocks.

The facts that have been set forth in the preceding paragraphs appear to have the following important consequences: The igneous rocks of the region show in general a close consanguinity, and their variations follow definite laws. This fact appears to indicate that they were all derived from a homogeneous magma. If this be true, this parent magma, as indicated by the composition of the derived rocks, was characterized chemically by relatively low content of alkalies and predominance of soda over potash.

It is worthy of note that the assertions of the last paragraph seem applicable also to the rocks of the Sierra Nevada, of eastern Oregon, and of the more southern portions of the Cascades. In other words, the regions in question all belong to a single great petrographic province.

STRUCTURE.

GENERAL FEATURES.

In a general way the Cascade Mountains at the forty-ninth parallel may be said to consist of a synclinorium. As far as age relations are known the oldest rocks occur upon the extreme east and extreme west flanks of the range, being the slates and greenstone of Okanogan Valley and the schists on the boundary north of Maple Falls. Both the east and the west sides of this synclinorium are anticlinal, for Tertiary rocks occur resting against these oldest rocks. The large area of Cretaceous strata, the Pasayten formation, constitutes the central portion of the synclinorium, and minor synclines and anticlines will undoubtedly be worked out eventually; indeed, their position can be suggested from the results of this reconnaissance.

The presence of intrusive rocks in large masses naturally makes the structural relations less apparent than would be the case in a mountain range including only stratified rocks. The batholith of granitic rocks which makes up the Okanogan Mountains is perhaps the most important igneous member of the Cascades. Little can be definitely determined as to the original upper limit of such a batholith; but if the intrusive contact was approximately horizontal, the present relations indicate the subsequent development of an anticline that forms the eastern limb of the synclinorium mentioned above. These relations are: The intrusive contact, or upper surface of the granitic batholith, has an elevation of from 1,000 to 2,000 feet at Lake Haipwil, where the granodiorite is quite involved with the older rocks; a few miles farther west, on Mount Chopaka, it is at least 5,000 feet higher, while west of that the intruded rocks disappear altogether.

If, on the other hand, the upper limit of the granitic magma did not approach in any degree a horizontal plane, then the remnants of older rocks resting upon the intrusive rocks may represent portions of an older anticline or possibly owe their present position to elevation resulting from the invasion of this magma. In either case it appears justifiable to consider the granite mass as playing the rôle of an anticline between the Okanogan Valley depression containing Tertiary sediments and the Pasayten Valley area of Cretaceous strata.

FOLDS IN THE PASAYTEN FORMATION.

The portion of the Hozomeen Range which is made up of this formation may be described as anticlinal. Along Pasayten Valley the dips observed were all to the east and northeast. On Chuchuwanten Creek a minor syncline is a probable element in the structure, becoming more important north of the boundary. The main anticline is well shown at the head of Canyon Creek, where the axis is in the valley. North of this the rugged crest, which forms the main divide, is composed of conglomerate with a steep western dip (Pl. II, *B*), while to the south the divide is on the eastern dip. This fold has a general north-south trend, and the western limb of the anticline extends well down Slate Creek, so that the so-called slate on that creek and on Canyon Creek have the same west dip as the similar shales at the head of Three Fools Creek and are believed to represent the same portion of the Pasayten formation. West of the intrusive diorite on Ruby Creek the dips in the altered shale are steep, indicating possible reduplication of the strata by close folding. This compression would account largely for the degree of alteration noted here, by which the rocks appear older than the shales near the divide.

In the quartzite, slate, chert, limestone, and schists of Skagit Valley the structural relations were not worked out. On Devil Creek the Cretaceous shales appeared to overlie unconformably these older rocks. Near the mouth of Lightning Creek the chert, quartzite, and schist, while much broken, appear to show a general east-west structure, while in the schists farther south the schistosity trends more north-south.

STRUCTURE IN THE MOUNT BAKER DISTRICT.

The older rocks in the eastern part of this area are closely folded and the structural relations could not be ascertained in the rapid reconnaissance. The general trend of the structure is probably not far from north-south. Northwest of Mount Shuksan the shale and sandstone beds are vertical and strike N. 40° W. Farther north, on the peaks south of Twin Lakes, the schists and associated rocks strike N. 5°–30° E. and show steep dips both to the east and to the west. The structure here is doubtless a closely compressed anticline, with its axis near Twin Lakes. This type of folding may be regarded as characteristic for this region.

In his more careful survey of the area immediately north of this Daly[a] has been able to determine the structural relations in similar rocks which are of Paleozoic age. The axial direction of the folds there is east-west, and northwest-southeast faults are responsible for a fivefold duplication of beds.

Along the North Nooksak the sedimentary rocks appear younger and the structure is much less involved. The Eocene strata farther west are only moderately folded and appear to occupy embayments in the older schists.

PHYSIOGRAPHY.

SCOPE OF DISCUSSION.

The earlier geologic history of this northern portion of the Cascade province has been broadly outlined in the foregoing descriptions of the formations and their structural relations. The present attitude

[a] Summary Report Geol. Survey Canada, 1901, p. 46.

of the Cascade Range and the origin of its topographic features, however, are to be attributed to geologic action of more recent date than any of the rocks described except the Mount Baker lavas. Certain observations were made on the physiography of the region which may bear upon the broader problem of the origin of the ranges of the Pacific slope. In this discussion reference will be made to the nature of the uplift by which the Cascade Range received its present elevation, and also to the vigorous erosion by which these mountains have been sculptured to their present form. In the latter process glacial action has been most important.

In the boundary section of the Cascade Range the only rocks known to be younger than the Cretaceous are the andesitic lavas which appear to overlap the Pasayten formation on the east, and therefore to be somewhat younger. The very late lavas from Mount Baker are excepted in this statement. Farther south, however, Miocene lavas and sediments are involved in the very heart of the range, which is known to have been uplifted somewhat after the close of the Miocene.

The Cascades therefore constitute a relatively young range, and it becomes of importance to determine if any traces remain of the uplifted surface.

RECOGNITION OF A PENEPLAIN SURFACE.

The difficulties attending the search for topographic features antedating the uplift of the Cascades have been succinctly stated as follows by Daly in his preliminary report:[a]

> All indications point to the fact that erosion is responsible for the existing form of these mountains. No constructional surfaces other than those slopes assumed by moving rock waste have been recognized in the belt; no fault scarp or fold recent enough to have preserved any of its original form, even in a damaged condition, has been observed. Vigorous dissection by denuding agencies has removed a vast volume of rock from the structurally complex range. Yet the existing diversity of relief can not be far from the maximum due to the cycle of degradation through which the mountains are now passing.

The area thus described is not exceptional in the degree of dissection attained, yet it is adjacent to a region where the best evidence of an older surface can be seen. Standing on the summit of the peak immediately south of Twin Lakes, in the Mount Baker district, at an elevation of approximately 6,000 feet, one can see two types of topography. To the north and east the peaks are acute and the ridges serrate, so that the sky line presents a most irregular aspect; to the west the sky line is even and the region as far as the eye can see appears a high plateau upon which rests the white cone of Mount Baker. More careful observation shows that this apparent plateau is composed of flat-topped ridges, with a somewhat uniform elevation of 5,000 to 6,000 feet and a gentle westward inclination, between which

[a] Summary Report Geol. Survey Canada, 1901, p. 41.

are the deep, steep-sided canyons of the North Nooksak and its tributary streams.

These ridges have rather broad crests, of smooth and grassy character, in marked contrast to the valley walls below and to the cliffs, pinnacles, and crags a few miles farther east. The completeness of dissection or maturity of relief that characterizes the latter case is most plainly not yet attained in this adjacent area, since here there exist remnants of the topography that apparently antedated the present cycle of erosion.

The recognition of this older surface agrees with the results of the physiography study of other parts of the Northern Cascades.[a] Before the uplift which inaugurated the erosional activity which has so

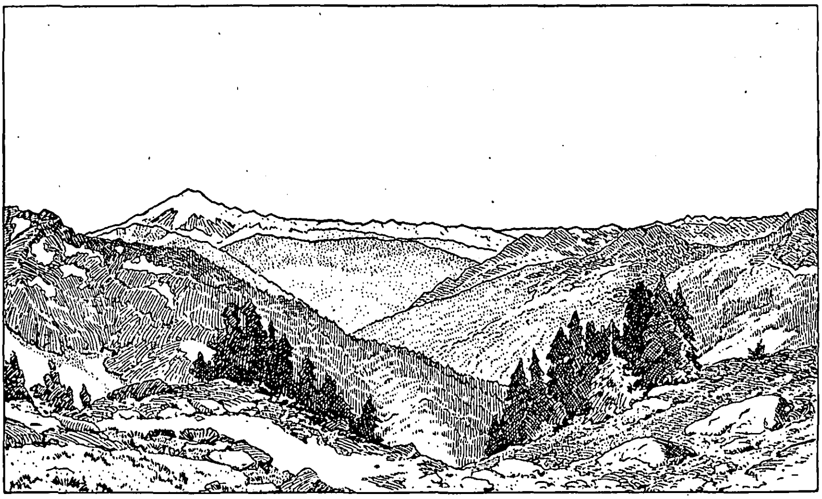


FIG. 1.—Plateau representing uplifted lowland surface; western portion of Skagit Mountains, with Mount Baker; looking west from Bear Mountain.

thoroughly sculptured most portions of the range, the Cascade area had been more or less thoroughly reduced to a lowland. Where this old lowland surface has been recognized the degree of peneplanation appears to have been fairly perfect, with relatively few monadnocks remaining above the general surface. Uplift of this lowland gave opportunity for the streams to intrench themselves and to cut deep canyons, as in the vicinity of Mount Baker. Where the uplift reached its maximum, as in the more eastern portion of the Skagit Mountains, the rock mass was brought into the zone of most effective erosion and the work of dissection was more rapid, reaching within the same period a more mature stage in the topographic cycle than where the uplight was less in amount. Expressed more definitely, where the change in elevation was only 5,000 to 6,000 feet remnants of the uplifted surface remain and can be seen in the broad, flat divides;

[a] Smith, G. O., and Willis, Bailey, Geology of Washington: Prof. Paper U. S. Geol. Survey No. 19, 1904.

where it was 7,000 feet and over no traces of the old lowland persist, the peaks being acute pinnacles and the divides mere knife edges. This difference can be seen by comparing the views illustrated in fig. 1 and Pl. IV, *B*, the point of view being the same.

In other parts of the boundary section identification of the old lowland surface has been less certain. In the Okanogan Mountains there is an approximate uniformity in the heights of the prominent peaks, which are about 8,000 feet, and in several cases the summits exhibit flat surfaces that suggest an older topography. A case of this kind is Ampitheater Peak, illustrated in Pl. III, *A*, where the steep slopes are in marked contrast with the fairly level top. This feature is especially noticeable from the summit of Cathedral Peak (Pl. III, *B*), which itself has an even-topped shoulder at the same elevation as the top of Ampitheater Peak.

In the Hozomeen Range, near the head of Three Fools Creek, there are several long spurs with approximately the same elevation, that extend westward from the crest. Pl. II, *B*, shows the beginning of two of these spurs, from a point on the third. The crest here is extremely rugged, and the coarse conglomerate which composes it is a rock that would naturally form monadnocks above the lowland surface, which may be represented by the crests of these long spurs. The Cretaceous rocks here are steeply inclined, and the structure could not determine the form of the spurs.

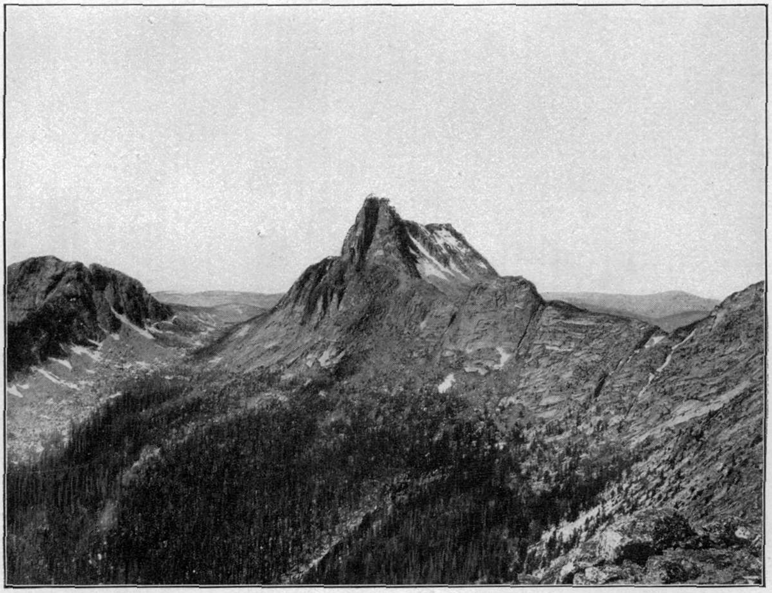
PHYSIOGRAPHIC SUBDIVISION OF CASCADE RANGE.

The subdivision of the northern portion of the Cascade Mountains, as proposed on page 14, appears to possess some basis in the physiography of the range. It has been thought probable from the observations in other parts of this mountain range that the uplift was effected not by a simple broad elevation of the lowland surface, but by an upwarp which in some areas at least was complex in character and comprised upwarps along several parallel axes. So, in this northernmost part of the Cascades, the Okanogan Mountains, Hozomeen Range, and Skagit Mountains may represent distinct upwarps separated by downwarps which determined the position of Pasayten and Skagit rivers. Along these relatively lower lines the valleys of these rivers have been eroded, so that the broad valleys are not to be considered as indicating the altitude of the downwarped surface, but only the positions of such axes.

The valley of the west fork of Pasayten River is a broad feature, quite different in type from the valley of the West Ashnola or of the other fork of Pasayten River. This may be in part due to the difference between the Cretaceous sediments and the granite and andesite of the other valleys, but the hypothesis that it represents in part a downwarp seems plausible. The divide between this valley and Chuchuwanten Creek is broad and flat-topped and possibly approxi-

A. AMPHITHEATER PEAK, OKANOGAN MOUNTAINS, WASHINGTON.

Sculptured by glacial cirques.



B. CATHEDRAL PEAK, OKANOGAN MOUNTAINS, WASHINGTON.

mates the actual warped surface, inclining upward to connect with some rather even-crested spurs on the flanks of the Hozomeen Range. Another argument for the downwarp hypothesis for the Pasayten Valley is that this axis probably finds its continuation southeastward in Methow Valley, where Mr. Willis has believed a similar downwarp to exist. The existence of a depression between the Hozomeen Range and the Skagit Mountains is even more hypothetical. It must be noted, however, that the valley of the upper course of Skagit River is a broad feature as compared to the deep canyon below, where the river turns west and crosses what is considered the axis of the upwarp of the Skagit Mountains. This canyon is one of the wildest gorges in the whole Cascade region and is similar in scenic beauty to the better-known Frazer River Canyon.

There is a suggestive parallelism between this warping of the post-Miocene lowland surface and the older structure of the range. The upwarp slope that so abruptly differentiates Mount Chopaka from Okanogan Valley appears to correspond with the structure, as described on page 84. Thus the upwarp of the Okanogan Mountains follows apparently an anticlinal axis, and the downwarp that is supposed to adjoin it on the west accords in position with the broad syncline by which the younger rocks of Cretaceous age are infolded in the range. The highest parts of the Hozomeen Range, which lie west of the divide, are also composed of older rocks, and this anticlinorium extends probably to the western slope of the Skagit Mountain upwarp. This parallelism between the old structure and the later warping can only be mentioned in this provisional way, since what is at present known of the structural and physiographic relations is insufficient to warrant more definite or conclusive statements.

RELATION OF CASCADE MOUNTAINS AND INTERIOR PLATEAU.

One other characteristic of this portion of the Cascade Mountains must be mentioned. The remarkable manner in which these practically stop at the boundary has already been described. This prominent feature in the orography of the western border of the continent was recognized by G. M. Dawson, who especially states that the Coast system of British Columbia should not be confounded with the Cascade Mountains of Washington, as the former "replaces and partially overlaps" the latter.[a]

Thus it is the interior plateau of British Columbia which is found immediately north of the Cascade Range, the forty-ninth parallel being the approximate line of division between these two diverse topographic provinces. The reason for this abrupt change can be found, possibly, by the extension of the hypothesis worked out in the physiographic study of the Cascade Range in central Washington. There the upwarped surface of the Cascades gradually slopes down until it

[a] Trans. Royal Soc. Canada, sec. 4, 1890, p. 4.

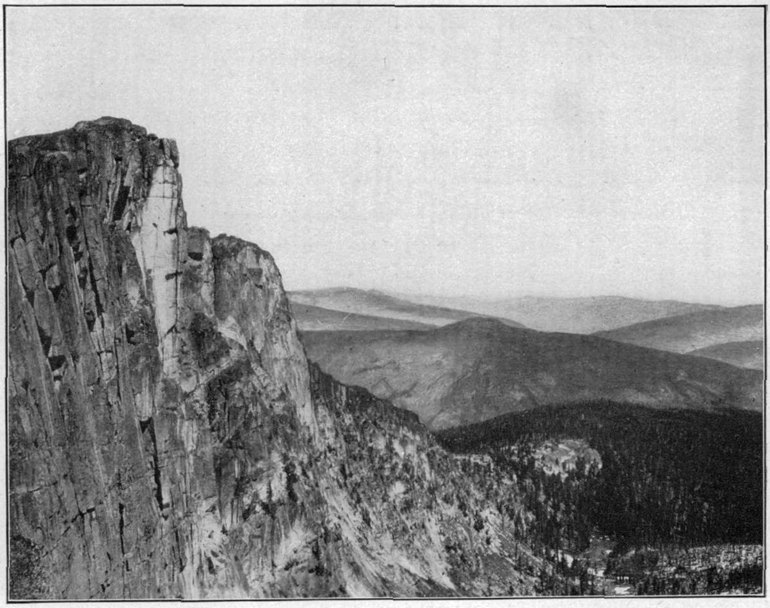
reaches the plain of the Columbia and the marginal warpings of the old peneplain surface merge into the even plateau surface bordering Columbia River and extending far eastward. The difference between plateau and mountain range is there simply one of degree of elevation. In a similar manner it appears that the upwarps by which the Cascade Mountains were uplifted and to which they owe their prominence in the vicinity of the international boundary suddenly die out. Pl. IV, *A*, illustrates the abruptness of this change in topographic character. North of the forty-ninth parallel, then, the eastern portion of the Cascades is replaced by the interior plateau. Farther west the western portion of the Skagit Mountains might possibly be considered as continued by the Coast Ranges, but the wide area occupied by the Frazer delta makes such orographic continuity very doubtful.

This physiographic differentiation of the Cascade Mountains and the interior plateau is on the basis simply of a difference in amount of uplift. The geologic history of these adjacent provinces may show no important differences, and indeed, as far as known, the earlier structures appear to extend from the one to the other. Slight differences may develop, however, in the course of the investigation of these areas. An example of this is found in the occurrence of an Eocene peneplain in the interior plateau region, while in the Cascades peneplanation of Eocene age has not been recognized, and indeed in central Washington the Miocene lavas are known to rest upon a surface possessing considerable relief. The post-Miocene folding and the subsequent peneplanation which have been determined for the Cascade region appear to have been also epochs in the history of the interior plateau. G. M. Dawson recognized both of these periods of peneplain development and described the latter period as follows:

> Local accumulations of volcanic material, together with the slight folding to which the Miocene beds, whether volcanic or otherwise, have been subjected, must have caused the area of the old Eocene peneplain to be less uniform than before; and denudation, acting on its projecting parts, began again to reduce these toward the general level. This action was long continued and had important effects in bringing the interior plateau region again down nearly to the base-level of erosion.[a]

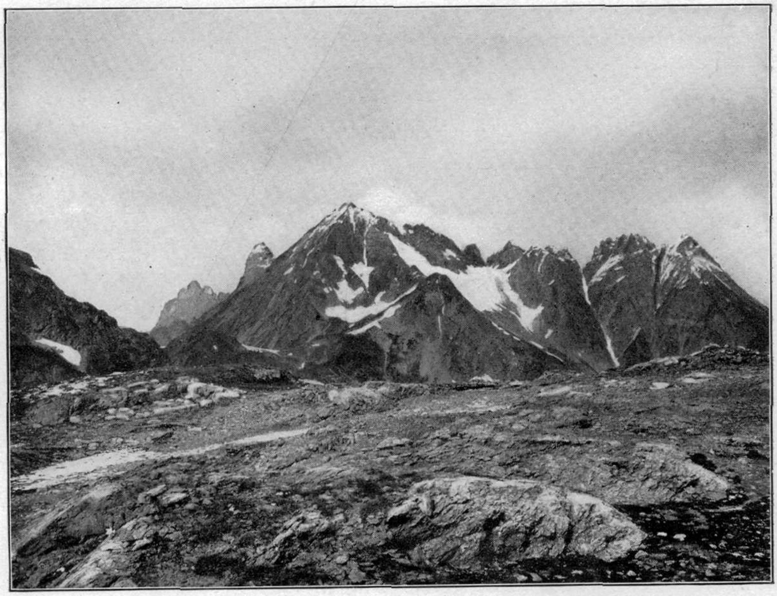
This surface, which largely represents post-Miocene reduction, was uplifted in the latter part of Pliocene time; over the Cascade Mountains area the amount of general elevation was about 8,000 feet, but north of the forty-ninth parallel, judging from published descriptions of the interior plateau, one-half of that amount may be regarded as an approximate measure of the mean elevation. During the uplift of the interior plateau the antecedent Frazer intrenched itself, just as, at the same time, Skagit River maintained its right of way across the uplifted Skagit Mountains and the Columbia cut its canyon across the broad upwarp of the Cascade Range.

[a] Trans. Royal Soc. Canada, sec. 4, 1890, p. 16.



A. INTERIOR PLATEAU OF BRITISH COLUMBIA.

Seen from Bauerman Ridge, Okanogan Mountains, Washington.



B. RUGGED TOPOGRAPHY NEAR FORTY-NINTH PARALLEL, MOUNT BAKER MINING DISTRICT, WASHINGTON.

Looking north from Bear Mountain.

GLACIAL SCULPTURE.

Mention has already been made of the part played by glacial sculpture in the production of the present topography. The great number of glacial cirques throughout this boundary region is the most noticeable evidence of such erosion. In the Okanogan Mountains every peak has at least one such amphitheater, with its flat débris-covered floor often containing a small pond. Some peaks, like Amphitheater Peak, have four or five cirques, so that there is only a remnant of the originally dome-shaped mountain mass. Only rarely, however, has the cutting back of these cirques produced a peak of the Matterhorn type, as the crest is usually long and even, although very narrow. In many cases it is evident that the vertical jointing of the granite has materially assisted the ice in its work. Everywhere the indications are that glacial erosion began its attacks on a much less rugged topography than that of the present.

The asymmetric character of the sculptural features produced by the later alpine glaciation impressed the authors in the field, and is evident from an inspection of the contour map of the eastern part of the area surveyed. Some of the clearest examples of the phenomena are afforded by the U-shaped canyons which drain eastward from the main divide into the west fork of the Pasayten. Their northern walls are of the greatest simplicity, hardly modified by the small post-Glacial torrents that flow down their slopes, but their southern or "shady" sides are broken by niches or hanging cirques, obviously of glacial origin, and the heads of the main canyons themselves have a northerly direction.

The higher peaks, from which the glaciers retreated at a comparatively recent date, show equally an asymmetric form—a characteristic profile like that of a breaking wave. But the most cursory glance at the map reveals the curious fact that while the high cirques generally have, as we should naturally expect, an aspect more northerly than southerly, the great majority of them face in an easterly direction, and their average or prevailing aspect is about due northeast. The prevalence of this tendency can not be accidental, but must have resulted from some cause that has obtained throughout the region where it is observed.

It in fact appears that the predominance of eastward-facing cirques is dependent on at least two concurrent causes. The first of these is the prevailing northwest-southeast trend of the principal drainage lines—a feature, it may be remarked in passing, that can hardly be without significance, but whose origin the authors are not yet prepared to explain. It is evident, however, that the northeastern slopes of the ridges, since they receive less sunlight than their southwestern slopes, offer more favorable sites for the establishment of alpine glaciers. It is believed, therefore, that the peculiarity of the drainage mentioned above has been the most important factor in determining the prevailing aspect of the cirques.

The most notable examples of cirques that, contrary to the general rule, have a westerly outlook, occur along the divides whose directions are transverse to the prevailing trend, notably along those, already mentioned, which separate the western tributaries of the main branch of the Pasayten and along the crest of the Hozomeen Range, where it has a direction almost strictly north and south. This north-south portion of the main divide has been carved by the eating back of the glaciers from both east and west, but seems to have proceeded rather more actively on the east.

Such irregularity here can hardly be explained as a result of pre-Glacial topography. It is suggested, therefore, that it may be due to the prevalence of west winds, which would have the effect of drifting a part of the snowfall across the divide, thus causing a greater accumulation on the east, or leeward, side. This climatic factor may be supposed to have acted over the whole region where east-facing cirques prevail, its influence being concurrent with that of the prevailing trend of the streams.

The peak north of Park Pass, with four cirques containing rock-rimmed tarns upon its northeastern flank, also appears to require the agency of the climatic cause, though the position of these cirques may be in part explained by the proximity of the deep valley of Ashnola River on the east, on the slopes of which the snow would accumulate more readily than on the more open and gentle declivity west of the mountain.

In the Cascades the glaciers that produced these cirques appear to have been of the valley type and to have largely followed the direction of present drainage lines. The largest of these was, of course, the Okanogan Glacier, but smaller ice streams occupied the valleys farther west and flowed northward. Remnants of the Pasayten Glacier still persist in the mountains at the head of the valley, and the shape of the valley shows the former extent of the ice. Upper Skagit Valley has also been thoroughly glaciated.

COULEES.

Within the glaciated Okanogan Valley there is a perfect labyrinth of deserted stream channels, by which the Similkameen and other tributaries united with the Okanogan at various stages of glaciation. Willis mentioned these in an early paper,[a] and clearly stated their origin. These channels, which commonly take the name of "coulees," were observed from the vicinity of Lake Chelan northwest to the international boundary, and in the upper portion of Okanogan Valley are so complex that a careful and detailed survey would be necessary before a correct interpretation of the drainage changes could be made. Mention can here be made, therefore, only of a few of these occur-

[a] Willis, Bailey, Changes in river courses in Washington Territory due to glaciation: Bull. U. S. Geol. Survey No. 40, 1887.

rences, without any attempt even to outline the interesting history which may sometime be worked out for this region.

On the east wall of Okanogan Valley there are several parallel gaps—steep-sided gashes in the general western slope. These have much of the aspect of "displaced blocks" and are striking features, one cliff being a precipice of 600 feet. Thirteen miles due west, on the opposite side of the valley, however, there is to be seen a similar series of gaps, which plainly represent abandoned channels of Salmon Creek. These channels were successively occupied and deserted by this stream as the advancing Okanogan Glacier pushed the lateral drainage higher up the valley wall. There are four of them, the floors of which are successively higher, proceeding west, until the deep canyon at present occupied by Salmon Creek, which owes its depth to post-Glacial erosion, is reached.

Antoine Coulee near the mouth of the Methow is a similar feature on a much larger scale. It is 10 miles in length, and its floor is approximately at the level of the Great Terrace of the Columbia. This steep-walled defile, which cuts across the spurs sloping down to Columbia River, is believed to be also an abandoned stream channel. Russell[a] explains it as the fissure behind a displaced block. His argument rests upon a supposed greater pre-Glacial depth of the Columbia Canyon, whereby the bounding slopes were steeper and therefore better fitted for landslides. This supposition is opposed by the fact that at the point in question the present flood plain of the Columbia is on bed rock even to the water's edge. The thickness of the Okanogan Glacier at this point was undoubtedly sufficient to divert the Methow drainage along the valley side, where it would have started the excavation of such a side channel as Antoine Coulee.

Throughout northern Washington it is apparent that stream erosion may have accomplished tasks that seem incredible, and nowhere is its efficiency more forcibly shown than in Okanogan Valley, with its intricate system of channels, many of which show glacial action to have also contributed to their erosion.

RESOURCES.

AGRICULTURE.

Within the section described in this bulletin, agriculture can not be regarded as very important. In Okanogan Valley the meadows at the foot of Lake Osoyoos and bordering Similkameen River and Haipwil Lake furnish limited areas for raising hay. Along the east side of Haipwil Lake there are also bench lands where grain and vegetables are cultivated, the soil being fertile, but irrigation necessary, so that the scarcity of available water limits the productive area. The

[a] Russell, I. C., Geology of the Cascade Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 201-202.

uplands of Okanogan Valley are used for grazing small bands of horses, but the rainfall is insufficient to make this range very valuable.

West of Okanogan Valley several ranches have been taken up on the southern slope of Mount Chopaka, but the elevation is too great for the land to have much agricultural value. The open grassy slopes of this vicinity, however, furnish an excellent summer range for cattle, and by opening the trail through the thickly wooded ravines the area available for grazing might be increased. The ridge tops and south slopes are covered with a luxuriant growth of bunch grass and other nutritious forage plants, so that the area east of the forest-reserve boundary has value for grazing purposes. The distance to present shipping points, however, detracts from the importance of stock raising in this region.

The next agricultural land encountered in the boundary section is in Skagit Valley near the mouth of Beaver Creek. A few acres of bottom land on the east side of the valley and a natural meadow on Beaver Creek have been utilized for raising hay, which is cut and baled by hand and packed out. In this vicinity forage is extremely scarce, and this hay is the only supply that can be depended upon.

West of the Skagit Mountains the region has the same agricultural value as other parts of western Washington. Small ranches have been established and fruit raising and dairying are proving profitable. Whatcom County will doubtless become more and more important as an agricultural district.

FORESTS.

The greater part of this area is included within the Washington Forest Reserve. In the Okanogan Mountains and the higher portion of the Hozomeen Range the forests are quite open and few trees attain a size comparable with those of the forests of west Washington. In upper Skagit Valley heavy forests become a characteristic feature of the region, and along the lower course of Skagit River the forest trees are large and symmetrically developed. Here and east of the Skagit Mountains the lumber industry is very important, and the magnificent forests of fir and cedar are rapidly disappearing.

GOLD AND SILVER.

EASTERN DISTRICTS.

Okanogan Valley has been the scene of mining operations for a considerable period. The search for placer gold dates back to the time of the original survey of the boundary, when coarse gold was found on the Similkameen, immediately south of the forty-ninth parallel, in quantities that caused much excitement. In later years development work has been carried on to a considerable extent in the gold-quartz mines, although there was less activity in 1901 than a few years before.

The Palmer Mountain tunnel near Loomis had been driven for several thousand feet into the greenstone, and had cut twenty-eight veins, which follow sheer zones but have well-defined walls. The larger of the veins are of quartz, while the smaller ones contain much calcite. The ore minerals are pyrite, chalcopyrite, and galena. The Golden Zone mine is located on the west side of the Similkameen about 2 miles south of the boundary. The principal vein trends N. 20° E., with the hanging wall well defined and persistent. The country rock is granite and the vein material quartz and pyrite, with free-milling gold except where galena occurs in association. The highest value in these lead ores is $10, but the average gold value is reported as about $25, with silver never exceeding 4 ounces. The ore is concentrated and amalgamated at the mill immediately below the mine. These two mines are probably fairly representative of this Palmer Mountain district.

In the Okanogan Mountains, from Mount Chopaka west to Pasayten River, and along the higher part of the Hozomeen Range, the country in the vicinity of the forty-ninth parallel appears quite barren of ore deposits. In the lower valley of Pasayten River the alluvial gravels have been thoroughly test-pitted many years since, apparently without promising results. All of the rocks of this region are remarkably free from even the common quartz veins.

In the vicinity of Barron, and below on Slate and Ruby creeks, there have been mining operations. The rocks here are more closely folded and quartz veins become numerous. Several mines are worked at Barron, and prospecting is being done throughout the Slate Creek district. Ruby Creek was the scene of great activity in early days, when the placers yielded rich returns to the miners, creating a typical rush of short duration. Recently hydraulic mining on a large scale was attempted at the mouth of Ruby Creek, but the extensive plant, which includes a long and expensive flume, has proved a failure. Prospecting has been done on the upper Skagit in the vicinity of Lightning Creek, but no success has been reported.

MOUNT BAKER DISTRICT.

The Mount Baker district is a more promising field for investigation by mining men. Some veins of free-milling gold have been found and partly developed. This district is yet young, since prospecting only began a few years ago, a condition easily understood in view of the difficulties of travel in the Skagit Mountains. The first find of importance was made as late as 1897, and the mine that was developed in consequence is the only one that could be said to be upon a producing basis in 1901. This is the Lone Jack, on the Post-Lambert group of claims, on the eastern slope of Bear Mountain and near the head of the west fork of Silicia, or Slesse, Creek. The vein is 4 to 5 feet, of clear-looking, solid quartz, which does not suggest by its general appearance any value as a metalliferous vein. The ore, which is both free gold and telluride, occurs throughout the vein, although mostly concentrated in a pay streak which lies near the hanging wall, or more rarely near the foot wall, or even in the center of the vein. Samples from any part of the vein are apt to show minute particles of free gold. This vein outcrops for several thousand feet, strikes a little west of north, and has an inclination of about 45° to the west, or into the mountain. It is a fairly regular fissure vein, including some horses of country rock, but having no great variation in width. The rock cut is a schist with lenses and stringers of quartz resembling gold veins, which often give the rock a gneissoid appearance. There is, however, no evidence of transition between such quartz stringers and the large fissure veins.

The value of the Lone Jack ore was reported in 1901 as averaging $25 to $30 to the ton. Picked samples from the pay streak have been reported as assaying as high as $850, and a 2-ton smelter test is said to have netted $450. In 1901 the work of building a stamp mill on the creek below the mine was being actively pushed. This will treat the ore by amalgamating the free gold and concentrating the tellurides.

Another type of ore deposit is at the Grand Excelsior mine, on Wells Creek, about 1 mile southeast of the bridge over the Nooksak. Here the work done has been in a mineralized zone in the green conglomerate and chert. Sulphides occur, scattered through the rock, and the irregular body of mineralized rock appears to be near the surface and approximately parallel with the slope. No definite information could be obtained as to the values in this ore.

Other properties on Tummeahai Creek and in the vicinity of Hannegan and Twin Lake basins were visited in the course of the rapid reconnaissance, but underground development had not reached a point where much could be ascertained as to the true value of the ore deposits. Gold appears to be the principal ore value, but both silver and copper ores are also reported.

The only suggestions that can be made in this report for the guidance of the prospector in this district are those based upon the general structural relations of the region. The older rocks of the eastern part of the district have been closely folded, crushed, and fissured, and also cut by dikes of igneous rocks. The conditions here appear to have been more favorable for the introduction and deposition of ore minerals. In the granite, yet farther east, the prospectors report less evidence of ore-bearing veins, while below Shuksan, in the western part of the district, the rocks have been less metamorphosed and the ore minerals present do not appear to have been concentrated in well-defined veins.

COAL.

There are productive coal mines in the extreme northwestern part of Washington at Cokedale and at Blue Canyon. In Skagit Valley near Hamilton there are also coal prospects in beds the age of which, according to fossil leaves determined by Dr. F. H. Knowlton, is the same as that of the beds at Cokedale, but no development has been accomplished at that locality. None of these localities were visited in the course of this reconnaissance, and of others that were visited none appear sufficiently encouraging to warrant development. Among them was a prospect in the Swauk formation in the hills southwest of Wenatchee. The country rocks there are shales with a northwesterly strike and fairly steep westerly dip. The principal seam shows about 2 feet of soft, shaly coal of poor quality. It is noteworthy that the important coal measures in the Cascade Mountains southwest of this locality are not in the Swauk formation, but in the younger Roslyn formation.

Three prospects in the vicinity of the international boundary were visited. One of these is situated in the southeast quarter of sec. 17, T. 40 N., R. 5 E., about midway between Sumas and Keese. The coal seam strikes north-south with a dip 75°–85° W. The coal is from 2½ to 3 feet thick and is bright for outcrop coal. It is much crushed, with slips cutting across the vein, displacements of this character having the effect of increasing the apparent thickness of the seam. North and west of this locality green schist is found, so it is probable that the coal measures are cut off on that side by faulting.

The second prospect is in the bank of Canyon, or Cowap, Creek, about 1 mile from its mouth. The seam, which strikes east-west and dips steeply to the north, has a total thickness of about 4 feet, but contains much bony material.

South of the Nooksak, in a canyon emptying nearly opposite Cowap Creek, at an elevation of about 3,000 feet, there is a third coal prospect, to which a good trail has been constructed from the road in the valley. The country rocks are shales, sandstones, and conglomerates, presumably of Tertiary age, striking northwest and dipping 45° northeast. They are underlain a short distance to the south by metamorphosed sediments of much greater age. The coal vein is nearly 4 feet thick, but is divided by a thin seam of shale. The coal is soft and much broken and slickensided, as though by shearing and squeezing, a fact which suggests that the contact with the older rocks may be a fault plane.

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